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Evaluation of textile fabric properties utilized in foam-in-place head restraints

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EVALUATION OF TEXTILE FABRIC PROPERTIES UTILIZED IN FOAM-IN-PLACE HEAD RESTRAINTS

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DEDICATION

This work is dedicated to my family

and to the faculty and staff at Eastern Michigan University

who fostered its successful completion.

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ABSTRACT

The purpose of this research was to evaluate and compare the physical properties of knitted fabrics in bilaminate and trilaminate composite forms used in Foam-In-Place (FIP) manufacturing technology for automotive applications. Seven physical tests employed by the automotive industry to evaluate the physical properties of fabric were used. The factors tested were Elongation, Boardiness, Weight, Thickness, Stretch and Set, Breaking Radius, and Ravel. Each test was performed according to standard test methods established by American Society for Testing and Materials (ASTM) or Society of Automotive Engineers (SAE) or the specifications of tier-one automotive seat suppliers. Fabric samples consisted of three flat knit fabrics as bilaminate and trilaminate composites, laminated by one source, using the same method and polymer. The fabric specimens were tested for the foregoing properties.

Independent Samples Tests were performed to determine statistically significant differences between the knitted fabric test data. The analysis indicated that there were differences in the physical properties of bilaminated and trilaminated knitted fabrics.

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CHAPTER I

INTRODUCTION AND BACKGROUND

The automobile has become a staple in the lives of many Americans and people around the world. Public transportation has offered a means of travel for those who choose to use it; however, the automotive sector continues to be one of the largest industries in the world. With a density of 1.4 persons per vehicle in the U.S., which is the highest in the world, the automotive industry composes one fifth of the entire Fortune 500 (Smith, 1996, p. 71). The automobile is, and continues to be, one of the most revolutionary inventions ever created.

The automotive industry provides many challenges for automakers and, in turn, their suppliers. Competition and overcapacity cause the Original Equipment Manufacturer (OEM) to eliminate cost from vehicle manufacturing, therefore placing stress on their tier suppliers to produce higher quality products. Emphasis on more efficient components, including cheaper and lighter fabrics, has caused research and development budgets to expand and put a greater emphasis on fabric technology (Smith, 1996, p. 71). Tier suppliers are trying to keep pace with greater expectations from the consumer. DesMarteau and Meadows (2000) claim, “Automotive interiors firms are anticipating the need to keep pace with greater expectations from the end consumer. Manufacturers say demand for quality and craftsmanship is at an all-time high” (para. 5). In addition, Smith (1994) stated, “We pay more attention to and demand more of the automobile than any other labor saving or recreational devices on which we are so dependent” (para. 1). Consumers expect more, and suppliers are responsible for satisfying those demands.

One of the most noted areas of consumer expectations is vehicle interior. At the present time, manufacturers are creating vehicles from the inside out; they know that the greatest amount of time is spent inside the vehicle, not outside of it (Flint, 2002, p. 64). Consumers purchasing vehicles consider more than the color of the interior; they look at all of the interior components, specifically the seat system. Manufacturers have realized that good interior styling, noted by fabric appearance, can no longer be specific to high-cost vehicles; General Motors (GM) recognizes that features of high-level luxury vehicles have moved through to almost every level, including trucks (Winter & Corbett, 2003, Materials section, para. 3). Intier Automotive interiors unit stated that the appearance of the interior has seen a drastic change in recent years and has now become one of the most prominent features of the vehicle, with manufacturers actually designing around the interior concept (Schweinsberg, 2003, p. 41). Further, DesMarteau and Meadows (2000) stated, "Auto interior firms, especially tier-one suppliers . . . are long accustomed to operating in a 'change-on-a-dime' environment – in which style or equipment changes determined by the OEMs must be implemented immediately, lest they risk losing an OEM's business. Today, there also is a strong focus on providing product development services, and there is increased emphasis on how automotive fabrics affect everything..." (para. 3). Suppliers are challenged with providing the ultimate interior at no additional cost in order to meet consumer requirements.

Statement of the Problem

The changing needs of consumers, who provide the demand for automobiles, create a competitive environment for seat suppliers. Upholstery fabrics are expected to meet many requirements such as construction flexibility, ease of installation, and weight and thickness specifications; automotive fabrics are considered the most competitive component of the automobile today (Smith, 1996, p. 72). Further, DesMarteau and Meadows (2000) reported that Robert Stevenson, president and CEO of Eastman Machine Co., an automotive fabric technology supplier, stated upholstery fabric utilization is one of the main focuses as it is estimated to account for 70 percent of the seat trim cover cost (Fueling Profits section, para. 5).

In 2000(a) Johnson Controls, Inc. (JCI), a tier-one automotive seat manufacturer, claimed that upholstery fabrics are the first component of the vehicle interior noticed by the consumer, and the head restraint is the first component of the seat noticed by the consumer. Due to its complex contours and sharp corners, the head restraint has provided a challenge to manufacturers to utilize fabrics best suited for the application; seat manufacturers struggle with appearance issues on the trim cover due to inherent physical properties. JCI (2003a) stated that, "Although it is the most innocuous looking and seemingly simple part on the seat, the headrest has historically given the engineering community the most headaches" (p. 50). As there is no documented research on the properties of fabrics used in upholstery trim covers, this study may allow manufacturers to improve one of the most complex shapes of the seat.

Today, head restraints are mostly being formed using Foam-In-Place (FIP) processing rather than the traditional Cut & Sew (C&S) fabrication method. FIP technology allows head restraints to be formed more quickly and efficiently than C&S. FIP "takes a sewn trim cover, places it in a foam tool, and injects urethane foam directly into it" (JCI, 2000a). This technology is quite different from C&S technology that slides a C&S trim cover over a foam pad by hand or with a vacuum. "Advantages include the ability to achieve concave contours without conventional tie-down methods, reduced ergonomic issues at the . . . assembly plant, improved appearance at the bottom closeout area, and elimination of cover twisting on armrests" (JCI). At present, there is no evidence of evaluation of the physical properties of the most commonly used upholstery fabric in the automotive industry, knitted fabric, and its response to the FIP process.

Purpose of the Study

The automotive sector provides the largest single market (in dollars) for industrial textiles (Smith, 2001, para. 1). "With some 25 sq yd of fabric used in the interior and trunk of an average automobile, and 15-million vehicles produced in a good year, over 375-million sq yd are used—not counting replacement business and trucks and special vehicles" (Smith, 1999, p. 91). Upholstery fabrics, part of this market of textiles, are the interface between the occupant and the seating surface, head restraint, armrest, ceiling, and floor. Investigation of the physical properties of knitted fabric, the most commonly used upholstery material in automotive seating, will provide an understanding of the type of requirements needed from fabrics in order to meet consumers' requests for higher quality and appearance in automotive seating.

Suppliers are asked to design and provide complete interior systems that will offer perfect interiors, add value, meet specifications, and not add cost. In 2000 DesMarteau and Meadows quoted Lectra Systems, Inc., director of technical textiles for North America, Roy Shurling, saying "There is constant pressure placed on the tier-one suppliers by the OEMs to reduce costs, decrease work in progress and provide more flexibility. This has led many of our clients to reevaluate their traditional manufacturing methods. We are continually working with them to refine our solutions and ensure that we are planning the right developments" (Fueling Profits section, para. 2). Knitted upholstery fabric needs to be evaluated and analyzed in conjunction with FIP manufacturing processes so that manufacturers can gain a clear understanding of the properties that allow it to work well.

The purpose of this study is to evaluate the difference between seven physical properties of three knitted fabrics as bilaminated and trilaminated composites. A series of seven standardized tests will be conducted, typically used by tier suppliers to analyze the physical properties of fabric.

Research Question

The research question posed for this study asked: will the physical properties of knitted fabrics, when evaluated in bilaminated and trilaminated composite forms, differ from one another?

Hypothesis

The following was the hypothesis for this study:

H1: Trilaminated knitted fabrics exhibit different physical properties than bilaminated knitted fabrics in relation to the following:

A: elongation test data;

B: boardiness test data;

C: weight test data;

D: thickness test data;

E: stretch and set test data;

F: breaking radius test data;

G: ravel test data.

Significance of the Study

An understanding of the physical properties of knitted fabrics used in the manufacture of head restraint trim covers produced by FIP technology may allow manufacturers to increase volume and reduce scrap rates. This information is needed by manufacturers in order to engineer a successful head restraint from an appearance and craftsmanship standpoint as the head restraint has been cited as the most challenging component to manufacture within the interior of the vehicle. DesMarteau and Meadows (2000) quoted Terry Talmoose, manager of Lear Corporation, color and trim studio, saying “A lot of companies are putting money back into interiors, and materials play a big factor in beautifully executed seating” (Meeting OEM Demands section, para. 7). Fabric properties play a significant role in appearance and craftsmanship characteristics and affect the behavior of the trim cover on the head restraint system. In addition, there is insufficient evidence whether research has been performed on knitted fabrics, in bilaminated and trilaminated constructions appropriate for FIP manufacture, in order to attain craftsmanship expectations on finished head restraints.

Definitions and Operational Terms

Backing fabric – “a fabric into which a pile yarn is inserted, or a reinforcing layer which is adhered to the reverse side of a fabric” (ASTM, 2001a, p. 3).

Bleedthrough – in FIP manufacturing operations, the result of foam seeping through seams, needle-holes, and/or the fabric itself, allowing visibility on the face side of the fabric.

Constant-rate-of-extension type tensile testing machine – “a testing machine in which the rate of increase of specimen length is uniform with time” (ASTM, 2001a, p. 9).

Defect, in inspection and grading – “the departure or non-conformance of some characteristic from its intended level or state” (ASTM, 2001a, p. 11).

Elongation – “the ratio of the extension of a material to the length of the material prior to stretching” (ASTM, 2001a, p. 14).

Environmental conditions – “the atmosphere in which specified moisture levels, temperature ranges, and concentrations of gases are controlled” (ASTM, 2001a, p. 14).

Fabric growth – “the difference between the original length of a specimen and its length after the application of a specified tension for a prescribed time and the subsequent removal of the tension” (ASTM, 2001a, p. 15).

Face side – “the side of the material that is outward in the completed object” (ASTM, 2001a, p. 15).

Filling – “yarn running from selvage to selvage at right angles to the warp in a woven fabric” (ASTM, 2001a, p. 16).

Force – “a physical influence exerted by one body on another which produces acceleration of bodies that are free to move and deformation of bodies that are not free to move” (ASTM, 2001a, p. 17).

Grab test – “a tensile test in which the central part of the width of the specimen is gripped in the clamps” (ASTM, 2001a, p. 19).

Knitted fabric – “a structure produced by interloping one or more ends of yarn or comparable material” (ASTM, 2001a, p. 22).

Laminated fabric – "a layered fabric structure wherein a face or outer fabric is joined to a continuous sheet material, such as polyurethane foam, in such a way that the identity of the continuous sheet material is retained, either by the flame method or by an adhesive, and this in turn normally, but not always, is joined on the back with a backing fabric such as tricot" (ASTM, 2001a, p. 22).

Lengthwise direction – "the direction in a machine-made fabric parallel to the warp yarns" (ASTM, 2001a, p. 23).

Load – "to apply a force" (ASTM, 2001a, p. 23).

Percent elongation – "the increase in length of a specimen expressed as a percentage of the original length" (ASTM, 2001a, p. 29).

Re-sew marks – needle-holes in a fabric, resulting from sewing thread being removed after a sewing operation.

Resilience – "that property of a material by virtue of which it is able to do work against restraining forces during return from a deformed state" (ASTM, 2001a, p. 32).

Seam chatter – puckering or gathering of a fabric, visible on the face side, occurring during sewing operations.

Selvage – "the woven edge portion of a fabric parallel to the warp" (ASTM, 2001a, p. 34).

Upholstery fabric – "the exterior fabric covering applied to a furniture unit" (ASTM, 2001a, p. 45).

Walnut – in FIP manufacturing, dimpled indentations or voids on the face side of the fabric, taking on a similar appearance to the shell of a walnut.

Warp – "(1) the yarn running lengthwise in a woven fabric" (ASTM, 2001a, p. 46).

Width – “the distance from the outer edge of one selvage to the outer edge of the other selvage, measured perpendicular to the selvages while the fabric is held under zero tension and is free of folds and wrinkles” (ASTM, 2001a, p. 47).

Woven fabric – “a structure produced when at least two sets of strands are interlaced, usually at right angles to each other, according to the predetermined pattern of interlacing, and such that at least one set is parallel to the axis along the lengthwise direction of the fabric” (ASTM, 2001a, p. 47).

Wrinkle – “an objectionable crease, generally short and irregular in shape” (ASTM, 2001a, p. 48).

CHAPTER II

REVIEW OF RELATED LITERATURE

Automobile interiors are changing drastically in today's modern world. From vehicle floors made entirely of rubber and military-inspired toggle switches for controls to instrument panels made of molded wood, the inside of a typical vehicle has become everything but typical. Seat systems are also facing modifications like never before. Today's automobile seats are technologically advanced pieces of equipment inside a complex interior environment. New fabrics for seating components are being proposed into the vehicle interior; technological advances in fabrics are abundant, and suppliers are moving to push these products into the vehicles of the 21st century. In order to acquire knowledge and understanding of issues surrounding upholstery fabric and automotive head restraints, the following literature was examined: (a) an overview of the automotive industry, (b) automotive seat components, (c) head restraints, (d) fabrics in automotive seating, and (e) craftsmanship and appearance expectations.

Overview of the Automotive Industry

In 2004 alone, North America produced more than 16 million vehicles, with a total of more than 19 million vehicles sold (Strategis, 2005b). These vehicles, comprising passenger cars, lightweight, medium-weight, and heavyweight trucks, provide one of the largest incomes for the North American market. Of the 16 million vehicles produced in 2003, the United States manufactured approximately 75 percent of production vehicles (Strategis, 2005a). J.T. Battenberg, III, (1995) president of Delphi Automotive Systems and executive vice president of General Motors, stated that "the United States is now the highest-quality, lowest-cost, most-productive manufacturer of cars and trucks in the world" (para. 3).

OEMs have expanded production into the world economy and expect automotive interior suppliers and textile suppliers to meet their needs to develop even more. And as a result, automotive interior suppliers are outperforming many companies in the automotive arena. Lear Corporation, JCI, and Intier Automotive have approximately a 70-percent share of the domestic-outsourced interior market (Fahey, 2003, para. 7). The expectations consumers are placing on interior textiles in the automotive sector have forced consolidation and specialization on fabric suppliers. "It is a daunting task to come up with a unique or new material and convince the automakers, and/or the tier-one suppliers responsible for the interior, you can produce to the volume and quality standards—and cost—demanded in today's market" (Smith, 1999, p. 91). More than 25 square yards of automotive textiles are used on the interior and trunk of the average vehicle, creating more than 375 million square yards of materials used annually (Smith, p. 91). "It's becoming a market of giants, certainly one of devoted specialists willing to commit substantial amounts of capital, marketing, design, quality programs and personnel to supply the market" (Smith, p. 91).

Innovations to the seat system seem almost inevitable as consumers demand more from vehicle interiors. In 2001 Smith stated, "Seating, the most difficult component in the automotive interior, presents special challenges and needs more development . . ." (Conclusion section). Vehicle manufacturers want to know what consumers want and are going so far as purchasing vehicles for benchmarking purposes to evaluate and identify critical factors in seating that consumers consider to be outstanding. Of these critical factors, upholstery fabric ranks highly. Perceived quality of interior upholstery fabric has become one of the most noticed elements of the vehicle and, as a result, one of the most scrutinized. Stein (2004) stated that "'perceived quality' even became an official phrase in GM's advanced vehicle development" (para. 4) in regards to vehicle interiors.

As a result of demand for higher craftsmanship, tier-one suppliers have been focusing on the relationship between design, engineering, and manufacturing of vehicles, in the hopes of creating a well-rounded, high quality interior environment. GM is one OEM that has recently put strong effort into interiors, and Dave Rand, executive director of GM's interior design studio, stated, "Interiors are where the customer makes a connection, and in the past we screwed up" (Stein, 2004, para. 2). Rand explained, "We have to strive for better interiors, and I think, as a corporation, we woke up and realized that" (Stein, para. 2). Ford Motor Company's design department is also working hard to ensure that the interior components become as important as, if not more important than, the exterior of the car. "Every vehicle we're working on right now, regardless of price point, has to be beautifully crafted," stated J. Mays, vice president of design. "Interior is where you spend all of your time. It makes total sense to me to want to get it right" (Stein, para. 5). Ford has even implemented high-end fabrics, such as leather, on lower class models and trucks. "It's not just the features," points out Paul Haelterman, market assessment director at CSM Worldwide, an automotive research firm. "It's the quality of the materials. There's more leather, more premium fabrics. You're starting to see leather in Ford Focus-class vehicles. Five years ago that would have been unthinkable" (Fahey, 2003, para. 6).

Daimler Chrysler, part of what is known as the "Big Three," realizes the importance of vehicle interiors and has dedicated an entire department to it. A publication by the Chrysler Design Institute stated, "Aesthetically, the interior of a vehicle must harmonize with its exterior theme. Functionally, a vehicle interior has to meet many requirements, such as federally mandated safety standards. Ergonomically, the customer's interaction with the vehicle must be natural and allow for quick response. Controls must be placed within easy reach, instruments clearly visible and placement of components logical" (para. 2, "Design Process," n. d.). The experience one encounters inside of the vehicle is clearly just as significant as the appreciation of the vehicle exterior, yet there is no evidence of studies performed on quality and appearance of interior components.

Automotive Seat Components

The seat, which includes the head restraint and armrest, may be one of the most important components of the vehicle as a whole. Unlike most components of the vehicle, every occupant comes in contact with the seat, head restraint, and armrest every time the vehicle is used. Other than the powertrain, the seat is the second most expensive vehicle system in the car. The four functions that an automobile seat must perform, according to JCI (2000a), are (a) support the occupant, (b) position the occupant, (c) provide comfort for the occupant, and (d) protect the occupant.

Seat Functions

Supporting the occupant. Supporting the occupant is a critical function of the seat. Occupant position, comfort, and protection are dependent on the support of the occupant. As each consumer is unique in his/her body type, providing support may pose more of a challenge than it appears. The use of recliners and adjusters, power and/or manual, contributes to the difficult task of providing proper support as well.

Positioning the occupant. Another function that a vehicle seat must perform, positioning the occupant is critical to seat function. JCI (2000b) stated that three aspects of the occupants' position in the vehicle include "head, arm, and leg room, field of vision, and driver proximity to operation controls" (p. 51). All passengers must have enough headroom to prevent contact with the roof at all times while allowing for adequate vision. Passengers must also have adequate legroom: they should be able to touch the floorboards and have enough room to prevent cramping or other discomforts; drivers must be able to reach the floor pedals, have enough clear space from the steering wheel to the legs, and be able to move their arms and hands as necessary (JCI, 2000b). The driver and passengers' positions also demand proper vision line, specifically for the driver. All occupants should have a clear line of vision; however, the driver's view must be free of any obstructive items such as the steering wheel, dashboard, roof line, belt line, and pillars, and the driver must have a clear view of all of the vehicle's mirrors. The final aspect of the occupants' position in the vehicle is the driver's proximity to the vehicle's operation controls. The controls need to be accessible to the driver at all times, especially while the vehicle is in motion (JCI, 2000b).

Instrument controls, divided into two categories – primary controls and secondary controls – are essential to the operation of the vehicle and contribute to the comfort or convenience of the passenger cabin. In a seat that is properly positioned, primary controls must be within the driver's reach with the seat belt and the shoulder belt in place. Primary controls include steering control, gearshift control, turn signal control, ignition control, audible horn control, headlamp control, headlamp dimmer control, washer/wiper controls, defroster control, hazard flasher control, and hand brake control. In a seat that is properly positioned, secondary controls must be within the driver's reach with the lap belt in place. Secondary controls include headlamp optical warning control, climate control, radio controls, cigarette lighter, ashtray, and accessory controls (JCI, 2000b).

Provide comfort for the occupant. The third function of a seat, comfort for the occupant, must allow for short-term as well as long-term periods of driving or riding in a vehicle. Seat comfort is difficult to quantify as each occupant rates comfort differently. Some studies have shown that factors affecting overall comfort of seat design include the amount of seat padding, the angle of the seat back and the seat cushion, the amount of thigh and lumbar support, as well as the seat width and height (JCI, 2000b).

Although difficult to gauge comfort, three measurements are taken: Indention Load Deflection (ILD), the natural frequency, and the static pressure distribution of the seat. ILD indicates the firmness of the seat; testing involves measuring the load required to compress the cushion or back a specified distance or percentage. Testing is performed on the seat's foam pads and not on the finished seat. Natural frequencies, on the other hand, are the natural vibrations that occur in every object and are measured on the seat. In order for a seat to be considered comfortable, the natural vibrations must be below the level of human sensitivity. Occupants can suffer from a series of side-effects including "general discomfort, head symptoms, lower jaw symptoms, influence[d] speech, lump in the throat, chest pains, abdominal pains, urge to urinate, influence[d] breathing movements, and muscle contractions" (JCI, 2000b, p. 52) from vibrations. Static pressure distribution, the final item measured to determine a seat's comfort, can be measured by placing a pressure sensitive mat on the seat followed by an occupant. Several pressure sensors, found within the mat, are used to capture data that analyzes if the seat is comfortable (JCI, 2000b).

Protecting the occupant. The final function of a seat is protecting the occupant who uses it. Controlling inadvertent passenger movement is a key element to providing safety. Loss of vehicle control can quickly result in injury or damage and must be prevented. Any occupant must not move forward, backward, or laterally in the vehicle as the vehicle decelerates, accelerates, or turns. In addition, the occupant must not be able to move when seat harnesses are in place (JCI, 2000b).

Seat Components

As defined by JCI (2000a), “A seat set is comprised of all the seats required to produce a given vehicle, front and rear” (p. 2). One seat set contains several seat systems within the vehicle. “A seat system is a single seat with all its components included as shipped to the customer ready for installation into the vehicle” (JCI, p. 2). Seat systems are located in the front or the rear, or both locations, of an automobile.

One seat system is composed of several parts: seat back, seat cushion, wings, bolsters, inserts, head restraint, and armrest. The part of the seat that supports the occupant’s back is referred to as the seat back. The seat cushion, supporting the ischium (the lowest of three major bones that make up each half of the pelvis) and thighs of the occupant, may have a fore-aft adjuster, adjustable thigh support, and bolsters. To prevent the occupant’s torso from shifting laterally, protrusions know as “wings” are provided on the outsides of the seat back. Bolsters are provided to reduce lateral movement of the lower body. The insert area is in between the wings on the seat back and the bolsters on the seat cushion. The insert is the area of the seat cushion where the occupant sits and the area where the occupant leans on the seat back. Typically, trim covers for inserts are made of different fabrics than bolsters for design effect (JCI, 2000a).

Head restraints are at the top of the seat back and help prevent head and neck injuries if there is an accident. There are two classifications of head restraints in the industry that are based on function: head restraints that provide a resting place for the head and head restraints that absorb energy in case of an impact as a safety feature. When acting as a safety device, the restraint will absorb the force created by the weight of the head and neck and reduce the amount of movement to prevent whiplash. Although head restraints can function as both a resting place and a safety device, the trend in manufacturing is to design the head restraint so its primary function is for safety. The head restraint can be adjustable, in which case it is a separate component of the seat, or integrated, where the component is built into the seat. When head restraints are adjustable, as a separate component of the seat, they can be designed to include two-way and four-way mechanisms. JCI (2003a) stated that "the two-way design is the most prominent and commonly used" (p. 50). Four-way designs are being used much more today, and the six-way mechanism is rarely used. Currently, head restraints are required by law for both front seats of vehicles but are not necessarily required for the rear seats (JCI, 2000b).

The final component of an automotive seat system is the armrest. Armrests are created to allow for the occupant to rest his or her arm, forearm, or elbow on a fixture. Front seat system armrests are typically found in vehicles used for long distance travel or family travel in vehicles such as vans, minivans, sport utility vehicles, and buses. Rear seat armrests can be found in luxury vehicles and some mid-class vehicles. Three types of armrests are typically found within these vehicles: freestanding armrests, integral armrests, and side-mounted armrests. Freestanding armrests are usually not adjustable; they are not connected to the seat back and are typically on separate stanchions. Armrests that fold up flush with the seat back surface when not being used and fold down into a horizontal position for use are called integral armrests. Side-mounted armrests are adjustable, in most cases, and are secured to the seat back through bolts or another system (JCI, 2000b).

Seat Types

Surprisingly, there are many different types of seats that are manufactured in the world today. The type of seat that is used in a particular vehicle depends on several factors. The style of the vehicle, the function of the vehicle, and the end user all factor into what type of a seat will be utilized. OEMs determine the type of seat to be used in a vehicle, as they are responsible for vehicle design and target market. A seat can have many different components, as mentioned previously; however, only some seats may have those features. JCI (2000b) stated that "front seats in most vehicles are required to have head restraints, although back seats may not have them" (p. 5). In addition, seats may or may not be equipped with an armrest.

Similar to seat design, the adjustability of the seat also depends on vehicle type and end use. Front seats are usually adjustable; however, rear seats are not adjustable and are supported by the vehicle body. As technology advances, so do capabilities for seats. For example, rear seats are now able to recline in vehicles that are not vans. Seats found in full-size vans and minivans are typically removable and allow consumers to slide them forward and backward. These seats may face the front of the vehicle, the rear of the vehicle, or be side facing. These options all depend on vehicle type and end consumer (JCI, 2000b). Rear seats have many capabilities just within the seat back. For example, rear seats equipped with folding seat backs allow users to access the trunk space and use the seat back as a load floor. Some passenger cars, sport utility vehicles (SUVs), station wagons, vans, and minivans allow large items or over-sized items to be placed on the load floor providing space for long items (JCI, 2000b).

Seat designs offer consumers bucket seats, full bench seats, split back full bench seats, and split bench seats. Many of these types of seats are also removable for ease of use. The bucket seat holds one passenger, is usually freestanding, is mounted to the vehicle body, and can turn within a 90- to 360-degree radius. Full bench seats have one seat cushion and seat back that make up the entire seat. The seat back can be one unit or can be split into two units. If the seat back is split, it is called a split back full bench seat. This type of seat back allows the user greater ease of ingress and egress into and out of the vehicle. In some cases, the bench seat cushion and the bench seat back may be split, called a split bench seat. Each occupant can adjust the seat independent of the other occupants. JCI (2000b) stated that, "Adjustments such as forward and backward and seat recline may be adjusted differently for each occupant sharing the split bench seat" (p. 22). There are several variations to a split bench seat depending on where the split is located. In the industry, what is referred to as a 50/50 split bench seat is a bench seat cushion and seat back split down the center of the two. A 60/40-split bench seat is split to make up two portions: one portion is composed of 60 percent of the seat and the other portion is composed of 40 percent of the seat. Seat portions can be divided into different percentages to make up an overall split bench seat. Whether the seat accommodates one or more, there are several opportunities for the consumers to manipulate the component to fit their needs.

Seat design is constantly evolving and seems to always offer more than just a seating surface for its users. Manufacturers offer even more types of seats including seats that can be made into a bed, seats that flip up against the vehicle wall, seats that fold down into the floor, and bench seats that are side facing. A bed seat provides a horizontal flat surface when the bench seat is folded down, creating a bed. These types of seats can be found in station wagons, SUVs, vans, and minivans. Seats that fold and store into the floor of the vehicle are also offered to create endless opportunity for the vehicle owner and its users (JCI, 2000b).

Seat Subassemblies

JCI (2000b) explained that there are several subassemblies that make up the seat system components such as the frame assembly, suspension, foam pad, recliner, adjuster, and trim cover. The frame assembly provides structure for the seat system, offers support for the foam pad and suspension, allows attachment of soft trim components and some restraint components, and withstands static and dynamic loads and federally mandated load forces for crash. Supporting the occupant comfortably and safely is the responsibility of the suspension system. The suspension should support the occupant, allow comfortable pressure distribution, be soundless, absorb vibration and shock, and maintain the trim contour. The foam pad works with the suspension to provide cushioning and support. Recliners allow for rotation of the seat back in a motion downward toward the seat cushion from its original position while adjusters actually support the seat frame assembly, attach the seat system to the floor of the vehicle, and allow adjustment to the seated position in forward, backward, up, and down motions. The final subassembly of the seat system is the trim cover, which provides upholstery fabric on the seat system, including head restraints and armrests (JCI, 2000b).

The trim cover is composed of the upholstery fabric covering and any component required to attach the cover to the seat, head restraint, and armrest. Two methods of processing used to manufacture trim covers with a foam pad are C&S and FIP. The traditional method of trim cover construction, referred to as C&S by tier-one suppliers, is a process that wraps the sewn cover over the molded pad of the part. Hook and loop tape and metal rings are some of the fixtures used to fasten the trim cover to the seat, head restraint, or armrest. FIP processing utilizes the C&S method for trim cover assembly, but also requires liquid foam to be injected into a mold containing the trim cover and frame. This construction method is used to produce head restraints and armrests and is popular due to low scrap rates and limited warranty repair issues. The end result is the frame assembly embedded within solid foam, enclosed by the trim cover. C&S and FIP differ in the way in which the foam pad is formed: C&S allows a trim cover to wrap around a pre-molded foam pad and FIP requires foam to be injected into a trim cover that rests in a mold, forming a foam pad. Both processes use traditional cutting and sewing to form trim covers, but FIP is not typically used to form seat back and seat cushion components although some seat manufacturers have tried this method (JCI, 2000b).

The soft trim system, as it relates to the seat assembly, is composed of two parts: the foam pad and the upholstery fabric cover, referred to as the trim cover. JCI (2000a) explains that, “The main function of the trim cover is to provide a durable aesthetically pleasing cover for the seats systems assembly" (p. 104). Further, "designing the trim cover assembly involves selecting the materials and/or processing methods to be used, trim levels[,] and the attachments/closures that are used in the manufacture of the seat" (JCI, p. 104). Three important steps in developing a trim cover that will satisfy consumers' expectations of quality and appearance for the seat, head restraint, and armrest are (a) the evaluation of fabrics, (b) choosing the manufacturing technique, and (c) analyzing the relationship between the foam and frame assemblies (JCI, p. 104).

One of the key factors involved in developing a trim cover that can control quality and appearance is the inherent physical properties found within the upholstery fabrics. In order to provide a high quality finished seat, head restraint, or armrest with a selected design, manufacturers must evaluate fabric constructions and their properties as they relate to a particular style of seat, head restraint, or armrest. Fabric properties can be evaluated using standardized test procedures from organizations such as ASTM, SAE, or manufacturers that have established their own fabric standards and test methods. Predictions can be made about the potential quality and appearance of a completed seat component based on the physical properties of the upholstery fabric that is used. Test results can indicate how the fabric will perform on a particular seat, head restraint, or armrest contour, such as a basic design, a moderate design, or a complex design. Testing fabric properties such as weight, thickness, stretch, elongation, and so on can provide insight for manufacturers into soft trim behavior in the manufacturing process and on the finished seat, head restraint, and armrest from an appearance standpoint.

The processing method of the trim cover also has an impact on appearance. The C&S method, as defined by JCI (2000a), "is the traditional process used for automotive interior trim seating" (p. 106). The technique that involves "wrapping a pre-sewn cover around a molded pad/frame assembly" (JCI, p. 106) can allow for contours and styling with the use of attachments and decorative sewing methods. FIP processing, typically used to manufacture head restraints and armrests, allows manufacturers to create contours that are concave without using attachments and decorative sewing methods. Advantages of this method include "reduced ergonomic issues" at assembly plants, "an improved appearance at the bottom close-out area, and elimination of cover twisting on armrests" (JCI, p. 106).

The relationship that exists between the foam pad and frame assembly is also an important factor in meeting quality guidelines. "If the trim cover is to meet one of its major objectives (aesthetics), then the complete seat system must provide a positive foam to frame registration" (JCI, 2000a, p. 106). As the foam pad and the trim cover are placed on the frame, variation between the foam pad and the frame can create disconnection on the seat once complete. JCI (1994) claimed that the foam pad should "achieve the design position of the occupant, accomplish the design surface, provide the subjective comfort levels, provide a desirable material that will perform as functionally designed during the total life time of the vehicle, and provide aesthetic quality consistent with perceived functional requirements" (p. 6). All of these factors are dependent on accurate foam and frame alignment (JCI, 1994, p. 6).

Head Restraints

Components

Head restraints are composed of four parts: (a) foam pad, (b) trim cover, (c) rod structure, and (d) bezel. These parts provide shape, aesthetics, structure, and fit into the finished seat. Each component must be carefully designed in correlation with the others to produce a successful part.

Foam pad. The foam pad, which designates the shape of the head restraint, can be manufactured with C&S or FIP processing technology. The industry is moving toward FIP manufacturing as it can produce a more complex part. FIP can allow for “shapes that are difficult to cover in the normal cut and sew process without using wires or hook and loop fasteners” (JCI, 1994, p. 27) to manipulate the trim cover. FIP also provides a cleaner, neater closure on the base of the head restraint. Utilizing the FIP process on seat components is beneficial to keeping the trim cover in place as the trim cover is molded to the foam pad. A negative factor of this processing method is scrap expense. If a FIP part is scrapped, the trim cover and the foam are lost, whereas in C&S processing only the foam is lost as the trim cover has not been permanently altered by liquid foam poured into it. Foam-In-Place manufacturing is the direction most seat manufacturers are going with head restraint production today.

The FIP process, as defined by JCI (1994), is composed of several steps (p. 20). First, the manufacturer must “determine which physical properties and the levels of the physical properties the foam must achieve” (JCI, 1994, p. 20). Second, the care time, mold release type, and machine parts to be used in manufacture of the foam part should be determined. Next, the appropriate chemicals must be selected in order to achieve the physical properties and their levels. Surfactants and catalysts are also selected for this purpose. All ingredients are mixed, and performance and compatibility of the mixture are determined. A test block is then formed by mixing the polyol and isocyanate blend with the surfactants and catalysts to determine “foam-ability and preliminary physical properties” (JCI, 1994, p. 20). At this point adjustments are made, if required, and test blocks are molded with the adjusted formula. Physical properties and mold-ability are verified after reconfiguration of the formula, and the mixture is then tried in the appropriate production facility.

The foam process, used in FIP manufacturing, involves a series of key steps. First, all chemicals and components are received and inspected. All chemicals are then blended and transported to the production line. From this point, the trim cover, which has been cut and sewn, is placed into the mold that has been heated to a specific processing temperature. The foam chemicals are then injected into the trim cover that lies inside the heated mold. The mold is then closed to allow for the foam to cure. After cure time is complete, the part is removed from the mold. Once removed, the part is inspected and packaged in preparation for transportation to the customer (JCI, 1994, p. 14).

Foam chemistry used in FIP manufacturing is complex and constantly evolving. The chemicals needed to form a foam reaction can be varied to form different types of foam. Chemical composition typically includes standard polyols, polymer polyols, water, catalyst, surfactants, and isocyanates. Standard polyols are made from a combination of propylene and ethylene oxides and are the starting structure of polymer polyols. Polymer polyols are solids that contribute significantly to firmness. Water forms carbon oxide gas during the reaction and controls the density of the part. The catalyst promotes the water-isocyanate reaction and controls the cure rate. Catalysts are amine-based (organometallic) materials that create free electron pairs. The surfactants emulsify incompatible materials in blending, control the cell size, and stabilize the foaming reaction. Isocyanate is the major reactant with the polyol blend, and different ratios of the isocyanate and hydroxyl create different firmness (JCI, 1994, p. 19). Foam chemistry relies on the physical properties and the levels of those properties established by the OEM; based on this criteria, foam chemistry is developed.

In head restraint foam processing, it is the responsibility of the manufacturer to ensure that the physical properties of the foam, and their levels, meet OEM standards and specifications. There are three elements involved in ensuring customer standards are met: (a) firmness and density levels, (b) surface contours, and (c) size (JCI, 1994, p. 21). As mentioned previously for the seat pad, ILD is also used to measure the firmness of the foam part for the head restraint. Surface contours are important to achieve design specifications set by the OEM. Unlike C&S processing, FIP processing allows for sharp radii and high contoured shapes in head restraint designs. Achieving accurate size of the molded part is also important in ensuring customer standards have been met. Strict dimensions are placed on head restraints in order to meet safety and design requirements; it is critical that parts are formed within the correct limits.

Trim cover. The second component of a head restraint, the trim cover, is the most significant part from an appearance standpoint. The trim cover is the most prominent part of the head restraint, aesthetically, and requires the most attention. It is wrapped around the foam pad and formed to it during the FIP process. The trim cover performs an aesthetic role in head restraint production. It is made from a variety of fabrics, selected by the OEM, to fit with the rest of the vehicle interior. Some fabrics provide challenges to the trim cover manufacturing process, which may be due to inherent physical properties. Identifying fabric properties will allow seat manufacturers to determine the expectations of fabric performance in manufacturing. No research has identified the relationship between fabric properties and laminate types to date, causing manufacturing to be a struggle.

Rod Structure. The third component of a head restraint, the rod, is the main structure supporting a head restraint within the seat. The rod is found embedded within the foam pad, which is wrapped with the trim cover. The rod is placed within the trim cover inside the mold prior to liquid foam being poured into the mold. Typical rod diameters are 10 mm, 12 mm, or 12.7 mm (JCI, 2003a, p. 53). SAE 1010 or high strength alloys, such as SAE 4340 are the materials that make up the rod (JCI, p. 53). Two items should be considered when manufacturing head restraint rods as defined by JCI (2003a): the head restraint must be compatible with the seat structure, and design and material should be simple (p. 53).

JCI (2003a) stated that, “The rod or headrest structure is an integral part of the seat system and must behave in unison with the seat structure when absorbing energy and distributing deflection and stress” (p. 53). This is a critical element to the function of the head restraint. In regards to design and material, proper rod design should eliminate the use of rare, more costly materials. Rods can be solid or hollow to reduce weight. When a hollow construction is utilized, the material that makes up the rod is generally more costly and rod material must be a minimum 12.7 mm in diameter with a matching bezel sized to accommodate it. In addition to a 12.7 mm rod diameter requirement when using a hollow rod, in order to control the adjustment effort(s), a 0.1 mm tolerance must be adhered to. There are two reasons for the 12.7 mm requirement: notches formed on the rod do not rupture the rod, and the rod can be bent into the appropriate shape for the part without collapsing (JCI, 2003a, p. 54).

Notches position the head restraint in place and allow for easy adjustment by the consumer. Notch angle and manufacturing method are very important in order to ensure discomfort when adjusting is kept to a minimum. There are two types of notches as stated by JCI (2003a): “notches that will not allow the headrest to move unless the detent on the [bezel] is operated” and “notches that hold the headrest in place under normal conditions, but still allow it to be moved without operating the detent on the [bezel]” (p. 54). Notches that do not allow head restraint movement unless the detent on the bezel is operated should have a notch ramp angle of 90 degrees. Notches that hold the restraint in place but allow movement without activating the detent should have a ramp angle between 30 and 45 degrees (JCI, 2003a, p. 54).

The ramp angle manipulates the effort required to compress the detent spring so that the head restraint can be moved. More vertical angles increase force, where more horizontal angles decrease it. If the ramp angle is less than 30 degrees, the head restraint requires less momentum to move; however, when the ramp angle is more than 45 degrees, the end user will need more momentum to move it. If the ramp angle is not within these ranges, it is considered unacceptable. Ramp angles have been engineered outside of the ranges to accommodate “non-conformance issues such as improper dimensions/tolerances of the rod/[bezel], or the back frame housing” (JCI, 2003a, p. 55). Ramp angles can also be engineered differently to compensate for the forces when moving upward and downward. For example, gravity assists in moving the head restraint downward; however, gravity works against the occupant when moving the head restraint upward. Ramp angles can be manipulated to “even out the efforts between the headrest going up and coming down” (JCI, 2003a, p. 55).

Bezel. The final component of a head restraint, the bezel, is the device that guides the rod structure into the seat back. Although “seemingly unimportant and easily designed,” the bezel “supports many critical aspects of the performance specifications” (JCI, 2003a, p. 71) required by the OEM. The bezel (a) supports the rod during upward and downward movement, (b) assures smooth travel in upward and downward movement, (c) provides proper clearance between parts, (d) transfers loads to the seat back frame, (e) finishes the top of the seat back from an aesthetic standpoint, and (f) “houses the detent mechanism for locking the headrest into place” (JCI, 2003a, p. 71). Bezels are usually made of polypropylene, “which is inexpensive and meets government and customer requirements such as FMVSS 302” (JCI, p. 74).

The bezel is considered a structural part of the head restraint design because it transfers loads. Therefore, it is critical to position the bezel in the appropriate location within the seat back during initial layout and design. The bezel location relies on three elements: (a) the trim lines, (b) location of the back frame, and (c) relationship between the head restraint and the top of the seat back (JCI, 2003a, p. 71). The relationship between the trim cover and the bezel are critical for positioning. The trim cover is contained by the bezel when the part is complete; to which extent this occurs is determined on the type of locking mechanism. Where locking mechanisms are to be used, the bezel must be higher than the face side of the fabric on the seat back. Design must configure trim lines to ensure proper bezel location.

Location of the back frame, in accordance with the bezel location, is critical as the back frame "is a key structural part that helps carry load into the recliner and also gives a sense of stability to the seat in general" (JCI, 2003a, p. 57). The back frame "also plays a critical role in energy management during frontal, side and especially rear impact situations" (JCI, p. 57). The upper cross member of the back frame is in direct contact with the head restraint system, whereas the side members, both right and left, and the lower cross member carry loads to the floor from the head restraint. "The accuracy between the headrest holes [in the upper cross member of the back frame] and the tolerance for the holes is critical and should be held closely" (JCI, p. 65).

The top of the seat back and the head restraint must also work in conjunction with each other, from styling and performance perspectives, to determine bezel location. The overall look of the head restraint with the rest of the seat is important to styling of the seat. The fit of the head restraint with the rest of the seat from a performance aspect is also crucial. Bezel location is determined after seat back and head restraint fit are worked through (JCI, 2003a, p. 71).

The bezel's most critical role is to ensure clearance where the rod structure and the bezel move in relation to each other. It is difficult, however, to satisfy both the clearance requirement(s) and the effort requirement(s) for consumers. If the clearance is made tighter in order to reduce the movement, this can increase the effort. On the other hand, if the clearance is relaxed, the movement of the part can increase. Controlling the movement and effort really depend on (a) rod finish and tolerance, (b) bezel finish and tolerance, (c) bezel size tolerance, (d) relationship between the rod structure and the bezel, (e) relationship between the metal support and the bezel, (f) seat back frame hole size and tolerance, (g) upper and lower holes alignment in the seat back frame, and (h) side to side tolerance on the holes in the seat back frame (JCI, 2003a, p. 72). There are many measures that can be taken to ensure appropriate clearance is available; however, they can be cost prohibitive. There must be a compromise between effort and movement.

Requirements

As with most products, head restraints must follow three types of requirements in order to be successful: OEM standards and design specifications, government regulations and standards, and consumer demands. There are strict design requirements set by OEMs for the head restraint in the industry today. "The OEM will specify a minimum and maximum height for the top of the back and the top of the extended headrest. The minimum and maximum height requirements seem to change every few years" (JCI, 2003a, p. 50). In addition, the operator's head must be a specified distance from the metal posts used to place the head restraint into the seat. Seat manufacturers must comply by these OEM requirements for part success.

The head restraint and seat must also blend, from the OEM design perspective, seamlessly. "Blending the headrest into seat styling and more importantly into the top end of the back assembly is critical" (JCI, 2003a, p. 51). This blending is achieved by successfully fitting, with the seat, the trim cover and foam pad that make up the head restraint. The trim cover is wrapped around the foam pad that defines the shape of the head restraint. The way in which this trim cover is closed at the underside of the head restraint significantly affects the fit between the top of the seat back and the head restraint. “Closing the bottom of the headrest needs careful attention and many times becomes an appearance issue, both when it is up and down. Fit and function need to be worked out on the layout before any parts are made” (JCI, p. 51). The way in which the trim cover opening is closed at the base of the part can create a significant impact on design. This, along with the shape of the foam pad against the shape of the top of the seat back, affects overall head restraint and seat compatibility.

There are also requirements set by Federal Motor Vehicle Safety Standards and Regulations (FMVSS) for the manufacture of head restraints. The head restraint must be able to accommodate a specific load when applied 65 mm from the top of the trimmed surface per FMVSS 202 (JCI, 2003a, p. 50). In order to meet this requirement, seat manufacturers must incorporate a metal structure to transfer the load(s) to the seat structure. FMVSS 201, on the other hand, requires that the head restraint must be able to accommodate loads from the rear of the vehicle (JCI, p. 51). This load may come from a front-end collision, where the rear occupants would move forward, striking the rear of the head restraint attached to the front seats. FMVSS 201 can conflict with FMVSS 202 and provides difficulty in head restraint design for seat manufacturers. In any case, the head restraint is considered a structural member of the seat and has to provide support to the occupant.

Once OEM requirements and government regulations are met, consumer demands for head restraints are taken into account. Three critical desires of consumers identified by JCI (2003b) are effort to adjust the head restraint upward and downward, the overall feel of the part when operated in regards to strength, and the noise of the part (p. 52). Four components, described by JCI, affect the occupant effort(s) during use: metal rod tolerances and finish, bushing or bezel, back frame, and lubrication on the rod (p. 52). It is important that the head restraint designer focus on the relationship between these four components in order to achieve a good part. In addition, if the head restraint will include a lock feature that will eliminate it from moving to its lowest position, the designer must first determine whether the adjustment operation of the head restraint will require the occupant to use one or two hands. After this is decided, the type of lock that will be used must be selected. Selection of the locking feature impacts cost and effort specifications. The range of effort expected from the occupant to move the part was 30 N to 100 N in the past; this has moved to 20 N to 40 N today (JCI, p. 52). Because there is a direct correlation between the effort to move the part and the noise the part makes, the designer must control this relationship (JCI, p. 52).

Fabrics in Automotive Seating

In the past, fabrics used in the production of automotive seating were not unlike those used in the production of furniture. As technology advances and more resources become available, manufacturers are able to offer more cutting-edge, state-of-the-art fabrics for use in the demanding world in which we live today. As Smith (1994) stated, "We want our car to look good, to 'feel' good when we are in it; we want it to be comfortable; to be quiet or sound good; we want good gas mileage; we want it to last a long time, to be safe, and reliable. And now we even want our car to be recyclable. Automotive upholstery fabric makes a major contribution toward realizing all these 'wants'" (para. 2). Seat manufacturers have taken monumental steps since the days of bench-like seats offered in vehicles, and, in turn, so have fabric manufacturers.

Fabrics used in the transportation industry compose a large product category. Smith (1994) stated that the "transportation industry is indeed a major textile customer" (para. 3). Whether a result of the demand the motor vehicle industry has placed on the textile arena over the last decade or not, the methods for developing automotive upholstery fabric have advanced extensively. Some of these developments consisted of improvements in woven and knitted fabric constructions, innovations in three-dimensional fabrics, and the expanded use of nonwoven fabric constructions.

Types of Fabrics

Fabrics can be made from a wide array of materials, such as (a) solutions used to form films and foams; (b) fibers to form felts, fiberwebs, and nonwovens; (c) yarns to form woven fabrics; and (d) fabrics to form composite fabrics combining solutions, fibers, yarns, or fabrics to produce a fabric (Kadolph & Langford, 1998, p. 176).

Prior to the 1940s, leather and leather imitations were the most widely used fabrics for trim covers; wool and cotton were only used to add design elements to the cover. Copolymers of vinyl and vinylidene chloride were used in the production of fabrics after this point. These fabrics provided increased clean-ability but were uncomfortable to the consumer due to their inability to absorb and transfer moisture away from the occupant. A decade later, polyvinyl chloride (PVC) coated fabrics became increasingly popular and remained that way until the 1970s. Post World War II, nylon and cotton blends replaced PVC (Fung & Hardcastle, 2001). Certain fabric constructions, such as circular knits, tend to have higher stretch and elongation properties than woven fabric constructions. Because this property can allow for ease in manufacture and greater ability to form around a sharp radius, nylon knitted fabrics are the most prevalent upholstery fabric found in automotive seat systems (Smith, 1996, p. 74). As Smith (1994) pointed out, a spokesperson for Chrysler indicated that the industry will use “more yarn dyed polyester fabrics, variations of jacquard produced patterns, circular knits (for stretch and formability) for new seat manufacturing methods such as ‘foam-in-place’ technique, and, with developing technologies, greater use of prints” (para. 10).

Types of Fibers

Each fiber used in the manufacture of seat systems has “physical, performance, and cost factors that make it useful in specific areas” (Smith, 1994, para. 9). Polyester, nylon, or polyester/nylon blends are the main fibers found in trim cover upholstery fabric today. Polyester is also the only fabric in seat belts and trunk liners, which are a polyester heather blend. Nylon, considered to have excellent physical properties, “has been the standard of luxury in velours and pile fabrics” (Smith, para. 7). Nylon is also used to produce air bags, headliners, and carpets. Package trays are polypropylene and nylon, and door trim parts are polypropylene, nylon, and polyester. For recyclability and simplification, textile manufacturers are working toward creating one fiber that could be used throughout the vehicle for interior trim. This concept appears to be far from reality “specifically because of the demands put on each area, and cost constraints” (Smith, para. 9).

Fabric Structures

Woven fabric structures. Flat woven and flat woven velour fabrics are two types of woven fabric structures most prevalent on trim covers today. Woven fabrics are composed on warp yarns, which run parallel to the selvage edge, and weft yarns, sometimes referred to as filling yarns, which are perpendicular to warp yarns. These two sets of threads are interlaced at right angles to each other. Flat woven velour fabrics consist of warp and weft yarns with a third set of vertical yarns interwoven into the warp and weft yarns, creating a pile. Flat woven velour fabrics are more costly than most flat woven fabrics and have been classified as high quality fabrics (Fung & Hardcastle, 2001, pp. 57, 58, 69-73). Woven fabric structures do not allow for as much flexibility as knitted fabric structures, and therefore are less easy to trim into automotive upholstery fabric covers. Elastomeric and poly-butylterephthalate fibers can be used in the production of woven fabric structures to provide more stretch and greater pliability for use on the trim covers (Fung & Hardcastle, pp. 74-75).

Knitted fabric structures. Warp-knit tricot and double-needle-bar raschel are two knitted fabric structures, both warp-knit, used in trim covers. Warp-knit structures are formed from a warp, as are woven fabric structures; however, weft yarns are not interlaced at right angles. Instead, wales are created using needles that interlace adjacent yarns, in loop formations, around the warp yarns, creating vertical stitches. Each loop is referred to as a course; therefore, wales and courses make up knitted fabric structures (Fung & Hardcastle, 2001, p. 77). Wales and courses are manipulated by guide bars; warp-knit tricot fabrics are created from one to four guide bars, whereas raschel fabrics can use up to forty-eight guide bars. Double-needle-bar raschel fabric structures are composed of two knitted fabrics joined with warp yarns; these fabric structures are used widely in trim covers (Fung & Hardcastle, p. 80).

Circular knitted fabric structures are known as weft knit structures and are produced by a group of horizontal loops instead of vertical loops. This technology is more recent than woven and warp-knitted fabric structures. Circular knitted fabrics exhibit high stretch that is usually controlled with the addition of another knitted fabric laminated to it as a composite for trim covers (Fung & Hardcastle, 2001, p. 86).

Polyvinyl chloride fabric structures. PVC fabric structures combine the characteristics of a fabric with a polymer film. They are "made directly form a polymer solution by melt-extrusion or by casting the solution onto a hot drum" (Kadolph & Langford, 1998, p. 244). Expanded PVC is typically used for trim covers; these constructions have been modified with the use of a "blowing agent that incorporates tiny air cells into the compound" (Kadolph & Langford, p. 244). In automotive applications, PVC is combined with a woven or knitted fabric that provides strength and elongation control, improved durability and ability to sew, and support to the film (Kadolph & Langford). It is then referred to as a supported film.

Composites. Kadolph & Langford (1998) described composite fabrics as "fabrics that combine several primary and/or secondary structures, at least one of which is a recognized textile structure, into a single structure" (p. 255). In head restraint applications, trim covers are composed of fabrics used as a composite with foam lamination to provide support, improve hand of the finished part, and aid in the manufacturing process. Kadolph & Langford explained that "laminates include those fabrics in which two layers of fabric are combined into one fabric with an adhesive or foam" (p. 261). The foam lamination used for FIP manufacturing in trim covers is a high-density polymer that prevents foam bleedthrough and provides support to the trim cover. The laminate is adhered to the fabric with a foam-flame process. Kadolph & Langford described the process as the following: "The foam is made tacky first on one side and then on the other by passing under a gas flame" (p. 262). Trim covers for FIP manufacturing are either composed of two components, the fabric and the foam lamination, or three components, the fabric, the foam lamination, and a polyethylene film to resist bleedthrough to the technical face side of the fabric during FIP manufacturing.

Fabric Properties

There are several properties that fabrics exhibit that are indicators of cutting, sewing, and appearance-related issues in seat manufacturing.

Elongation. Elongation is the maximum length that a fabric is able to stretch prior to break. ASTM has developed a test, ASTM D 5034, that allows the elongation property of a fabric to be measured. JCI (2000a) stated that this test "…measures the material's ability to stretch, and is reported as a percentage of the distance a sample increases when a load is applied" (p. 105). For more aggressively contoured head restraint designs, a higher elongation property is required to allow for the fabric to "handle compound radii and convex-to-concave transitions" (JCI, p. 105) and not form breaks on the technical face side of the fabric. Balanced elongation properties, between the length of the roll (parallel to the selvedge edge) and the width of the roll (perpendicular to the selvedge edge) is also important in manufacturing to avoid puckers and seam chatter.

Boardiness. Boardiness defines the softness of a fabric. It can be measured with a proprietary test created by JCI. There is currently not a similar test method, established in the industry that relates to boardiness. The test assigns a numerical value to the softness of a fabric. This property assists seat manufacturers in determining if the fabric will bridge, walnut, or create a void on the seat.

Weight. The weight of a fabric, in its unlaminated state, can assist seat manufacturers in determining if the fabric will curl during cutting, and/or form puckers, seam chatter, re-sew marks, and bleedthrough on the finished product. The ASTM test method that measures this property is ASTM D 3776.

Thickness. In its unlaminated form, the thickness of a fabric can assist seat manufacturers in determining if the fabric will curl during cutting, and/or form puckers, seat chatter, re-sew marks, and bleedthrough on the finished product. The ASTM test method that measures this property is ASTM D 1777.

Stretch. The elastic property of a fabric significantly impacts the bagginess or looseness of a fabric and its likelihood of forming seam chatter and puckers on the built part. The test used to measure this property is SAE J855.

Set. The recovery property of a fabric significantly impacts the bagginess or looseness of a fabric and its likelihood of causing appearance defects on the built part. The test used to measure this property is SAE J855.

Breaking radius. Breaking radius defines the steps required to determine the minimum radius the technical face side of a fabric can curve around without breaking. This property assists seat manufacturers in determining if a fabric will break or crease on a seat.

Ravel. Ravel determines the severity of raveling and loose pile fibers that may occur during cutting processes. This property assists seat manufacturers in determining if the yarns within a fabric will unravel and displace from their original position within the fabric structure, causing interference in sewing operations. It also allows seat manufacturers to determine if a fabric will shed or lint, referred to as dust off.

Craftsmanship and Appearance Expectations

Fabrics are a critical part of the trim cover; they provide the interface between the occupant and the seat system. Consumers have strong expectations of the appearance of the seats in their vehicles. Daimler Chrysler's Design Institute (n.d.) realized that, "Interior design is critically important to customer satisfaction because the customer interacts in a very personal way with the inside of the vehicle" (para.1). Further, it is important to realize that customers hold the look of the trim cover in high regard, as the fabrics used are the most obvious components of the seat as a whole. Evaluating fabrics for physical properties is important in understanding the finished product. Manufacturers have realized, in recent years, the critical role fabrics play in vehicle interiors and how important it is to identify typical issues that may result due to specific fabric constructions.

Summary

Today's automotive seating is far from what it once was. Tier-one suppliers and OEMs strive to remain competitive in the demanding automotive market. Automotive upholstery fabric is increasingly important and needs continuing research to evolve. To date, no research has been performed regarding fabric properties of bilaminated and trilaminated composites used in FIP manufacturing. Mike Van Nieuwkuyk, market-research manager Lear Corp, stated that, "Urban sprawl is growing. Neighborhoods are moving farther and father out. Traffic is getting heavier and drive times are getting longer. So even though the exterior style is the emotional connection that draws you to a car, once you start spending time in it, the interior is everything" (Fahey, 2003, para. 3). Vehicles have seen drastic changes in interior construction. There are new options and features that never existed before. The industry is in great need of well-engineered fabrics to place in interior systems.

Knowledge of behavior, value systems, and consumer trends is invaluable information to vehicle designers around the world. In a recent consumer research survey, results indicated that vehicle purchase decisions were influenced by how well the interior design was developed, including fabric quality and appearance (JCI, 2003b, para. 2). Consumers want “well thought-out and executed” interior cabins and seating components (JCI, para. 1). Consumer Benefits Rating Studies try to determine which features consumers consider the most important in the interior of a vehicle. “The results of this study show us that people want products that are aesthetically appealing and distinguished,” (JCI, para. 4) stated Bill Fluharty, vice president of industrial design and market research for JCI, North America. The study asked consumers to rate what was most important among 14 features; they rated fabrics in the top five for all but one vehicle segment: minivans, where “participants replaced ‘materials’ with ‘multi-purpose’ and ‘quantity of storage’ (JCI, para. 8). Perceived quality of fabrics, cleanability, and pleasing touch were characteristics of materials that were all ranked high by consumers (JCI, para. 5). Understanding what customer preferences are and ensuring they are met in head restraint design is the key to successful production parts.

With the heightened awareness of upholstery fabric in vehicles, it is important that automakers pay close attention to the physical properties of fabrics. This study will benefit automakers and seat manufacturers by evaluating the physical properties of knitted fabric in two forms: bilaminated and trilaminated composites used in FIP head restraints.

CHAPTER III

RESEARCH DESIGN AND METHODOLOGY

The purpose of this study was to evaluate the difference between seven physical properties of three knitted fabrics as bilaminated and trilaminated composites. A series of seven standardized tests was conducted, typically used by tier suppliers to analyze the physical properties of fabric. Research paradigm, sample size and selection, unit of analysis, data collection process, limitations of the process, validity of test procedures, and data analysis are discussed in this chapter.

Introduction

Research Question

The research question posed for this study asked: will the physical properties of knitted fabrics, when evaluated in bilaminated and trilaminated composite forms, differ from one another?

Hypothesis

The following was the hypothesis for this study:

H1: Trilaminated knitted fabrics exhibit different physical properties than bilaminated knitted fabrics in relation to the following:

A: elongation test data;

B: boardiness test data;

C: weight test data;

D: thickness test data;

E: stretch and set test data;

F: breaking radius test data;

G: ravel test data.

Research Design

Laboratory testing was performed on fabric samples to provide a quantitative analysis of the physical properties of three fabrics, each with two types of composite. Seven laboratory tests, considered by the industry to be the medium for evaluating the physical properties of fabric, were used. The tests included Elongation, Boardiness, Weight, Thickness, Stretch and Set, Breaking Radius, and Ravel. Each test was performed according to standard test methods established by ASTM, SAE, or tier-one automotive seat supplier specifications.

Fabric Selection

Fabric samples consisted of three flat knit fabrics as bilaminated and trilaminated composites. All samples were laminated by one source using the same method and polymer and tested for the seven properties. Fabric construction type was chosen based on industry trends: knitted fabrics were more commonly used for head restraints than woven fabrics.

Fabrics were obtained from one automotive textile supplier and taken out of current production runs. Fabrics were flame laminated with the same polyurethane foam to form a bilaminated composite and a trilaminated composite. The bilaminated composites consisted of fabric and 1.7 lb foam lamination. The trilaminated composites consisted of fabric, 3.0 lb foam lamination, and polyethylene film. Composite types were selected based on industry trends: fabric combined with polyurethane foam alone and with polyethylene film commonly used for FIP applications.

Laboratory Conditions

Laboratory tests were performed in a tier-one automotive seat supplier accredited laboratory. Laboratory tests were not conducted in a controlled environment, nor were fabrics conditioned in a controlled environment prior to testing. Test procedures were performed as typical by the tier-one automotive seat supplier and the textile fabric supplier. Temperature and humidity were recorded prior to each laboratory test performed.

Data Collection Process

Physical properties of the fabric samples were evaluated using standard test methods developed by ASTM, SAE, and a tier-one automotive seat supplier. Seven test methods were selected because they have been identified by the industry as a vehicle for measurement of fabric physical properties. Table 1 lists the characteristic to be tested and the method used for evaluation. Where applicable, test specimens were taken in the warp direction, fill direction, and bias direction.

Table 1

Laboratory Tests

Test Characteristic	Test Method
Elongation	ASTM D 5034 – 95 (2001), Grab Method
Boardiness	Tier-one Automotive Seat Supplier
Weight	ASTM D 3776 – 95 (2002), Option C
Thickness	ASTM D 1777 – 96
Stretch and Set	SAE J855, SEP2002
Breaking Radius	Tier-one Automotive Seat Supplier Method
Ravel	Tier-one Automotive Seat Supplier Method

Elongation

Test method. Standard Test Method for Breaking Strength and Elongation of Textile Fabrics (Grab Test) designated by: ASTM D 5034 – 95 (2001), Grab Method, was used to evaluate the elongation of each fabric. This test method was used to determine the ratio of the extension of a fabric to the length of the fabric before stretching. “A 100-mm (4.0 in.) wide specimen is mounted centrally in clamps of a tensile testing machine and a force applied . . .” (ASTM, 2001, p. 2). The grab test procedure is used to determine the effective strength of the fabric, indicating “the strength of the yarns in a specific width together with the fabric assistance from the adjacent yarns” (ASTM, 2001, p. 2). This test is used by seat manufacturers as a tool to predict how a fabric trim cover will reposition after enduring the load of an occupant resting in a seat, referred to as fabric growth, with increased fabric growth indicating a likelihood of bagginess on the trim cover. The result was reported as a percent.

Specimen size and number. Test specimens were taken from unflawed areas of rolled goods, disregarding one tenth of the width of the rolled good from the selvage edge. Test specimens measured 100 x 150 mm (3.9 x 5.9 in.) each. Five specimens each were cut in the warp, fill, and both 45-degree bias directions.

Apparatus. A constant-rate-of-extension tensile testing machine (Instron, Model 4464) was used with a 50 N load force. A gauge length was set to 75 mm (3.0 in.) between the upper and lower jaws and a jaw speed of 300 mm/min was maintained.

Procedure.

1. Specimen was mounted centrally between the upper and lower clamp jaws. Care was taken to ensure markings on the specimen were aligned with clamp jaws so that the same amount of fabric extended beyond the upper and lower jaws.
2. A 50 N force was applied to the specimen.
3. The amount of elongation prior to breaking point was recorded for the specimen as a percent.

Steps 1-3 were repeated for each test specimen.

Evaluation. The percent elongation of each specimen was read from a computer interfaced with the testing machine. The average percent (%) elongation to the nearest 0.1% for each direction was reported.

Boardiness

Test method. Test Method for Boardiness, designated by a tier-one automotive seat supplier, was used to evaluate the boardiness of each fabric. This test method was used to quantify the softness or hardness of each fabric into a numerical value. This test is used by seat manufacturers as a tool to predict whether a fabric is likely to bridge, walnut, or create a void on the trim cover. The result was reported as a Durometer unit.

Specimen size and number. Test specimens were taken from unflawed areas of rolled goods, disregarding one tenth of the width of the rolled good from the selvage edge. One specimen was cut from each rolled good, measuring 35 x 35 cm (13.79 x 13.79 in.).

Apparatus. Type 000 Durometer was used with a foam block. Foam block measured 38 x 38 x 10 cm; 710 g in weight; 430 N ILD at 65% compression. Foam block was marked with a 20 cm square in center of the testing surface, with lines intersecting in the exact center of the square. Each corner of the 20 cm square was labeled with a number from 1 to 4, and the center was numbered as 5. The foam block was labeled with a unique identification letter "C".

Procedure.

1. Foam block was set on a flat surface.
2. Durometer was placed on the foam block at test area 1, without applying pressure, and reading was taken immediately in a whole number.
3. Step 2 was repeated for test areas 2 through 5 of the foam block.
4. Test specimen was centered on the foam block with face side of the fabric up.
5. The Durometer was placed on the test specimen at test area 1, without applying pressure, and reading was taken immediately in a whole number.
6. Step 5 was repeated for test areas 2 through 5 of the fabric specimen.
7. Five foam readings and five specimen readings were averaged and recorded in whole numbers.

Evaluation. Boardiness was reported out in Durometer units and calculated using the following formula: S – F = B, where S = the average of Durometer readings from test specimen; F = the average of Durometer readings from foam block; and B = boardiness. The boardiness of each specimen was recorded along with the foam block ID letter.

Weight

Test method. Standard Test Method for Mass Per Unit Area (Weight) of Fabric designated by: ASTM D 3776 – 95 (2002), Option C, was used to evaluate the weight of each fabric. This test method was used to determine the measurement of fabric mass per unit area and is expressed as grams per square meter (ounces per square yard). "Fabric mass is calculated from the mass of a specimen the length and width of which have been measured . . ." (ASTM, 2002, p. 1). This test is used by seat manufacturers as a tool to predict whether components found underneath a fabric will be visible through the face side of the fabric trim cover, referred to as read-through. It is also used to predict whether needle marks will be visible on the trim cover if sewing thread is removed due to sewing error, referred to as re-sew marks, and whether needle holes will elongate after sewing operation, referred to as needle-hole elongation. Further, this test is used to predict the durability of a fabric. The result was reported in grams.

Specimen size and number. Test specimens were taken from unflawed areas of the rolled goods, disregarding one tenth of the width of the rolled goods from the selvage edge. Test specimens measured 50 x 50 mm (2.0 x 2.0 in.) each. Five specimens were cut from different locations of the rolled goods.

Apparatus. A Denver Instruments TR-203 Balance was used to weigh the specimens within 0.1 % of mass (weight) on the balance.

Procedure.

1. The specimen was placed on the balance individually.
2. The mass (weight) in grams was read directly from the Denver Instruments Balance.

Steps 1-2 were repeated for each test specimen.

Evaluation. The fabric mass in grams was recorded to three significant figures. The fabric mass for all five specimens was averaged and recorded. The fabric mass in grams was reported to three significant figures.

Thickness

Test method. Standard Test Method Thickness of Textile Materials designated by ASTM D 1777 – 96 was used to evaluate the thickness of each fabric, which is expressed in millimeters. "A specimen is placed on the base of a thickness gauge and a weighted presser foot lowered. The displacement between the base and the presser foot is measured as the thickness of the specimen" (ASTM, 1996, p. 1). Similar to the test to determine weight, this test is used by seat manufacturers as a tool to predict whether components found underneath a fabric will be visible through the face side of the fabric trim cover, referred to as read-through. It is also used to predict whether needle marks will be visible on the trim cover if sewing thread is removed due to sewing error, referred to as re-sew marks, and whether needle holes will elongate after sewing operation, referred to as needle-hole elongation. Further, like the Weight test, this test is used to predict the durability of a fabric. The result was reported in millimeters.

Specimen size and number. Test specimens were taken from unflawed areas of the rolled goods, disregarding one tenth of the width of the rolled goods from the selvage edge. Test specimens measured 50 x 50 mm (2.0 x 2.0 in.) each. Five specimens were cut from different locations of the rolled goods.

Apparatus. An Ames 225-20 Thickness Gauge was used to measure the specimen's thickness in millimeters.

Procedure.

1. Specimen was placed, face side up, on the anvil of the thickness gauge. The presser foot was gradually lowered into contact with the specimen.
2. The thickness value was read and recorded directly from the Ames Thickness Gauge.

Steps 1-2 were repeated for each test specimen.

Evaluation. The fabric thickness in millimeters was recorded to three significant figures. The fabric thickness for all five specimens was averaged and reported.

Stretch and Set

Test method. Test Method of Stretch and Set of Textiles and Plastics designated by SAE J855, SEP2002 was used to evaluate the measurement of elastic and recovery properties of each fabric after being subjected to a low-static load. This test is used by seat manufacturers as a tool to predict how an upholstery fabric trim cover will reposition while enduring the load of an occupant resting in a seat and return to its original position after enduring that load, and therefore whether bagginess of the trim cover will result. The results for the stretch and the set of each fabric were each reported as a percent.

Specimen size and number. Test specimens were taken from unflawed areas of rolled goods, disregarding one tenth of the width of the rolled good from the selvage edge. Test specimens measured 76 x 229 mm (3 x 9 in.) each. Three specimens each were cut in the warp, fill, and both 45-degree bias directions.

Apparatus. A clamp and fixture assembly for Stretch and Set of textiles was used and included the following: bench, clamp support, vice grip with 76 mm (3 in.) jaws, and 11.35 kg (25 lb) weight. The weight was attached to the clamp on the suspended end of the test specimen. The clamp and the weight together totaled 12.25 kg (27 lb).

Procedure.

1. Specimen was marked with parallel and perpendicular lines to provide benchmarks for measurement and to allow for proper clamp alignment.
2. Specimen was measured between two parallel benchmarks to provide original length prior to stretch and set to the closest 0.40 mm (1/64 in.) and recorded as L_1.
3. Specimen was mounted centrally between the upper and lower clamp jaws. Care was taken to ensure that parallel and perpendicular markings on the specimen were aligned with clamp jaws so that the same amount of fabric extended beyond the upper and lower jaws.
4. A 12.25 kg (27 lb.) load was carefully applied to the specimen for five minutes after clamps were firmly fastened.
5. With weight still applied, the length of the section between the parallel markings on the specimen was measured to the closest 0.40 mm (1/64 in.) and recorded as L_2.
6. The weight and clamps were removed, and the specimen was allowed to recover on a horizontal, flat surface for five minutes.

7. The length of the section between the parallel markings on the specimen was measured to the closest 0.40 mm (1/64 in.) and recorded as L_3.

Steps 1-7 were repeated for each test specimen.

Evaluation. Data were reported as the percent stretch and the percent set and calculated using the following formulas:

$$\% \text{ Stretch} = \frac{L_2 - L_1}{L_1} \text{ x } 100$$

$$\% \text{ Set} = \frac{L_3 - L_1}{L_1} \text{ x } 100$$

where measured lengths were taken between two parallel lines at benchmarks:

L_1 = the original length between parallel lines at benchmarks.

L_2 = measured length after weight is applied for five minutes.

L_3 = measured length after five minutes of recovery time.

Breaking Radius

Test method. Test Method for Breaking Radius, designated by a tier-one automotive seat supplier, was used to evaluate the minimum radius that the face side of a fabric can curve around without breaking, defined as a disturbance in the fabric face. This test is used by seat manufacturers as a tool to predict the pliability of a fabric and whether the fabric is likely to break and therefore form wrinkles on the trim cover. The result was reported in millimeters.

Specimen size and number. Test specimens were taken from unflawed areas of rolled goods, disregarding one tenth of the width of the rolled good from the selvage edge. Three specimens each were cut in the warp, fill, and both 45-degree bias directions, measuring 100 x 350 mm (3.9 x 13.79 in.).

Apparatus. A radius gage was used consisting of a series of round discs, 5 mm (0.2 in.) thick, with radii ranging from 10 to 150 mm (0.4 to 5.9 in.) changing at 10 mm (0.4 in.) increments.

Procedure.

1. Fabric face was slowly wrapped around circumference of 150 mm (5.9 in.) radius disc, lengthwise, so that the entire length of the specimen was touching the circumference of the disc.
2. Fabric face was evaluated for a break while held in position against 150 mm (5.9 in.) radius disc. If no breaks were present, specimen was moved to the next smallest radius disc and evaluated for breaks until a break appeared at a radius. When break occurred, at any radius disc, the number located on the radius disc where the specimen rested was recorded as the minimum radius at break.
3. Steps 1-2 were repeated for each specimen.

Evaluation. Breaking Radius was reported out in millimeters, and the largest radius of the 3 specimens for warp, fill, and both 45-degree bias directions were reported separately. If the fabric face broke on 150 mm (5.9 in.) radius, break at greater than 150 mm was reported. If no break appeared after using all radii, 10 mm (0.4 in.) was reported as minimum radius.

Ravel

Test method. Test Method for Ravel, designated by a tier-one automotive seat supplier, was used to determine if the yarns making up a fabric unravel and/or if the fibers making up the yarns of the fabric shed or create dust or lint. Seat manufacturers use this test as a tool to predict whether a fabric is likely to cause issues with cutting or sewing operations during seat manufacture due to yarns unraveling. This test is also used to predict whether a fabric is likely to cause additional problems during cutting and sewing operations due to dust or lint causing ergonomic issues. Dust or lint can also adhere to the upholstery fabric trim cover, causing increased labor time to remove it. The result was reported as a rating.

Specimen size and number. Test specimen was taken from unflawed areas of rolled goods, disregarding one tenth of the width of the rolled good from the selvage edge. One specimen measuring 150 x 150 mm (5.9 x 5.9 in.) was taken from rolled goods.

Apparatus. None

Procedure.

1. Fabric was evaluated along the edge of the specimen by observing the yarns and fibers along the cut edge. The exposed ends of the yarns were pulled two times to determine how easily they separate from the body of the specimen. The cut edges of the fabric were rubbed three times to determine how easily the backing and/or pile yarns separate from the body of the fabric.
2. Fabric was rated based on whether yarns were displaced from cut edge and whether fibers created dust or lint when touched by hand. Good ravel was recorded where no yarns unraveled or displaced from cut edges and where no dust or lint was evident. Poor ravel was recorded where yarns unraveled from the cut edge and dust or lint was high and adhered to the fabric and/or the operator. Fair ravel was recorded where yarns partially unraveled from the

cut edge and dust or lint was minimum and did not adhere to the fabric and/or the operator.

3. Rating was recorded.

Evaluation. Severity of loose yarns and pile fallout were rated as follows:

Good = No yarns unraveled or displaced from the cut edges and no dust or lint was evident.

Fair = Yarns partially unraveled from the cut edge and dust or lint was minimum and did not adhere to the fabric and/or the operator.

Poor = Yarns unraveled from the cut edge and dust or lint was high and adhered to the fabric and/or the operator.

Limitations of the Process

In this study, laboratory testing was not conducted in a controlled environment, nor were fabrics conditioned in a controlled environment prior to testing.

Validity of Test Procedures

The test methods used in this study comply with the standards specified by ASTM, SAE, and a tier-one automotive seat supplier. These test methods were used by the automotive industry for upholstery fabric evaluation for automotive seat applications regularly.

Data Analysis

Data were coded and analyzed using SPSS V12.02. Basic descriptive statistics were performed, indicating the mean and standard deviation of the laboratory test data. An Independent Group t-Test was conducted to determine equality of means between bilaminated and trilaminated laboratory test data, in addition to Levene's Test to determine equality of variances. Chapter IV provides a detail of the results and statistical methods used for these analyses.

CHAPTER IV

PRESENTATION AND ANALYSIS OF DATA

The purpose of this study was to evaluate the difference between seven physical properties of three knitted fabrics as bilaminated and trilaminated composites. A series of seven standardized tests were conducted, typically used by tier suppliers to analyze the physical properties of fabric. Results are discussed in three sections within this chapter: 1) laboratory test results, 2) descriptive statistics, and 3) hypothesis testing.

Basic descriptive statistics were performed, indicating the mean and standard deviation of the laboratory test data. An Independent Group T-Test was then conducted to determine equality of means between bilaminated and trilaminated laboratory test data, in addition to Levene's Test to determine equality of variances for testing the hypothesis. The results of each of the seven laboratory tests conducted are presented in this chapter, followed by the statistical analysis.

Introduction

Research Question

The research question posed for this study asked: will the physical properties of knitted fabrics, when evaluated in bilaminated and trilaminated composite forms, differ from one another?

Hypothesis

The following was the hypothesis for this study:

H1: Trilaminated knitted fabrics exhibit different physical properties than bilaminated knitted fabrics in relation to the following:

A: elongation test data;

B: boardiness test data;

C: weight test data;

D: thickness test data;

E: stretch and set test data;

F: breaking radius test data;

G: ravel test data.

Laboratory Testing

The results of the physical testing collected are presented in this section. Seven tests were performed: Elongation, Boardiness, Weight, Thickness, Stretch and Set, Breaking Radius, and Ravel. Fabrics were labeled with the first letter of the fabric type followed by a numeral. Knitted bilaminated and trilaminated fabrics were labeled K1, K2, and K3.

Elongation

This test was used to determine the ratio of the extension of a fabric to the length of the fabric before stretching. The values obtained from this test were used to compare the fabric growth of each material, with high elongation values corresponding to increased fabric growth, indicating an increased likelihood of bagginess on the trim cover.

Bilaminated Test Data. Results of this test ranged from 6.5 % to 14.7% elongation for bilaminated fabrics. The results indicated that, on average, bilaminated fabrics had highest elongation in the bias direction and lowest elongation in the fill direction, therefore suggesting a higher potential for fabric growth in the bias direction. Comparisons of test data indicated that, on average, the warp direction was consistent with the fill direction, whereas test data from the bias directions was higher than the aforementioned. The results for bilaminated fabrics were reported as a percent and are presented in Table 2.

Trilaminated Test Data. Results of this test ranged from 6.1% to 18.6% elongation for trilaminated fabrics. The results indicated that, similar to the bilaminated sample, trilaminated fabrics had highest elongation in the bias direction and lowest elongation in the fill direction therefore suggesting a higher potential for fabric growth in the bias direction. Comparisons of test data indicated that, on average, the warp direction was consistent with the fill direction, whereas test data from the bias directions were slightly higher than the aforementioned. Overall, test data averages indicated greater elongation in trilaminated fabrics, in each direction, than bilaminated fabrics. The results for trilaminated fabrics were reported as a percent and are presented in Table 2.

Table 2

Elongation Test Data

	Results			
	K1	K2	K3	Avg.
Bilaminated Fabric Specimens				
Warp (N=15)	8.9	9.7	7.8	8.8
Fill (N=15)	6.9	9.8	6.5	7.7
Bias 1, Bias 2 (N=30)	11.8	14.7	11.1	12.5
Trilaminated Fabric Specimens				
	K1	K2	K3	Avg.
Warp (N=15)	17.0	8.4	8.7	11.4
Fill (N=15)	18.6	8.9	6.1	11.2
Bias 1, Bias 2 (N=30)	16.3	11.8	10.2	12.8

Note. Test data are expressed as a percent. K = knitted fabric samples.

Boardiness

This test was used to quantify the softness or hardness of each fabric into a numerical value. The values obtained from this test were used to compare the softness of materials, with high boardiness values corresponding to harder materials, indicating a likelihood for bridging, walnuting, or creating voids on the trim cover. Due to the nature of this test, direction of the specimen was not a factor for comparison.

Bilaminated Test Data. Results of this test ranged from 48 to 50 units for bilaminated fabrics. The results indicated a range of 2 units, with K1 representing a lower test result than K2 and K3, suggesting a softer material and a lower potential for bridging, walnuting, or creating voids on the trim cover. The results for bilaminated fabrics were reported in Durometer units and are presented in Table 3.

Trilaminated Test Data. Results of this test ranged from 65 to 73 units for trilaminated fabrics. The results indicated a range of 8 units, with K1 representing a lower test result than K2 and K3, indicating a softer material and suggesting a lower potential for bridging, walnuting, or creating voids on the trim cover. Overall, the results indicated that trilaminated fabrics were harder than bilaminated fabrics. The results for trilaminated fabrics were reported in Durometer units and are presented in Table 3.

Table 3

Boardiness Test Data

	Results			
	K1	K2	K3	Avg.
Bilaminated Fabric Specimens (N=15)				
	48	50	50	49
Trilaminated Fabric Specimens (N=15)				
	65	73	73	70

Note. Test data are expressed as a Durometer unit. K = knitted fabric samples.

Weight

This test was used to determine the weight of each fabric. The values obtained from this test were used to compare the differences in weight of materials with higher values corresponding to increased durability and a decreased likelihood of read-through, re-sew marks, and needle-hole elongation on the trim cover. Due to the nature of this test, direction of the specimen was not a factor for comparison. The results for bilaminated and trilaminated fabrics were measured in grams, converted, and then reported in grams.

Bilaminated Test Data. Test results ranged from 530 to 573 g/m^2 for bilaminated fabrics. The results indicated a range of 43 g/m^2, with K3 representing a lower test result than K1 and K2 and suggesting an increased likelihood of read-through, re-sew marks, and needle-hole elongation. Further, test results for K3 suggested a potential for decreased durability. The results for bilaminated fabrics are presented in Table 4.

Trilaminated Test Data. Test results ranged from 523 to 739 g/m^2 for trilaminated fabrics. The results indicated a range of 216 g/m^2, with K1 representing a lower test result than K2 and K3, suggesting an increased likelihood of read-through, re-sew marks, and needle-hole elongation. Overall, the results indicated that trilaminated fabrics were heavier than bilaminated fabrics. The results for trilaminated fabrics are presented in Table 4.

Table 4

Weight Test Data

	Results			
	K1	K2	K3	Avg.
Bilaminated Fabric Specimens (N=15)				
	1.336	1.432	1.326	1.365
Trilaminated Fabric Specimens (N=15)				
	1.307	1.848	1.771	1.642

Note. Test data are expressed in grams. K = knitted fabric samples.

Thickness

This test was used to determine the thickness of each fabric. Similar to the Weight test, the values obtained from this test were used to compare the differences in thickness of materials with higher values corresponding to increased durability and a decreased likelihood of read-through, re-sew marks, and needle-hole elongation. Due to the nature of this test, direction of the specimen was not a factor for comparison.

Bilaminated Test Data. Test results ranged from 5.08 to 5.36 mm for bilaminated fabrics. The results indicated a range of 0.28 mm, with K3 representing a lower test result than K1 and K2 and suggesting an increased likelihood of read-through, re-sew marks, and needle-hole elongation. Further, test results for K3 suggested a potential for decreased durability. The results for bilaminated fabrics were reported in millimeters and are presented in Table 5.

Trilaminated Test Data. Test results ranged from 5.63 to 5.81 mm for trilaminated fabrics. The results indicated a range of 0.18 mm, with K1 representing a lower test result than K2 and K3, suggesting an increased likelihood of read-through, re-sew marks, and needle-hole elongation. Overall, the results indicated that trilaminated fabrics were thicker than bilaminated fabrics. The results for trilaminated fabrics were reported in millimeters and are presented in Table 5.

Table 5

Thickness Test Data

	Results			
	K1	K2	K3	Avg.
Bilaminated Fabric Specimens (N=15)				
	5.20	5.36	5.08	5.21
Trilaminated Fabric Specimens (N=15)				
	5.63	5.85	5.81	5.76

Note. Test data are expressed in millimeters. K = knitted fabric samples.

Stretch

This test was used to determine the amount of stretch within a fabric. The values obtained from this test were used to compare the elasticity of materials, with high stretch values corresponding to increased elasticity and decreased likelihood of bagginess.

Bilaminated Test Data. Test results ranged from 8.3% to 20.5% stretch for bilaminated fabrics. The results indicated that, on average, bilaminated fabrics had highest stretch in the bias direction and lowest stretch in the fill direction, therefore suggesting a higher potential for bagginess in the bias direction. Comparisons of test data indicated that, on average, the warp direction was consistent with the fill direction, whereas test data from the bias directions were higher than the aforementioned. The results for bilaminated fabrics were reported as a percent and are presented in Table 6.

Trilaminated Test Data. Results of this test ranged from 6.7% to 30.1% stretch for trilaminated fabrics. The results indicated that, similar to the bilaminated sample, trilaminated fabrics had highest stretch in the bias direction and therefore suggested a higher potential for bagginess in the bias direction. Comparisons of test data indicated that, on average, the warp direction was more consistent with the fill direction, whereas test data from the bias directions were slightly higher than the aforementioned. Overall, test data averages indicated greater stretch in trilaminated fabrics, in each direction, than bilaminated fabrics. The results for trilaminated fabrics were reported as a percent and are presented in Table 6.

Table 6

Stretch Test Data

	Results			
	K1	K2	K3	Avg.
Bilaminated Fabric Specimens				
Warp (N=9)	10.6	10.5	9.6	10.2
Fill (N=9)	8.3	10.9	8.5	9.2
Bias 1, Bias 2 (N=18)	15.6	20.5	15.4	17.2
Trilaminated Fabric Specimens				
	K1	K2	K3	Avg.
Warp (N=9)	23.1	8.7	9.0	13.6
Fill (N=9)	30.1	11.0	6.7	15.9
Bias 1, Bias 2 (N=18)	25.8	17.2	12.8	18.6

Note. Test data are expressed as a percent. K = knitted fabric samples.

Set

This test was used to determine the amount of recovery a fabric exhibits following the removal of a load applied during a Stretch test. The values obtained from this test were used to compare the elastic recovery of materials with high set values corresponding to decreased recovery and increased likelihood of bagginess.

Bilaminated Test Data. Test results ranged from 0.6% to 1.8% set for bilaminated fabrics. The results indicated that, on average, bilaminated fabrics had highest set in the bias direction and lowest set in the warp direction, therefore suggesting a higher potential for bagginess in the bias direction. Comparisons of test data indicated that, on average, the warp direction was consistent with the fill direction, whereas test data from the bias directions were higher than the aforementioned. The results for bilaminated fabrics were reported as a percent and are presented in Table 7.

Trilaminated Test Data. Results of this test ranged from 0.2% to 2.2% set for trilaminated fabrics. The results indicated that, similar to the bilaminated sample, trilaminated fabrics had highest set in the bias direction and therefore suggested a higher potential for bagginess in the bias direction. Comparisons of test data indicated that, on average, the fill direction was more consistent with the bias directions. Overall, test data averages indicated similar set test data for bilaminated and trilaminated fabrics. The results for trilaminated fabrics were reported as a percent and are presented in Table 7.

Table 7

Set Test Data

	Results			
	K1	K2	K3	Avg.
Bilaminated Fabric Specimens				
Warp (N=9)	1.1	0.7	0.6	0.8
Fill (N=9)	0.8	0.7	1.2	0.9
Bias 1, Bias 2 (N=18)	1.7	1.8	1.3	1.6
Trilaminated Fabric Specimens				
	K1	K2	K3	Avg.
Warp (N=9)	1.2	1.1	0.2	0.8
Fill (N=9)	1.5	2.2	0.8	1.5
Bias 1, Bias 2 (N=18)	1.4	1.7	1.7	1.6

Note. Test data are expressed as a percent. K = knitted fabric samples.

Breaking Radius

This test was used to determine the minimum radius the face of a fabric can curve around without exhibiting a break on the face side of the fabric. The values obtained from this test were used to compare the pliability of materials, with high breaking radius values corresponding to decreased pliability and increased likelihood of breaking and wrinkles on the trim cover. The results for bilaminated and trilaminated fabrics were reported as a whole number in millimeters.

Bilaminated Test Data. Test results ranged from 10 to 20 millimeters for bilaminated fabrics. The results suggested little variation between the directions of the specimens, with all directions exhibiting high pliability. The average breaking radius for each fabric was the same: 10 millimeters. The results for bilaminated fabrics are presented in Table 8.

Trilaminated Test Data. Results of this test ranged from 20 to 30 millimeters for trilaminated fabrics. The results suggested, similar to bilaminated fabrics, little variation between the directions of the specimens, with all directions exhibiting high pliability. The results for trilaminated fabrics are presented in Table 8.

Table 8

Breaking Radius Test Data

	Results			
	K1	K2	K3	Avg.
Bilaminated Fabric Specimens				
Warp (N=9)	10	10	20	10
Fill (N = 9)	10	10	20	10
Bias 1, Bias 2 (N=18)	10	10	10	10
Trilaminated Fabric Specimens				
	K1	K2	K3	Avg.
Warp (N=9)	20	30	30	30
Fill (N=9)	20	20	20	20
Bias 1, Bias 2 (N=18)	20	20	20	20

Note. Test data are expressed in millimeters. K = knitted fabric samples.

Ravel

This test was used to determine if the yarns making up a fabric may unravel and/or if the fibers making up the yarns of the fabric may shed or create dust or lint. The values obtained from this test were used to compare the maintenance of materials during cutting, sewing, and other manufacturing operations, with lower values corresponding to increased maintenance. The results for bilaminated and trilaminated fabrics were reported as a rating of Good, Fair, or Poor, with a rating of Good suggesting no issues will occur with unraveling, dust, or lint.

Bilaminated Test Data. Results of this test were ratings of Fair and Good for bilaminated fabrics, with K1 representing a lower test result than K2 and K3, suggesting an increased likelihood of unraveling, dusting, or linting. The results for bilaminated fabrics are presented in Table 9.

Trilaminated Test Data. Results of this test did not range and were reported as Good for trilaminated fabrics. The results for trilaminated fabrics are presented in Table 9.

Table 9

Ravel Test Data

	Results			
	K1	K2	K3	Avg.
Bilaminated Fabric Specimens (N=3)				
	F	G	G	G
Trilaminated Fabric Specimens (N=3)				
	G	G	G	G

Note. G = good. F = fair. K = knitted fabric samples.

Descriptive Statistics

In order to answer the research question posed for this study, basic descriptive statistics were performed indicating the mean and standard deviation of the laboratory test data. Basic descriptive statistics are discussed in this section.

Basic descriptive statistics for bilaminated and trilaminated fabrics identified the minimum, maximum, mean, standard deviation, and the variance of the laboratory test data. All bilaminated knitted fabrics were grouped and evaluated, as were all trilaminated knitted fabrics.

Elongation. The elongation test data mean ranged from 7.726 to 12.631 for bilaminated fabrics and from 11.201 to 12.910 for trilaminated fabrics. The results indicated that trilaminated fabric specimens had a higher mean than bilaminated fabric specimens in the warp and fill directions and therefore had greater elongation in those directions. Further, the mean for both bias directions was similar.

The variance ranged from 0.721 to 4.201 for bilaminated fabrics and from 6.578 to 31.187 for trilaminated fabrics. Overall, the variance for trilaminated fabrics in all directions was higher than bilaminated fabrics. More specifically, the variance for the warp and fill directions for trilaminated fabrics was greater than for bilaminated fabrics. Due to the properties of the film used to manufacture the trilaminated fabric, specimens may slip in the clamps of the tensile testing machine used to test elongation, during testing, whereas this may not occur with bilaminated fabrics. This slippage may specifically occur more in the warp and fill directions, as these directions typically do not elongate as much as the bias directions. This slippage may contribute to a high variance for trilaminated fabrics.

The standard deviation ranged from 0.849 to 2.050 for bilaminated fabrics and from 2.565 to 5.585 for trilaminated fabrics. Trilaminated fabric test data indicated a much greater standard deviation than bilaminated fabric test data. As stated previously, slippage may occur and therefore contribute to a high standard deviation for trilaminated fabrics.

Basic descriptive statistics for elongation test data for bilaminated and trilaminated fabrics are presented in Table 10.

Table 10

Descriptive Statistics Comparisons for Elongation Test Data

	Minimum	Maximum	Mean	Std. Deviation	Variance
Bilaminated Fabric Specimens					
Warp (N=15)	7.553	10.120	8.806	0.849	0.721
Fill (N=15)	6.050	10.381	7.726	1.562	2.439
Bias 1 (N=15)	11.265	15.530	12.631	1.406	1.976
Bias 2 (N=15)	10.322	15.464	12.507	2.050	4.201
Trilaminated Fabric Specimens					
Warp (N=15)	7.977	17.969	11.378	4.178	17.453
Fill (N=15)	5.829	19.467	11.201	5.584	31.187
Bias 1 (N=15)	10.100	17.234	12.910	2.822	7.962
Bias 2 (N=15)	9.618	16.028	12.657	2.565	6.578

Boardiness. The mean for boardiness test data was 49 for bilaminated fabrics and 70 for trilaminated fabrics. The results indicated that trilaminated fabric specimens had a higher mean than bilaminated fabric specimens and therefore had higher boardiness in those directions.

The variance was 4 for bilaminated fabrics and 16 for trilaminated fabrics. Variability was likely between specimens as there was significant room for variation of test measurements taken due to the nature of the test equipment. This variation may contribute to a high variance for bilaminated and trilaminated fabrics.

The standard deviation was 2 for bilaminated fabrics and 4 for trilaminated fabrics. Trilaminated fabric test data indicated a much greater standard deviation than bilaminated fabric test data. As stated previously, variation was likely with test measurements due to the nature of the equipment and therefore may have contributed to a high standard deviation for both bilaminated and trilaminated fabrics.

Basic descriptive statistics for boardiness test data for bilaminated and trilaminated fabrics are presented in Table 11.

Table 11

Descriptive Statistics Comparisons for Boardiness Test Data

	Minimum	Maximum	Mean	Std. Deviation	Variance
Bilaminated Fabric Specimens (N=15)	46	53	49	2	4
Trilaminated Fabric Specimens (N=15)	64	77	70	4	16

Weight. The mean for weight test data was 1.365 for bilaminated fabrics and 1.642 for trilaminated fabrics. The results indicated that trilaminated fabric specimens had a higher mean than bilaminated fabric specimens and therefore weigh more.

The variance was 0.003 for bilaminated fabrics and 0.061 for trilaminated fabrics. The variance for trilaminated fabrics was slightly higher than bilaminated fabrics.

The standard deviation was 0.051 for bilaminated fabrics and 0.248 for trilaminated fabrics. Trilaminated fabric test data indicated a much greater standard deviation than bilaminated fabric test data. Due to potential differences in thickness of the film, trilaminated specimens may exhibit higher standard deviation than bilaminated fabric.

Basic descriptive statistics for weight test data for bilaminated and trilaminated fabrics are presented in Table 12.

Table 12

Descriptive Statistics Comparisons for Weight Test Data

	Minimum	Maximum	Mean	Std. Deviation	Variance
Bilaminated Fabric Specimens (N=15)	1.308	1.455	1.365	0.051	0.003
Trilaminated Fabric Specimens (N=15)	1.288	1.875	1.642	0.248	0.061

Thickness. The mean for thickness test data was 5.213 for bilaminated fabrics and 5.763 for trilaminated fabrics. The results indicated that trilaminated fabric specimens had a higher mean than bilaminated fabric specimens and therefore were thicker.

The variance was 0.022 for bilaminated fabrics and 0.041 for trilaminated fabrics. The variance for trilaminated fabrics was slightly higher than bilaminated fabrics. As in the case with weight testing, due to potential differences in thickness of the film used to manufacture the trilaminated fabric, trilaminated specimens may exhibit higher variance than bilaminated fabric, as bilaminated fabrics were not manufactured with film.

The standard deviation was 0.148 for bilaminated fabrics and 0.202 for trilaminated fabrics. Trilaminated fabric test data indicated a slightly greater standard deviation than bilaminated fabric test data. Due to potential differences in thickness of the film, trilaminated specimens may exhibit higher standard deviation than bilaminated fabric.

Basic descriptive statistics for thickness test data for bilaminated and trilaminated fabrics are presented in Table 13.

Table 13

Descriptive Statistics Comparisons for Thickness Test Data

	Minimum	Maximum	Mean	Std. Deviation	Variance
Bilaminated Fabrics Specimens (N=15)	4.96	5.44	5.213	0.148	0.022
Trilaminated Fabric Specimens (N=15)	5.46	6.16	5.763	0.202	0.041

Stretch. The stretch test data mean ranged from 9.233 to 17.380 for bilaminated fabrics and from 13.598 to 18.865 for trilaminated fabrics. The results indicated that trilaminated fabric specimens had a higher mean than bilaminated fabric specimens in all directions and therefore had greater stretch.

The variance ranged from 0.450 to 8.033 for bilaminated fabrics and from 32.845 to 117.685 for trilaminated fabrics. Overall, the variance for trilaminated fabrics in all directions was higher than bilaminated fabrics. More specifically, the variance for the warp and fill directions for trilaminated fabrics was greater than for bilaminated fabrics. Due to the properties of the film used to manufacture the trilaminated fabric, specimens may slip in the clamps of the fixture assembly used to test stretch, during testing, whereas this may not occur with bilaminated fabrics. This slippage may specifically occur more in the warp and fill directions, as these directions typically do not stretch as much as the bias directions. This slippage may contribute to a high variance for trilaminated fabrics.

The standard deviation ranged from 0.671 to 2.834 for bilaminated fabrics and from 5.731 to 10.848 for trilaminated fabrics. Trilaminated fabric test data indicated a much greater standard deviation than bilaminated fabric test data. Slippage may occur and therefore contribute to a high standard deviation for trilaminated fabrics.

Basic descriptive statistics for stretch test data for bilaminated and trilaminated fabrics are presented in Table 14.

Table 14

Descriptive Statistics Comparisons for Stretch Test Data

	Minimum	Maximum	Mean	Std. Deviation	Variance
Bilaminated Fabrics					
Warp (N=9)	9.512	11.608	10.227	0.671	0.450
Fill (N=9)	8.030	12.471	9.23311	1.661	2.776
Bias 1 (N=9)	15.502	21.000	17.276	2.171	4.713
Bias 2 (N=9)	14.627	22.219	17.380	2.834	8.033
Trilaminated Fabrics					
Warp (N=9)	7.924	24.564	13.598	7.146	51.068
Fill (N=9)	5.486	30.946	15.923	10.848	117.685
Bias 1 (N=9)	12.603	27.392	18.865	5.859	34.330
Bias 2 (N=9)	11.312	25.612	18.215	5.731	32.845

Set. The set test data mean ranged from 0.813 to 1.621 for bilaminated fabrics and from 0.888 to 1.876 for trilaminated fabrics. The results indicated that trilaminated fabric specimens had a higher mean than bilaminated fabric specimens in warp, fill, and bias 1 directions and therefore had greater set in those directions. The bias 2 direction indicated a smaller mean in trilaminated fabric specimens than in bilaminated fabric specimens.

The variance ranged from 0.054 to 0.152 for bilaminated fabrics and from 0.353 to 0.608 for trilaminated fabrics. Overall, the variance for trilaminated fabrics in all directions was higher than bilaminated fabrics. Due to the properties of the film used to manufacture the trilaminated fabric, specimens may curl during and after relaxing, allowing for variation of measurements, whereas this may not occur with bilaminated fabrics. This curling may contribute to a high variance for trilaminated fabrics.

The standard deviation ranged from 0.231 to 0.390 for bilaminated fabrics and from 0.594 to 0.779 for trilaminated fabrics. Trilaminated fabric test data indicated a much greater standard deviation than bilaminated fabric test data. Curling may occur and therefore contribute to a high standard deviation for trilaminated fabrics.

Basic descriptive statistics for set test data for bilaminated and trilaminated fabrics are presented in Table 15.

Table 15

Descriptive Statistics Comparisons for Set Test Data

	Minimum	Maximum	Mean	Std. Deviation	Variance
Bilaminated Fabrics					
Warp (N=9)	0.367	1.215	0.813	0.304	0.092
Fill (N=9)	0.260	1.296	0.910	0.310	0.096
Bias 1 (N=9)	1.116	1.962	1.546	0.231	0.054
Bias 2 (N=9)	1.042	2.304	1.621	0.390	0.152
Trilaminated Fabrics					
Warp (N=9)	0.233	1.814	0.888	0.594	0.353
Fill (N=9)	0.220	2.635	1.523	0.695	0.483
Bias 1 (N=9)	1.143	3.015	1.876	0.779	0.608
Bias 2 (N=9)	0.466	2.300	1.323	0.621	0.385

Breaking Radius. The breaking radius test data mean ranged from 10 to 13 for bilaminated fabrics and from 19 to 26 for trilaminated fabrics. The results indicated that trilaminated fabric specimens had a higher mean than bilaminated fabric specimens and therefore were less pliable and more likely to exhibit breaking on a trim cover.

The variance ranged from 0 to 25 for bilaminated fabrics and from 0 to 28 for trilaminated fabrics. Overall, the variance for trilaminated fabrics was consistent with bilaminated fabrics.

The standard deviation ranged from 0 to 5 for bilaminated fabrics and trilaminated fabrics. Trilaminated fabric test data were consistent with bilaminated fabric test data.

Basic descriptive statistics for breaking radius test data for bilaminated and trilaminated fabrics are presented in Table 16.

Table 16

Descriptive Statistics Comparisons for Breaking Radius Test Data

	Minimum	Maximum	Mean	Std. Deviation	Variance
Bilaminated Fabrics					
Warp (N=9)	10	20	13	5	25
Fill (N=9)	10	20	11	3	11
Bias 1 (N=9)	10	10	10	0	0
Bias 2 (N=9)	10	10	10	0	0
Trilaminated Fabrics					
Warp (N=9)	20	30	26	5	28
Fill (N=9)	10	20	19	3	11
Bias 1 (N=9)	20	20	20	0	0
Bias 2 (N=9)	20	20	20	0	0

Ravel. Statistical analysis was not performed on the ravel test data as sample size prohibited the analysis of data.

Hypothesis Testing

In order to test the hypothesis posed, Independent Samples Tests were performed on the data obtained from this study to identify the differences between bilaminated and trilaminated fabrics. Independent Samples Tests results are discussed in this section.

Independent Samples Tests were run on bilaminated and trilaminated test data for each laboratory test identifying the group statistics: the mean, the standard deviation, and the standard error of the mean. Further, Levene's Test for Equality of Variances tested F and identified its level of significance. Finally, the T-Test for Equality of Means identified the value for *t*, the degrees of freedom, the significance (2-tailed), the mean difference between bilaminated and trilaminated fabric test data, the standard error of difference, and the lower and upper limits of the 95% confidence interval of the difference.

H1A: Elongation

Trilaminated knitted fabrics exhibit different physical properties than bilaminated knitted fabrics in relation to elongation test data.

Warp Direction. The group statistics for elongation test data in the warp direction indicated that the mean for trilaminated fabrics (11.378) was higher than bilaminated fabrics (8.806); therefore, trilaminated knitted fabrics, on average, had more elongation than bilaminated knitted fabrics in the warp direction. The mean of each sample indicated greater elongation in trilaminated fabrics than bilaminated fabrics and therefore suggested a higher potential for fabric growth in trilaminated fabrics than in bilaminated fabrics. Group Statistics for elongation test data for bilaminated and trilaminated fabrics are presented in Table 17.

Table 17

Group Statistics Comparisons for Elongation Test Data – Warp Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=15)			
	8.806	0.849	0.219
Trilaminated Fabric Specimens (N=15)			
	11.378	4.178	1.079

Analysis of the Independent Samples Test indicated that there was a significant difference, at the .05 level, between bilaminated and trilaminated elongation test data in the warp direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were significantly different ($p < 0.05$) and therefore not equal. The T-Test for Equality of Means indicated that t (15) = -2.337 (0.034 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for elongation test data for bilaminated and trilaminated fabrics is presented in Tables 18 and 19, respectively.

Table 18

Levene's Test for Equality of Variances for Elongation Test Data – Warp Direction

F	Sig.
60.397	0.000

Table 19

T-Test for Equality of Means for Elongation Test Data – Warp Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Not Assumed	-2.337	15	0.034	-2.572	1.001	-4.916	-0.228

The analyses performed support H1A; there was a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to elongation warp direction test data.

Fill Direction. The group statistics for elongation test data in the fill direction indicated that the mean for trilaminated fabrics (11.201) was higher than bilaminated fabrics (7.726); therefore, trilaminated knitted fabrics, on average, had more elongation than bilaminated knitted fabrics in the fill direction. The mean of each sample indicated greater elongation in trilaminated fabrics than bilaminated fabrics and therefore suggested a higher potential for fabric growth in trilaminated fabrics than in bilaminated fabrics. Group Statistics for elongation test data for bilaminated and trilaminated fabrics are presented in Table 20.

Table 20

Group Statistics Comparisons for Elongation Test Data – Fill Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=15)			
	7.726	1.562	0.403
Trilaminated Fabric Specimens (N=15)			
	11.201	5.584	1.442

Analysis of the Independent Samples Test indicated that there was a significant difference, at the .05 level, between bilaminated and trilaminated elongation test data in the fill direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were significantly different ($p < 0.05$) and therefore not equal. The T-Test for Equality of Means indicated that t (16) = -2.321 (0.034 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for elongation test data for bilaminated and trilaminated fabrics is presented in Tables 21 and 22, respectively.

Table 21

Levene's Test for Equality of Variances for Elongation Test Data – Fill Direction

F	Sig.
36.160	0.000

Table 22

T-Test for Equality of Means for Elongation Test Data – Fill Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Equal Variances Not Assumed	-2.321	16	0.034	-3.475	1.497	-6.646	-0.304

The analyses performed support H1A; there was a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to elongation fill direction test data.

Bias 1 Direction. The group statistics for elongation test data in the bias 1 direction indicated that the mean for trilaminated fabrics (12.910) was higher than bilaminated fabrics (12.631); therefore, trilaminated knitted fabrics, on average, had more elongation than bilaminated knitted fabrics in the bias 1 direction. The mean of each sample indicated slightly greater elongation in trilaminated fabrics than bilaminated fabrics and therefore suggested a slightly higher potential for fabric growth in trilaminated fabrics than in bilaminated fabrics. Group Statistics for elongation test data for bilaminated and trilaminated fabrics are presented in Table 23.

Table 23

Group Statistics Comparisons for Elongation Test Data – Bias 1 Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=15)			
	12.631	1.406	0.363
Trilaminated Fabric Specimens (N=15)			
	12.910	2.822	0.729

Analysis of the Independent Samples Test indicated that there was a significant difference, at the .05 level, between bilaminated and trilaminated elongation test data in the bias 1 direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were significantly different ($p < 0.05$) and therefore not equal. The T-Test for Equality of Means indicated that t (20) = -0.342 (0.736 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for elongation test data for bilaminated and trilaminated fabrics are presented in Tables 24 and 25, respectively.

Table 24

Levene's Test for Equality of Variances for Elongation Test Data – Bias 1 Direction

F	Sig.
17.834	0.000

Table 25

T-Test for Equality of Means for Elongation Test Data – Bias 1 Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Not Assumed	-0.342	20	0.736	-0.278	0.814	-1.973	1.417

The analyses performed support H1A; there was a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to elongation bias 1 direction test data.

Bias 2 Direction. The group statistics for elongation test data in the bias 2 direction indicated that the mean for trilaminated fabrics (12.657) was slightly higher than bilaminated fabrics (12.507); therefore, trilaminated knitted fabrics, on average, had slightly higher elongation than bilaminated knitted fabrics in the bias 2 direction. The mean of each sample indicated slightly higher elongation in trilaminated fabrics than bilaminated fabrics and therefore suggested a slightly higher potential for fabric growth in trilaminated fabrics and bilaminated fabrics. Group Statistics for elongation test data for bilaminated and trilaminated fabrics are presented in Table 26.

Table 26

Group Statistics Comparisons for Elongation Test Data – Bias 2 Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=15)			
	12.507	2.050	0.529
Trilaminated Fabric Specimens (N=15)			
	12.657	2.565	0.662

Analysis of the Independent Samples Test indicated that there was not a significant difference, at the .05 level, between bilaminated and trilaminated elongation test data in the bias 2 direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were not significantly different ($p > 0.05$) and therefore equal. The T-Test for Equality of Means indicated that t (28) = -0.177 (0.860 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for elongation test data for bilaminated and trilaminated fabrics are presented in Tables 27 and 28, respectively.

Table 27

Levene's Test for Equality of Variances for Elongation Test Data – Bias 2 Direction

F	Sig.
0.709	0.407

Table 28

T-Test for Equality of Means for Elongation Test Data – Bias 2 Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Assumed	-0.177	28	0.860	-0.150	0.848	-1.887	1.586

The analyses performed did not support H1A; there was not a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to elongation bias 2 direction test data.

In conclusion, based on elongation testing in the warp, fill, and both bias directions, H1A was only partially supported as there was a significant difference in the warp, fill, and bias 1 direction only; there was not a significant difference in the bias 2 direction.

H1B: Boardiness

Trilaminated knitted fabrics exhibit different physical properties than bilaminated knitted fabrics in relation to boardiness test data.

The group statistics for boardiness test data indicated that the mean for trilaminated fabrics (70) was higher than bilaminated fabrics (49); therefore, trilaminated knitted fabrics, on average, were harder than bilaminated knitted fabrics. The mean of each sample indicated that trilaminated fabrics were harder than bilaminated fabrics and therefore suggested a higher potential for trilaminated fabrics to bridge, walnut, or create voids. Group Statistics for boardiness test data for bilaminated and trilaminated fabrics are presented in Table 29.

Table 29

Group Statistics Comparisons for Boardiness Test Data

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=15)			
	49	2.100	0.542
Trilaminated Fabric Specimens (N=15)			
	70	4.015	1.037

Analysis of the Independent Samples Test indicated that there was a significant difference, at the .05 level, between bilaminated and trilaminated boardiness test data of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were significantly different ($p < 0.05$) and therefore not equal. The T-Test for Equality of Means indicated that t (21) = -17.949 (0.000 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for boardiness test data for bilaminated and trilaminated fabrics are presented in Tables 30 and 31, respectively.

Table 30

Levene's Test for Equality of Variances for Boardiness Test Data

F	Sig.
8.365	0.007

Table 31

T-Test for Equality of Means for Boardiness Test Data

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Not Assumed	-17.949	21	0.000	-21.000	1.170	-23.432	-18.568

The analyses performed supported H1B; there was a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to boardiness test data. In conclusion, based on boardiness testing, H1B was supported.

H1C: Weight

Trilaminated knitted fabrics exhibit different physical properties than bilaminated knitted fabrics in relation to weight test data.

The group statistics for weight test data indicated that the mean for trilaminated fabrics (1.642) was higher than bilaminated fabrics (1.365); therefore, trilaminated knitted fabrics, on average, weigh more than bilaminated knitted fabrics. The mean of each sample indicated that trilaminated fabrics had a higher mass than bilaminated fabrics and therefore suggested a decreased potential of read-through, re-sew marks, and needle-hole elongation on the trim cover. Group Statistics for weight test data for bilaminated and trilaminated fabrics are presented in Table 32.

Table 32

Group Statistics Comparisons for Weight Test Data

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=15)			
	1.365	0.051	0.013
Trilaminated Fabric Specimens (N=15)			
	1.642	0.248	0.064

Analysis of the Independent Samples Test indicated that there was a significant difference, at the .05 level, between bilaminated and trilaminated weight test data of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were significantly different ($p < 0.05$) and therefore not equal. The T-Test for Equality of Means indicated that t (15) = -4.244 (0.001 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for weight test data for bilaminated and trilaminated fabrics are presented in Tables 33 and 34, respectively.

Table 33

Levene's Test for Equality of Variances for Weight Test Data

F	Sig.
56.618	0.000

Table 34

T-Test for Equality of Means for Weight Test Data

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
Equal Variances Not Assumed	-4.244	15	0.001	-0.277	0.065	-0.416	-0.138

The analyses performed supported H1C; there was a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to weight test data. In conclusion, based on weight testing, H1C was supported.

H1D: Thickness

Trilaminated knitted fabrics exhibit different physical properties than bilaminated knitted fabrics in relation to thickness test data.

The group statistics for thickness test data indicated that the mean for trilaminated fabrics (5.763) was slightly higher than bilaminated fabrics (5.213); therefore, trilaminated knitted fabrics, on average, were thicker than bilaminated knitted fabrics. The mean of each sample indicated that trilaminated fabrics were slightly thicker than bilaminated fabrics and therefore suggested a slightly decreased potential of read-through, re-sew marks, and needle-hole elongation on the trim cover. Group Statistics for thickness test data for bilaminated and trilaminated fabrics are presented in Table 35.

Table 35

Group Statistics Comparisons for Thickness Test Data

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=15)			
	5.213	0.148	0.038
Trilaminated Fabric Specimens (N=15)			
	5.763	0.202	0.052

Analysis of the Independent Samples Test indicated that there was not a significant difference, at the .05 level, between bilaminated and trilaminated thickness test data of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were not significantly different ($p > 0.05$) and therefore equal. The T-Test for Equality of Means indicated that t (28) = -8.480 (0.000 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for thickness test data for bilaminated and trilaminated fabrics are presented in Tables 36 and 37, respectively.

Table 36

Levene's Test for Equality of Variances for Thickness Test Data

F	Sig.
2.139	0.155

Table 37

T-Test for Equality of Means for Thickness Test Data

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Assumed	-8.480	28	0.000	-0.549	0.065	-0.682	-0.417

The analyses performed did not support H1D; there was not a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to thickness test data. In conclusion, based on thickness testing, H1D was not supported.

H1E: Stretch

Trilaminated knitted fabrics exhibit different physical properties than bilaminated knitted fabrics in relation to stretch test data.

Warp Direction. The group statistics for stretch test data in the warp direction indicated that the mean for trilaminated fabrics (13.598) was higher than bilaminated fabrics (10.227); therefore, trilaminated knitted fabrics, on average, had more stretch than bilaminated knitted fabrics in the warp direction. The mean of each sample indicated that trilaminated fabrics had greater stretch than bilaminated fabrics and therefore suggested a higher potential of bagginess of the trim cover in trilaminated fabrics than in bilaminated fabrics. Group Statistics for stretch test data for bilaminated and trilaminated fabrics are presented in Table 38.

Table 38

Group Statistics Comparisons for Stretch Test Data – Warp Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=9)			
	10.227	0.671	0.224
Trilaminated Fabric Specimens (N=9)			
	13.598	7.146	2.382

Analysis of the Independent Samples Test indicated that there was a significant difference, at the .05 level, between bilaminated and trilaminated stretch test data in the warp direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were significantly different ($p < 0.05$) and therefore not equal. The T-Test for Equality of Means indicated that t (8) = -1.409 (0.196 at 2-tail significance). The Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for stretch test data for bilaminated and trilaminated fabrics are presented in Tables 39 and 40, respectively.

Table 39

Levene's Test for Equality of Variances for Stretch Test Data – Warp Direction

F	Sig.
47.536	0.000

Table 40

T-Test for Equality of Means for Stretch Test Data – Warp Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Not Assumed	-1.409	8	0.196	-3.371	2.393	-8.872	2.129

The analyses performed supported H1E; there was a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to stretch warp direction test data.

Fill Direction. The group statistics for stretch test data in the fill direction indicated that the mean for trilaminated fabrics (15.923) was higher than bilaminated fabrics (9.233); therefore, trilaminated knitted fabrics, on average, had more stretch than bilaminated knitted fabrics in the fill direction. The mean of each sample indicated that trilaminated fabrics had greater stretch than bilaminated fabrics and therefore suggested a higher potential of bagginess of the trim cover in trilaminated fabrics than in bilaminated fabrics. Group Statistics for stretch test data for bilaminated and trilaminated fabrics are presented in Table 41.

Table 41

Group Statistics Comparisons for Stretch Test Data – Fill Direction

Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=9)		
9.233	1.667	0.555
Trilaminated Fabric Specimens (N=9)		
15.923	10.848	3.616

Analysis of the Independent Samples Test indicated that there was a significant difference, at the .05 level, between bilaminated and trilaminated stretch test data in the fill direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were significantly different ($p < 0.05$) and therefore not equal. The T-Test for Equality of Means indicated that t (8) = -1.829 (0.103 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for stretch test data for bilaminated and trilaminated fabrics are presented in Tables 42 and 43, respectively.

Table 42

Levene's Test for Equality of Variances for Stretch Test Data – Fill Direction

F	Sig.
34.345	0.000

Table 43

T-Test for Equality of Means for Stretch Test Data – Fill Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Not Assumed	-1.829	8	0.103	-6.690	3.658	-15.060	1.681

The analyses performed supported H1E; there was a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to stretch fill direction test data.

Bias 1 Direction. The group statistics for stretch test data in the bias 1 direction indicated that the mean for trilaminated fabrics (18.865) was higher than bilaminated fabrics (17.276); therefore, trilaminated knitted fabrics, on average, had more stretch than bilaminated knitted fabrics in the bias 1 direction. The mean of each sample indicated that trilaminated fabrics had greater stretch than bilaminated fabrics and therefore suggested a higher potential of bagginess of the trim cover in trilaminated fabrics than in bilaminated fabrics. Group Statistics for stretch test data for bilaminated and trilaminated fabrics are presented in Table 44.

Table 44

Group Statistics Comparisons for Stretch Test Data – Bias 1 Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=9)			
	17.276	2.171	0.724
Trilaminated Fabric Specimens (N=9)			
	18.865	5.859	1.953

Analysis of the Independent Samples Test indicated that there was a significant difference, at the .05 level, between bilaminated and trilaminated stretch test data in the bias 1 direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were significantly different ($p < 0.05$) and therefore not equal. The T-Test for Equality of Means indicated that t (10) = -0.763 (0.463 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for stretch test data for bilaminated and trilaminated fabrics are presented in Tables 45 and 46, respectively.

Table 45

Levene's Test for Equality of Variances for Stretch Test Data – Bias 1 Direction

F	Sig.
12.555	0.003

Table 46

T-Test for Equality of Means for Stretch Test Data – Bias 1 Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Not Assumed	-0.763	10	0.463	-1.589	2.083	-6.220	3.042

The analyses performed supported H1E; there was a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to stretch bias 1 direction test data.

Bias 2 Direction. The group statistics for stretch test data in the bias 2 direction indicated that the mean for trilaminated fabrics (18.215) was higher than bilaminated fabrics (17.380); therefore, trilaminated knitted fabrics, on average, had more stretch than bilaminated knitted fabrics in the bias 2 direction. The mean of each sample indicated that trilaminated fabrics had greater stretch than bilaminated fabrics and therefore suggested a higher potential of bagginess of the trim cover in trilaminated fabrics than in bilaminated fabrics. Group Statistics for stretch test data for bilaminated and trilaminated fabrics are presented in Table 47.

Table 47

Group Statistics Comparisons for Stretch Test Data – Bias 2 Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=9)			
	17.380	2.834	0.945
Trilaminated Fabric Specimens (N=9)			
	18.215	5.731	1.910

Analysis of the Independent Samples Test indicated that there was a significant difference, at the .05 level, between bilaminated and trilaminated stretch test data in the bias 2 direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were significantly different ($p < 0.05$) and therefore not equal. The T-Test for Equality of Means indicated that t (12) = -0.392 (0.702 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for stretch test data for bilaminated and trilaminated fabrics are presented in Tables 48 and 49, respectively.

Table 48

Levene's Test for Equality of Variances for Stretch Test Data – Bias 2 Direction

F	Sig.
5.189	0.037

Table 49

T-Test for Equality of Means for Stretch Test Data – Bias 2 Direction

						95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Equal Variances Not Assumed	-0.392	12	0.702	-0.835	2.131	-5.492	3.822

The analyses performed supported H1E; there was a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to stretch bias 2 direction test data.

In conclusion, based on stretch testing in the warp, fill, and both bias directions, H1A was supported, as there was a significant difference in all directions.

H1E: Set

Trilaminated knitted fabrics exhibit different physical properties than bilaminated knitted fabrics in relation to set test data.

Warp Direction. The group statistics for set test data in the warp direction indicated that the mean for trilaminated fabrics (0.888) was higher than bilaminated fabrics (0.813); therefore, trilaminated knitted fabrics, on average, had higher set than bilaminated knitted fabrics in the warp direction. The mean of each sample indicated that trilaminated fabrics had slightly higher set than bilaminated fabrics and therefore suggested a slightly higher potential of bagginess of the trim cover in trilaminated fabrics than in bilaminated fabrics. Group Statistics for set test data for bilaminated and trilaminated fabrics are presented in Table 50.

Table 50

Group Statistics Comparisons for Set Test Data – Warp Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=9)			
	0.813	0.304	0.101
Trilaminated Fabric Specimens (N=9)			
	0.888	0.594	0.198

Analysis of the Independent Samples Test indicated that there was a significant difference, at the .05 level, between bilaminated and trilaminated set test data in the warp direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were significantly different ($p < 0.05$) and therefore not equal. The T-Test for Equality of Means indicated that t (12) = -0.337 (0.742 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for set test data for bilaminated and trilaminated fabrics are presented in Tables 51 and 52, respectively.

Table 51

Levene's Test for Equality of Variances for Set Test Data – Warp Direction

F	Sig.
5.681	0.030

Table 52

T-Test for Equality of Means for Set Test Data – Warp Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Not Assumed	-0.337	12	0.742	-0.075	0.222	-0.560	0.410

The analyses performed supported H1E; there was a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to set warp direction test data.

Fill Direction. The group statistics for set test data in the fill direction indicated that the mean for trilaminated fabrics (1.523) was similar to the bilaminated fabrics (0.910); therefore, trilaminated knitted fabrics, on average, had higher set than bilaminated knitted fabrics in the fill direction. The mean of each sample indicated that trilaminated fabrics had higher set than bilaminated fabrics and therefore suggested a higher potential of bagginess of the trim cover in trilaminated fabrics than in bilaminated fabrics. Group Statistics for set test data for bilaminated and trilaminated fabrics are presented in Table 53.

Table 53

Group Statistics Comparisons for Set Test Data – Fill Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=9)			
	0.910	0.310	0.103
Trilaminated Fabric Specimens (N=9)			
	1.523	0.695	0.232

Analysis of the Independent Samples Test indicated that there was not a significant difference, at the .05 level, between bilaminated and trilaminated set test data in the fill direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were not significantly different ($p > 0.05$) and therefore equal. The T-Test for Equality of Means indicated that t (16) = -2.416 (0.028 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for set test data for bilaminated and trilaminated fabrics are presented in Tables 54 and 55, respectively.

Table 54

Levene's Test for Equality of Variances for Set Test Data – Fill Direction

F	Sig.
2.461	0.136

Table 55

T-Test for Equality of Means for Set Test Data – Fill Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Assumed	-2.416	16	0.028	-0.613	0.254	-1.150	-0.075

The analyses performed did not support H1E; there was not a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to set fill direction test data.

Bias 1 Direction. The group statistics for set test data in the bias 1 direction indicated that the mean for trilaminated fabrics (1.876) was higher than bilaminated fabrics (1.546); therefore, trilaminated knitted fabrics, on average, had higher set than bilaminated knitted fabrics in the bias 1 direction. The mean of each sample indicated that trilaminated fabrics had higher set than bilaminated fabrics and therefore suggested a higher potential of bagginess of the trim cover in trilaminated fabrics than in bilaminated fabrics. Group Statistics for set test data for bilaminated and trilaminated fabrics are presented in Table 56.

Table 56

Group Statistics Comparisons for Set Test Data – Bias 1 Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=9)			
	1.546	0.231	0.077
Trilaminated Fabric Specimens (N=9)			
	1.876	0.779	0.260

Analysis of the Independent Samples Test indicated that there was a significant difference, at the .05 level, between bilaminated and trilaminated set test data in the bias 1 direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were significantly different ($p < 0.05$) and therefore not equal. The T-Test for Equality of Means indicated that t (9) = -1.216 (0.254 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for set test data for bilaminated and trilaminated fabrics are presented in Tables 57 and 58, respectively.

Table 57

Levene's Test for Equality of Variances for Set Test Data – Bias 1 Direction

F	Sig.
23.570	0.000

Table 58

T-Test for Equality of Means for Set Test Data – Bias 1 Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Not Assumed	-1.216	9	0.254	-0.330	0.271	-0.939	0.280

The analyses performed supported H1E; there was a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to set bias 1 direction test data.

Bias 2 Direction. The group statistics for set test data in the bias 2 direction indicated that the mean for trilaminated fabrics (1.323) was lower than bilaminated fabrics (1.621); therefore, trilaminated knitted fabrics, on average, had lower set than bilaminated knitted fabrics in the bias 2 direction. The mean of each sample indicated that trilaminated fabrics had slightly lower set than bilaminated fabrics and therefore suggested a slightly lower potential of bagginess of the trim cover in trilaminated fabrics than in bilaminated fabrics. Group Statistics for set test data for bilaminated and trilaminated fabrics are presented in Table 59.

Table 59

Group Statistics Comparisons for Set Test Data – Bias 2 Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=9)			
	1.621	0.390	0.130
Trilaminated Fabric Specimens (N=9)			
	1.323	0.621	0.207

Analysis of the Independent Samples Test indicated that there was a significant difference, at the .05 level, between bilaminated and trilaminated set test data in the bias 2 direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were significantly different ($p < 0.05$) and therefore not equal. The T-Test for Equality of Means indicated that t (13) = 1.220 (0.243 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for set test data for bilaminated and trilaminated fabrics are presented in Tables 60 and 61, respectively.

Table 60

Levene's Test for Equality of Variances for Set Test Data – Bias 2 Direction

F	Sig.
4.317	0.054

Table 61

T-Test for Equality of Means for Set Test Data – Bias 2 Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Not Assumed	1.220	13	0.243	0.298	0.244	-0.228	0.824

The analyses performed supported H1E; there was a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to set bias 2 direction test data.

In conclusion, based on set testing in the warp, fill, and both bias directions, H1E was only partially supported as there was a significant difference in the warp and both bias directions only; there was not a significant difference in the fill direction.

H1F: Breaking Radius

Trilaminated knitted fabrics exhibit different physical properties than bilaminated knitted fabrics in relation to breaking radius test data.

Warp Direction. The group statistics for breaking radius test data in the warp direction indicated that the mean for trilaminated fabrics (26) was higher than bilaminated fabrics (13); therefore, trilaminated knitted fabrics, on average, had higher breaking radius values than bilaminated knitted fabrics in the warp direction. The mean of each sample indicated that trilaminated fabrics were more pliable in trilaminated form than in bilaminated form, and therefore had a lower potential to cause breaking on the trim cover. Group Statistics for breaking radius test data for bilaminated and trilaminated fabrics are presented in Table 62.

Table 62

Group Statistics Comparisons for Breaking Radius Test Data – Warp Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=9)			
	13	5.000	1.667
Trilaminated Fabric Specimens (N=9)			
	26	5.270	1.757

Analysis of the Independent Samples Test indicated that there was not a significant difference, at the .05 level, between bilaminated and trilaminated breaking radius test data in the warp direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were not significantly different ($p > 0.05$) and therefore equal. The T-Test for Equality of Means indicated that t (16) = -5.047 (0.000 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for breaking radius test data for bilaminated and trilaminated fabrics are presented in Tables 63 and 64, respectively.

Table 63

Levene's Test for Equality of Variances for Breaking Radius Test Data – Warp Direction

F	Sig.
0.703	0.414

Table 64

T-Test for Equality of Means for Breaking Radius Test Data – Warp Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Assumed	-5.047	16	0.000	-12.222	2.422	-17.356	-7.089

The analyses performed did not support H1F; there was not a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to breaking radius test data in the warp direction.

Fill Direction. The group statistics for breaking radius test data in the fill direction indicated that the mean for trilaminated fabrics (19) was higher than bilaminated fabrics (11); therefore, trilaminated knitted fabrics, on average, had higher breaking radius values than bilaminated knitted fabrics in the fill direction. The mean of each sample indicated that trilaminated fabrics were more pliable in trilaminated form than in bilaminated form and therefore had a lower potential to cause breaking on the trim cover. Group Statistics for breaking radius test data for bilaminated and trilaminated fabrics are presented in Table 65.

Table 65

Group Statistics Comparisons for Breaking Radius Test Data – Fill Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=9)			
	11	3.333	1.111
Trilaminated Fabric Specimens (N=9)			
	19	3.333	1.111

Analysis of the Independent Samples Test indicated that there was not a significant difference, at the .05 level, between bilaminated and trilaminated breaking radius test data in the fill direction of knitted fabrics. The Levene's Test for Equality of Variances indicated that the two variances were not significantly different ($p > 0.05$) and therefore equal. The T-Test for Equality of Means indicated that t (16) = -4.950 (0.000 at 2-tail significance). Results of the Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for breaking radius test data for bilaminated and trilaminated fabrics are presented in Tables 66 and 67, respectively.

Table 66

Levene's Test for Equality of Variances for Breaking Radius Test Data – Fill Direction

F	Sig.
0.000	1.000

Table 67

T-Test for Equality of Means for Breaking Radius Test Data – Fill Direction

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Assumed	-4.950	16	0.000	-7.778	1.571	-11.109	-4.447

The analyses performed did not support H1F; there was not a significant difference between the physical properties of trilaminated knitted fabrics and bilaminated knitted fabrics in relation to breaking radius test data in the fill direction.

Bias 1 Direction. The group statistics for breaking radius test data in the bias 1 direction indicated that the mean for trilaminated fabrics (10) was not higher than bilaminated fabrics (10); therefore, trilaminated knitted fabrics, on average, had similar breaking radius values than bilaminated knitted fabrics in the bias 1 direction. The mean of each sample indicated that trilaminated fabrics were equal in pliability to bilaminated fabrics. Both indicated a low potential of causing breaking on the trim cover. Group Statistics for breaking radius test data for bilaminated and trilaminated fabrics are presented in Table 68.

Table 68

Group Statistics Comparisons for Breaking Radius Test Data – Bias 1 Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=9)			
	10	0.000	0.000
Trilaminated Fabric Specimens (N=9)			
	10	0.000	0.000

Analysis of the Independent Samples Test indicated that there was not a significant difference, at the .05 level, between bilaminated and trilaminated breaking radius test data in the bias 1 direction of knitted fabrics. The Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for breaking radius test data for bilaminated and trilaminated fabrics was not produced as the standard deviations of both groups were 0.

Bias 2 Direction. The group statistics for breaking radius test data in the bias 2 direction indicated that the mean for trilaminated fabrics (10) was similar to bilaminated fabrics (10); therefore, trilaminated knitted fabrics, on average, had similar breaking radius values than bilaminated knitted fabrics in the bias 2 direction. The mean of each sample indicated that trilaminated fabrics were equal in pliability to bilaminated fabrics. Both indicated a low potential of causing breaking on the trim cover. Group Statistics for breaking radius test data for bilaminated and trilaminated fabrics are presented in Table 69.

Table 69

Group Statistics Comparisons for Breaking Radius Test Data – Bias 2 Direction

	Mean	Std. Deviation	Std. Error Mean
Bilaminated Fabric Specimens (N=9)			
	10	0.000	0.000
Trilaminated Fabric Specimens (N=9)			
	10	0.000	0.000

Analysis of the Independent Samples Test indicated that there was not a significant difference, at the .05 level, between bilaminated and trilaminated breaking radius test data in the bias 2 direction of knitted fabrics. The Independent Samples Test (Levene's Test for Equality of Variances and T-Test for Equality of Means) for breaking radius test data for bilaminated and trilaminated fabrics was not produced, as the standard deviations of both groups were 0.

In conclusion, based on breaking radius testing in the warp, fill, and both bias directions, H1F was not supported, as there was not a significant difference in all directions.

H1G: Ravel

Trilaminated knitted fabrics exhibit different physical properties than bilaminated knitted fabrics in relation to ravel test data.

Statistical analysis was not performed on the ravel test data as sample size prohibited the analysis of the data. In conclusion, based on ravel testing, H1G could not be tested.

CHAPTER V

CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS FOR FURTHER RESEARCH

Introduction

The automotive sector provides the largest single market (in dollars) for industrial textiles (Smith, 2001, para. 1). Due to its complex contours and sharp corners, the head restraint had provided a challenge to manufacturers to utilize fabrics best suited for the application; seat manufacturers struggle with appearance issues on the trim cover due to inherent physical properties. As there was no documented research on the properties of fabrics used in upholstery trim covers, this study may allow manufacturers to improve one of the most complex shapes of the seat.

Knitted upholstery fabric was evaluated and analyzed in conjunction with FIP manufacturing processes in order to provide information to manufacturers about the properties that allow it to work well in head restraint systems.

The purpose of this study was to evaluate the difference between seven physical properties of three knitted fabrics as bilaminated and trilaminated composites. A series of seven standardized tests was conducted, typically used by tier suppliers to analyze the physical properties of fabric.

A summary of the study is discussed in this chapter, followed by conclusions, implications, and delimitations of the study. Finally, suggestions for further research are presented.

Summary of the Study

A comparative analysis was conducted between bilaminated and trilaminated knitted fabrics. Three knitted fabrics were evaluated, each with two composite types: bilaminated and trilaminated. Physical properties of the fabrics were evaluated using standard test methods established by ASTM, SAE, or tier-one automotive seat supplier specifications in a automotive seat supplier accredited laboratory.

The following seven physical properties of the fabrics were tested: Elongation, Boardiness, Weight, Thickness, Stretch and Set, Breaking Radius, and Ravel. All tests were conducted using specimens in the warp, fill, and both 45-degree bias directions (bias 1 and bias 2 directions) except Boardiness, Weight, Thickness, and Ravel, where test specimen direction was not a factor for evaluation.

Independent Samples Tests, including the Levene's Test for Equality of Variances and the T-Test for Equality of Means, were used to determine statistically significant differences between test data from bilaminated and trilaminated knitted fabrics.

Research Question

The research question posed for this study asked if the physical properties of knitted fabrics, when evaluated in bilaminated and trilaminated composite forms, will differ from one another; this was affirmed. The physical properties of knitted fabrics, when tested in bilaminated and trilaminated forms, differed from one another.

Hypothesis

H1A: Elongation. The Elongation test was used to compare fabric growth of the knitted fabrics, where higher elongation values corresponded to increased fabric growth and indicated an increased likelihood of bagginess on the trim cover. Trilaminated fabrics were found to have higher elongation values than bilaminated fabrics and therefore increased fabric growth, indicating a higher likelihood of bagginess on the trim cover.

H1A testing was supported in the warp, fill, and bias 1 directions, indicating that trilaminated fabrics had higher elongation than bilaminated fabrics in those directions. H1A testing was not supported in the bias 2 direction, indicating that trilaminated fabrics had equal elongation to bilaminated fabrics in that direction. Trilaminated fabrics had more fabric growth and were more likely to cause bagginess on the trim cover than bilaminated fabrics; therefore, bilaminated fabrics were recommended over trilaminated fabrics to reduce likelihood of baggy trim covers on head restraints. A detailed explanation of the results of hypothesis testing can be found in Chapter 4.

H1B: Boardiness. The Boardiness test was used to compare the softness or hardness of the knitted fabrics, where higher boardiness values corresponded to harder fabrics and indicated an increased likelihood for bridging, walnuting, or voids on the trim cover. Trilaminated fabrics were found to have higher boardiness values than bilaminated fabrics and, therefore, a higher likelihood for bridging, walnuting, or voids on the trim cover.

Based on the statistical analyses performed on boardiness test data, H1B was supported, indicating that trilaminated fabrics had higher boardiness than bilaminated fabrics. Trilaminated fabrics were harder and more likely to bridge, walnut, or create voids on the trim cover than bilaminated fabrics. Therefore, bilaminated fabrics were recommended over trilaminated fabrics to reduce likelihood of those issues on trim covers on head restraints. A detailed explanation of the results of hypothesis testing can be found in Chapter 4.

H1C: Weight. The Weight test was used to compare the mass of the knitted fabrics, where higher weight values corresponded to heavier fabrics and indicated an increased durability and decreased likelihood of read-through, re-sew marks, and needle-hole elongation on the trim cover. Trilaminated fabrics were found to have higher weight values than bilaminated fabrics and therefore a lower likelihood of read-through, re-sew marks, and needle-hole elongation on the trim cover and potential for increased durability.

Based on the statistical analyses performed on weight test data, H1C was supported, indicating that trilaminated fabrics weighed more than bilaminated fabrics. Trilaminated fabrics were therefore less likely to show read-through, re-sew marks, and needle-hole elongation than bilaminated fabrics. Further, durability was increased with trilaminated fabrics. Therefore, trilaminated fabrics were recommended over bilaminated fabrics to reduce likelihood of those issues on trim covers on head restraints and due to increased durability. A detailed explanation of the results of hypothesis testing can be found in Chapter 4.

H1D: Thickness. The Thickness test was used to compare the thickness of the knitted fabrics, where higher thickness values corresponded to thicker fabrics and indicated a potential for increased durability and decreased likelihood of read-through, re-sew marks, and needle-hole elongation on the trim cover. Trilaminated fabrics were found not to have higher thickness values than bilaminated fabrics and, therefore, similar durability, and a similar likelihood of read-through, re-sew marks, and needle-hole elongation on the trim cover.

Based on the statistical analyses performed on thickness test data, H1D was not supported, indicating that trilaminated fabrics were as thick as bilaminated fabrics and were just as likely to show read-through, re-sew marks, and needle-hole elongation as well as similar durability. As a result, neither trilaminated fabrics nor bilaminated fabrics were recommended over the other. A detailed explanation of the results of hypothesis testing can be found in Chapter 4.

H1E: Stretch and Set. The Stretch and Set test was used to compare the elastic and recovery properties of the knitted fabrics, where higher stretch and set values corresponded to increased elastic properties (stretch) and decreased recovery properties (set) and indicated an increased likelihood of bagginess on the trim cover when set properties were high. Trilaminated fabrics were found to have higher stretch values in all directions and higher set values in the warp and both bias directions than bilaminated fabrics and, therefore, a higher likelihood of bagginess on the trim cover in those directions. Trilaminated fabrics were not found to have higher set than bilaminated fabrics in the fill direction and therefore had a similar likelihood of bagginess on the trim cover.

Based on the statistical analyses performed on stretch and set test data, H1E was supported for all directions in Stretch testing, indicating that trilaminated fabrics were more likely to exhibit elastic properties than bilaminated fabrics. H1E testing was supported in the warp and both bias directions for set testing, indicating that trilaminated fabrics were more likely to create bagginess than bilaminated fabrics in those directions. H1E was not supported for the fill direction of set testing, indicating no difference in likelihood of bagginess between bilaminated and trilaminated fabrics in the fill direction.

Trilaminated fabrics were recommended for manufacturing purposes due to ease in cutting and sewing operations found with more elastic fabrics as indicted through Stretch testing, although Set testing indicated increased bagginess. Trilaminated fabrics were recommended over bilaminated fabrics, as elastic properties were more valuable than recovery properties in regards to head restraint applications where no load is applied, causing potential bagginess. A detailed explanation of the results of hypothesis testing can be found in Chapter 4.

H1F: Breaking Radius. The Breaking Radius test was used to compare the pliability of the knitted fabrics, where higher breaking radius values corresponded to an increased likelihood of breaking and wrinkles on the trim cover. Trilaminated fabrics were not found to have higher breaking radius values than bilaminated fabrics and therefore had a similar likelihood of breaking and wrinkles on the trim cover.

Based on the statistical analyses performed on breaking radius test data, H1F was not supported in the warp, fill, and both bias directions, indicating that trilaminated fabrics were as pliable as bilaminated fabrics and were just as likely to break and wrinkle. As a result, neither trilaminated fabrics nor bilaminated fabrics were recommended over the other. A detailed explanation of the results of hypothesis testing can be found in Chapter 4.

H1G: Ravel. The Ravel test was used to compare the likelihood of yarns unraveling and/or creating dust or lint of the knitted fabrics, where lower ravel values corresponded to increased maintenance. Due to limited sample size, hypothesis testing was not performed on the test data obtained from this test and H1G could not be tested although group statistics indicated trilaminated fabrics had lower ravel values than bilaminated fabrics and therefore were less likely to require increased maintenance. As a result, trilaminated fabrics were recommended over bilaminated fabrics to reduce likelihood of maintenance. A detailed explanation of the results can be found in Chapter 4.

Comparisons

Trilaminated knitted fabrics exhibited different physical properties than bilaminated fabrics in regards to Elongation, Boardiness, Weight, Stretch, and Set (in the warp and both bias directions) test results. Trilaminated knitted fabrics did not exhibit different physical properties than bilaminated fabrics in regards to Thickness, Set (in the fill direction), Breaking Radius, and Ravel.

Comparison of the analyses indicated that trilaminated fabrics had a higher likelihood of bagginess on the trim cover due to higher elongation and set (in warp and both bias directions) values than bilaminated fabrics. However, trilaminated fabrics had more elasticity and therefore better likelihood of ease in cutting and sewing operations due to increased stretch values. Comparisons also indicated that trilaminated fabrics had a higher likelihood of bridging, walnuting, or voids on the trim cover than bilaminated fabrics due to higher boardiness values. In addition, comparisons indicated that trilaminated fabrics had a lower likelihood of showing read-through, re-sew marks, and needle-hole elongation and had a potential for more durability than bilaminated fabrics due to higher values in weight. Further, comparisons indicated no difference between trilaminated fabrics and bilaminated fabrics in regards to thickness and breaking radius values, so any indication of performance on the trim covers could not be made in regards to those two properties. Finally, comparisons indicated that trilaminated fabrics were less likely to require increased maintenance than bilaminated fabrics due to lower ravel values. Table 70 summarizes the comparison of test results between bilaminated and trilaminated fabrics.

Table 70

Summary Comparison of Test Results

Laboratory Test	Composite Type	Comments
Elongation	B	Lower values; decreased likelihood of bagginess.
	T	Higher values; increased likelihood of bagginess.
Boardiness	B	Lower values; decreased likelihood of bridging, walnuting, and voids.
	T	Higher values; increased likelihood of bridging, walnuting, and voids.
Weight	B	Lower values; increased likelihood of read-through, re-sew marks, and needle-hole elongation as well as lower durability.
	T	Higher values; decreased likelihood of read-through, re-sew marks, and needle-hole elongation as well as higher durability.
Thickness	B	Similar values; no indication made.
	T	Similar values; no indication made.
Stretch and Set	B	Lower values; decreased likelihood of bagginess.
	T	Higher values; increased likelihood of bagginess.
Breaking Radius	B	Similar values; no indication made.
	T	Similar values; no indication made.
Ravel	B	Higher values; increased likelihood of unraveling, dusting, and linting.
	T	Lower values; decreased likelihood of unraveling, dusting, and linting.

Note. B = Bilaminated Fabric Specimens. T = Trilaminated Fabric Specimens. Comments based on potential issues on trim cover.

Conclusions and Implications

Based on the results of this study, it may be concluded that the physical properties of knitted fabrics, when evaluated in bilaminated and trilaminated composite forms, differed from one another. Trilaminated fabrics were recommended over bilaminated fabrics for ease in cutting and sewing operations; a lower likelihood of showing read-through, re-sew marks, and needle-hole elongation; a potential for increased durability; and decreased likelihood of maintenance. Bilaminated fabrics were recommended over trilaminated fabrics to avoid the likelihood of bagginess, bridging, walnuting, and voids.

Based on the conclusions, it was believed that neither composite type was more suitable than the other for head restraint applications as each composite type exhibited different benefits and drawbacks. For example, trilaminated fabrics may ease cutting and sewing operations, a critical issue in JIT manufacturing, to save time and reduce cost; however, likelihood of bagginess, bridging, walnuting, or voids may cause increased labor and finessing in order to remove the issues and therefore increase cost. Bagginess, bridging, walnuting, and voids are a critical issue in head restraint manufacture and cause significant increase in cost, as craftsmanship is a key element in head restraint manufacture. These issues can increase the amount of labor and the amount of time spent on each part during production and therefore cause a significant cost increase to the manufacturer.

In addition to ease of cutting and sewing operations, trilaminated fabrics had a lower likelihood of showing read-through, re-sew marks, and needle-hole elongation, another critical component to craftsmanship expectations and another area causing great headaches in the industry. Further, trilaminated fabrics indicated a decreased likelihood of maintenance, reducing labor time and, once again, cost. Trilaminated fabrics also indicated a likelihood of increased durability, which may or may not be a factor for head restraint applications, depending on the vehicle and types of wear expected.

Many factors lend themselves to trilaminated fabrics as the composite of choice for head restraint applications; however, bagginess (due to higher elongation and set values) and bridging, walnuting, and voids (due to increased boardiness values) may be of great concern to manufacturers.

Delimitations of the Study

1. Data were collected in a facility that was not environmentally controlled; therefore, validity may have been compromised, as fabrics were not assessed at the same temperature and humidity.
2. Accuracy could not be determined in this study because the true value of the textile fabric property was not known.

Recommendations for Further Research

1. This study evaluated knitted fabrics. Other fabric constructions, such as flat woven and woven velour, could be evaluated to determine differences between bilaminated and trilaminated composite forms of these fabrics.
2. This study evaluated the physical properties of bilaminated and trilaminated knitted fabrics in a laboratory setting. A useful extension of this study would be to evaluate bilaminated and trilaminated knitted fabrics during and after manufacture using FIP processing.
3. Ravel testing was performed in this study according to test method specifications. These specifications prohibited statistical analyses from being

performed due to limited sample size. Testing could be performed on the ravel properties of knitted fabrics in a bilaminated and trilaminated composite form with a larger sample size, allowing for analyses to be performed on the test data obtained.

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