



Sudan University of Science and Technology

College of graduate studies

College of Engineering and Technology of Industries

**Enhancement of Vehicle Airbag Nylon 66
Fabric Properties Coated with PVA/Silica
Nanoparticles Composite**

**تعزير خواص قماش نايلون 66 للوسائد الهوائية للمركبات
المطلي بتركيبه جسيمات السيليكا النانوية وكحول البولي
فينيل**

**Thesis submitted in fulfillment of the requierments for the Degree
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Ayah

الآية

قال تعالى: "اللَّهُ خَلَقَ كُلَّ دَابَّةٍ مِّن مَّاءٍ ۖ فَمِنْهُمْ مَّن يَمْشِي عَلَىٰ بَطْنِهِ
وَمِنْهُمْ مَّن يَمْشِي عَلَىٰ رِجْلَيْنِ وَمِنْهُمْ مَّن يَمْشِي عَلَىٰ أَرْبَعٍ ۗ يَخْلُقُ اللَّهُ مَا
يَشَاءُ ۗ إِنَّ اللَّهَ عَلَىٰ كُلِّ شَيْءٍ قَدِيرٌ" . سورة يس الآية (45)

Dedication

This dissertation is dedicated to my parents' soul who have supported me since I was born and my family especially my husband. And also, dedication goes to my teachers who have supported me along this continuing educational journey.

Abstract

The vehicle airbags are safety systems used to cushion the driver or passenger during a collision and reduce bodily injuries. Airbags are typically made from woven fabric, which may be coated or uncoated fabric. In this research nylon 66 fabric was Coated with composite of polyvinyl alcohol (PVA) and different concentration of silica (SiO_2) nanoparticles. The fabrics were characterized by different instruments such as Scanning Electron Microscopy (SEM), Fourier Transform Infrared (FTIR) Spectroscopy, Differential Scanning Calorimeter (DSC), Thermogravimetric Analysis (TGA), Water Contact Angle (WCA), Tensile Strength Tester and Airpermeability Tester. Nylon 66 fabric was coated with PVA and higher concentration of silica nanoparticles has a thin layer thickness rehead to (0.009mm). Moreover, the final dry weight of the coating (PVA/ SiO_2) material taken by the nylon 66 fabric is 0.4 gram per square meter. The thermal properties of nylon 66 coated with PVA/ SiO_2 nanoparticles has been improved, including better mechanical properties according to commercial guidelines airbag (FMVSS). Nylon 66 fabric coated with PVA/ SiO_2 nanoparticles demonstrated the a hydrophobicity property. The airpermeability has decreased by increasing the amount of silica nanoparticles in the composite material.

مستخلص البحث

الوسائد الهوائية في المركبات أنظمة أمان تستخدم لتخفيف التصادم وتقليل الإصابات للسائق والراكب , وعادة ما تصنع الوسائد الهوائية من القماش المنسوج ، والتي قد تكون مطلية أو غير مطلية. في هذا البحث تم طلاء قماش النايلون 66 بمركب من البولي فينيل الكحولي (PVA) وتراكيز مختلفة من جسيمات السيليكا (SiO_2) النانوية. وتم اختبار قماش النايلون 66 المطلي بمادتي (PVA/SiO_2) بواسطة عدة أجهزة منها جهاز المسح المجهر الإلكتروني (SEM) والكشف عن الزمر الوظيفية باستخدام (FT-IR) تم اختبار الخواص الحرارية بواسطة جهاز (DSC) و (TGA) تم اختبار الخواص السطحية بواسطة جهاز (WCA) واختبار متانة الشد بجهاز اختبار المتانة واختبار نفاذية الهواء بواسطة جهاز اختبار نفاذية الهواء. قماش النايلون 66 المطلي بـ PVA وتركيز عالٍ من جسيمات السيليكا النانوية ذو طبقة رقيقة جداً يصل سمكها الي (0.009mm) , الوزن الجاف النهائي لمادة الطلاء التي تم أخذها بواسطة قماش النايلون 0.4 جرام لكل متر مربع . و وجد أن الخواص الحرارية والميكانيكية لقماش النايلون للوسائد الهوائية المغطى ب (PVA/SiO_2) مطابقة ل (FMVSS) وأظهر نايلون 66 المطلي بالجسيمات النانوية PVA/SiO_2 خاصية كراهية الماء. و وجد أيضا نفاذية الهواء للقماش تنخفض بزيادة كمية جسيمات السيليكا النانوية في المواد المركبة.

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List of Abbreviations

NHTSA	National Highway Traffic Safety Administration
PVA	Polyvinyl Alcohol
SiO ₂ NP	Silica nanoparticles
FMVSS	Federal Motor Vehicle Safety Standards
AIL	Airbags International Limited
SEM	Scanning Electron Microscopy
FT-IR	Fourier Transform Infrared Spectroscopy
TGA	Thermogravimetric Analysis
DSC	Differential Scanning Calorimetry
WCA	Water Contact Angle

CHAPTER 1

INTRODUCTION

1.1 Introduction

Although ‘technical’ textiles have attracted considerable attention, the use of fibers, phenomenon yarns and fabrics for applications other than clothing and furnishing is not a new nor is it exclusively linked to the emergence of modern artificial fibers and textiles. Natural fibers such as cotton, flax, jute and sisal have been used for centuries (and still are used) in applications ranging from tents and tarpaulins to ropes, sailcloth and sacking. There is evidence of woven fabrics and meshes being used in roman times and before to stabilize marshy ground for road building early examples of what would now be termed geotextiles and geogrids (Anand and Horrocks, 2016). What is relatively new is a growing recognition of the economic and strategic potential of such textiles to the fiber and fabric manufacturing and processing industries of industrial and industrializing countries alike in some of the most developed markets, technical products (broadly defined) already account for as much as 50% of all textile manufacturing activity and output. The technical textiles supply chain is a long and complex one, stretching from the manufacturers of polymers for technical fibers, coating and specialty membranes through to the converters and fabricators who incorporate technical textiles into finished products or use them as an operation (Adanur, 2017). The economic scope and importance of technical textiles extends far beyond the textile industry itself and has an impact upon just about every sphere of human upon economic and social activity. And yet this dynamic sector of the textile industry has not proved entirely immune to the effects of economic recession, of product and market maturity, and of growing global competition which are all too well known in the more clothing and furnishings traditional sectors (Kumar and Thakur, 2017).

1.2 Definition and scope of technical textiles

The definition of technical textiles adopted by the authoritative Textile Terms and definitions, published by the Textile Institute, is ‘textile materials and products manufactured primarily for their technical and performance properties rather than their aesthetic or decorative characteristics’ (Kumar, 2016). Such a brief description clearly leaves considerable scope for interpretation, especially when an increasing number of Textile products are combining both performance and decorative properties and functions in equal measure (McCarthy, 2016).

1.3 Technical or industrial textiles

For many years, the term ‘industrial textiles’ was widely used to encompass all textile products other than those intended for apparel, household and furnishing end-uses. It is a description still more widely favoured in the USA than in Europe. The scopes of technical textiles are even greater. Several schemes have been proposed. For example, the leading international trade exhibition for, technical textiles, Techtex (organized biennially since the late 1980s by Messe Frankfurt in Germany and also in Osaka, Japan), defines 12 main application areas. Table 1-1 showed the application of technical or industrial textiles (Ronayne, 2015).

Table 1-1: The application of technical or industrial textiles (Ronayne, 2015).

Applications	Definition
Agrotech	Agriculture, aquaculture, horticulture and forestry
Buildtech	Building and construction
Cclothtech	Technical components of footwear and clothing
Geotech	Geotextiles and civil engineering

Oekotech	Environmental protection
Hometech	Technical components of furniture, household textiles and floorcoverings
Indutech	Filtration, conveying, cleaning and other industrial uses
Medtech	Hygiene and medical
Packtech	Packaging
Protech	Personal and property protection
Sporttech	Sport and leisure.
Mobiltech	Automobiles, shipping, railways and aerospace

1.3.1 Mobiltech

The market for automotive textiles is one of the most important in the technical textiles sector. Approximately 42 square meters or about 20 kg of textile materials is used as interior trims (such as seating areas, headliners, side panels, carpets, reinforcements, linings, underlay fabrics, tyres, hoses and airbags) in each of the 45 million or so cars sold every year globally (Drean et al., 2008). Figure 1.1 shows the distribution of fabrics used in the different parts of a car Airbags constitute about 3.7% of the textiles used in a car. In the last two decades, the use of airbags in cars has gained significant importance due to their active role in preventing injuries and saving lives in minor to severe crashes (KWON, 2018).

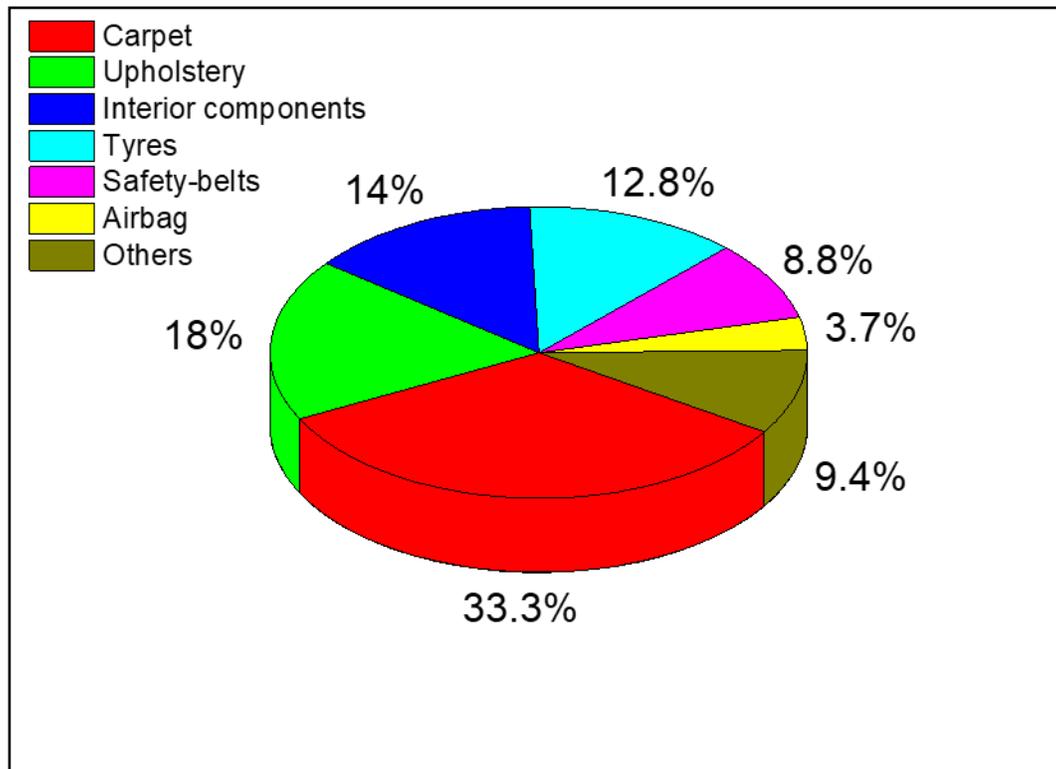


Figure 1-1: Typical breakdown of amounts of textiles used in a car (Nayak et al., 2013)

1.3.1.1 Airbags

Airbags are passive restraint devices that provide the greatest safety benefit when used in conjunction with properly-fitted and adjusted seat belts (Gray, 2016). The first-generation airbags in 1970s were neoprene-coated nylon airbags, which were also adopted in late 1980s and early 1990s (Menzel et al., 1992). In second- and third-generation developments, lighter weight and more pliable fabrics were needed, and to meet the requirements, lower weights of neoprene coating add-on were applied and light-weight silicone-coated fabrics were introduced (Adams et al., 2001). Airbag construction in the mid-1990s focused on cost reduction, pliability and permeability control. Present-day due to their lower cost and reduced environmental impact in their manufacture (Nishimura et al., 2018). The use of

airbags and seat belts helps in reducing severe injuries and deaths, although they themselves can cause certain injuries during an impact. From analysis of data collected by the US Fatal Accident Reporting System between 1992 and 1997 from head on collisions between matched cars, it was found that combined airbag and seat belt use reduced driver mortality by more than 80%. Having begun its evaluation of its Federal Motor Vehicle Safety Standards in 1975, by October 2004, the US had evaluated the effectiveness of virtually all the life-saving technologies introduced into passenger cars, pickup trucks, sports utility vehicles and vans in the USA from 1960 to the early part of the twenty-first century. Vehicle safety technologies saved an estimated 328,551 lives from 1960 through 2002 (Nagaoka and Ishii, 2004). The annual number of lives saved grew quite steadily from 115 in 1960, when a small number of people used lap seat belts, to 24,561 in 2002, when most cars and light trucks were equipped with numerous modern safety technologies and safety belt use on the road had risen to 75%. In 2002, according to the were the third most effective safety technological measure after seat belts and energy-absorbing steering assemblies (Kahane, 2015).

1.4 The Nanotechnology in automotive fabrics

The broad definition of nanotechnology: the design, characterization, production and application of materials, devices and system by controlling shape and size of the nanoscale .The nanoscale itself at present consensually considered to cover the rang from 1to100nm. Car industry's commercial strategy today is to improve the safety and convenience aspects of automobiles (Moscatelli, 2016). Textiles, especially fabrics, as the main substances in designing of interior parts of a vehicle, are very important. They are utilized in various parts such as interior panels for doors, pillars, seats coverings and paddings, parts of the dashboard, cabin roof and boot carpets, headliner, safety belts, airbags (Yetisen et al., 2016). Novel nano-

based coatings are widely used today, for instance, to functionalize surfaces, to provide protection against corrosion and dirt, to prevent biological soiling and graffiti or to create attractive designs by special colour effects. Parts of standard vehicles are treated with protective and decorative finishes (Gurjar and Tyagi, 2015). The most important properties of automotive fabrics which have been modified by the aid of nanotechnology include: anti-microbial, self-cleaning and fire-retardancy (Fan et al., 2018, Li et al., 2018). Table 1-2 showed the applications of nanomaterials in coatings and their functions (Asif and Hasan, 2018).

Table 1-2: applications of nanomaterials in coatings and their functions (Asif and Hasan, 2018)

Function	Nanomaterial (Examples)	Advantage/Effect	Industrial Branch
Colour brilliance, shade, colour effects (flip-flop effect), reproducible paints, easily dispersible paints	Carbon black; Oxides (TiO ₂ , Fe ₂ O ₃ , Fe ₃ O ₄ , SiO ₂ , Cr ₂ O ₃) (on mica flakes or SiO ₂ spheres, with metal pigments), ZnO	Intensify effects of metal pigments; Stabilize pigments and fillers; Positive effects in dispersion paints; Prevent crack formation (Phyllosilicates/sheet silicates); Improve resistance to fading	Automotive, consumer goods (furniture), construction
Scratch resistance	Oxide (synthetic amorphous silica), SiO ₂ , Al ₂ O ₃	Improved scratch resistance	Automotive, information and communication, parquet flooring, consumer goods (furniture), optics (lenses)

CHAPTER 2

LITERATURE REVIEW

2.1 The safety-restraint system

The safety-restraint system vehicle is combination of the seatbelt and airbag features synchronized to provide the most effective way of reducing injuries from automobile collisions. (Schneider, 2017) The seatbelt system works hand-in-hand with the airbag system to absorb the most energy exerted from the moving body, (Glover et al., 2018).

2.1.1 Seatbelt system

Seatbelts function is to keep an occupants safely in their seat during both regular automobile operation and a collision. The seatbelt system is fabricated from polyester fibers (An et al., 2017).

2.1.2 Airbag system

The airbag system functions to absorb the impact of the human body during an automobile collision. Federal Motor Vehicle Safety Standards (FMVSS 208) requires all passenger cars sold in the USA to have airbags for both the driver and front-seat passenger (Hinger and Clyde, 2001). A second federal standard FMVSS 201, requires 10% of cars to be fitted with some type of head protection. The standard does not specify the device by which this should be achieved and so it could be a type of airbag or some kind of padding in the headliner area of the car. FMVSS 201 requires all cars made by May 2003 to be fitted with some head protection facility (Smith et al., 2003).

2.1.3 Supplemental restraint system (SRS) airbag

The SRS airbags supplement the seat belts which restrain the body if the driver or passenger is endangered by a severe impact to the front of the vehicle. If an impact whose magnitude, exceeding the preset value is applied to the vehicle; the airbags inflate immediately to prevent the driver and front seat passenger being hit against the steering wheel, instrument panel or windshield (1997). Airbags reduce the risk of death when used in combination with seat belts (Estrada et al., 2004). A central module receives the sensory inputs and determines the necessity of deployment. If airbag deployment is necessary, the central module will transmit a current that will ignite the pellets of sodium azide, producing nitrogen gas on burning, to fill the airbag as shown in (Figure 2-1). The gas then gets filtered and enters the airbag cushion through the inflator ports. The airbag is inflated by the pressurised gas and is deployed through the steering column cover or passenger dash panel or other similar openings depending on the type of airbag (Huelke et al., 1997).

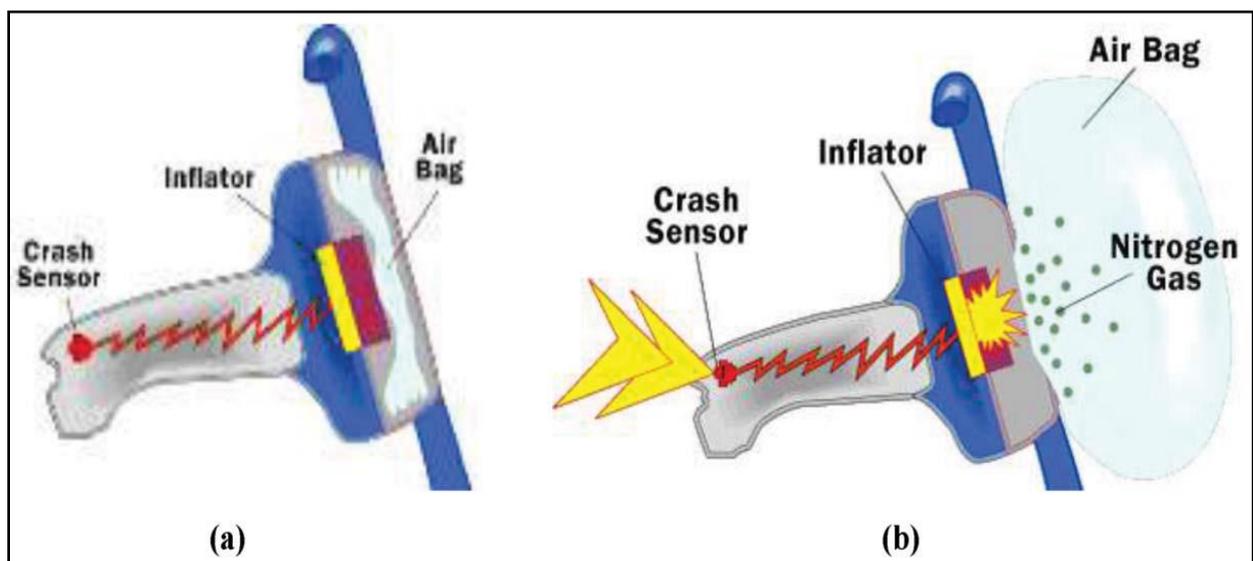


Figure 2-1: The airbag module: (a) before deployment and (b) during deployment
(Nayak et al., 2013)

2.2 Types of automotive airbags

There are two main types of airbag system

1. Frontal Airbags

2. Side-impact Airbags

2.2.1 Frontal Airbags

Frontal airbags are an integral part of the full protection system for occupants in the front seating positions. Located in the steering wheel (for driver seat) or instrument panel (for passenger seat), these airbags inflate during frontal collisions in order to provide protection for the driver and passenger. It has been reported that the airbags on driver and passenger sides require about 1.5 and 3.0 m² of fabric. Moreover, the driver's airbag with cushion sizes ranging from 30 to 60 L is an integrated part of the steering wheel system as shown in (Figure 2-2). The driver side airbag is generally designed to protect an adult, whereas the passenger side airbags are designed to protect a range of human body sizes, shapes and weights (Rokan, 2013). The typical dimension of a driver side airbag is 714 mm (diameter) and 152 mm (deep) (Crouch, 1994).

Frontal airbags can be further subdivided into three categories:

1. Driver Airbags

2. Passenger Airbags

3. Lower-body Protection

2.2.1.1 Driver airbag

Driver airbag modules consist of the textile airbag, inflator and an initiator. This module is housed inside the steering wheel. Pyrotechnic inflators are the most common. They contain a gas generate and during a crash, this generate is ignited and produces a harmless nitrogen gas. The textile airbag or the cushion is made from nylon fabric which is folded inside the module in such a way as to ensure fast and safe deployment during a crash. It has vent holes on the back of the fabric which lets out gas to assure a soft landing of the occupant on the bag (KOMATSU and YANAGISAWA, 2018).

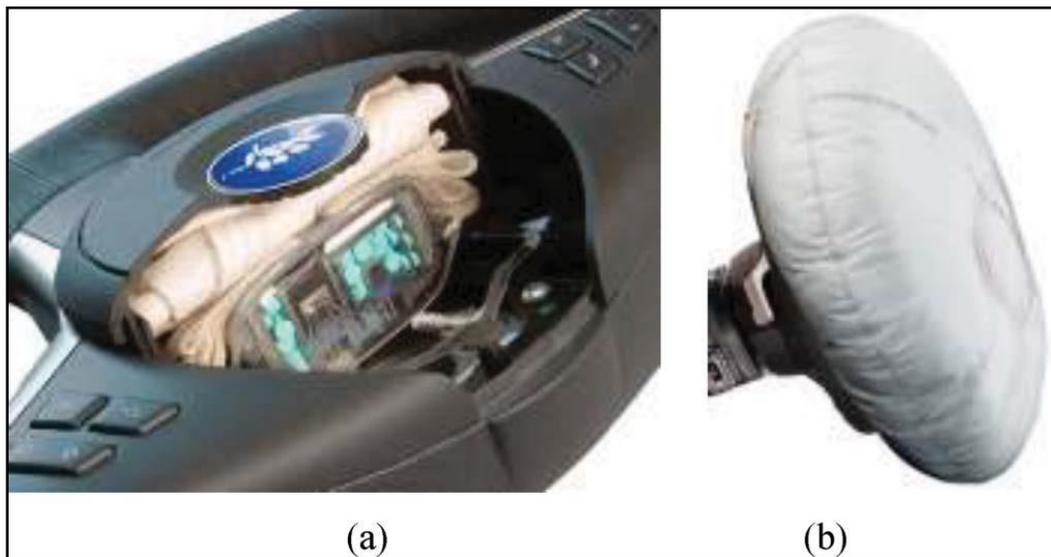


Figure 2-2: Driver airbags: (a) before deployment in the steering wheel and (b) after deployment (KOMATSU and YANAGISAWA, 2018).

2.2.1.2 Passenger airbag

Passenger airbag Module is very similar to the driver airbag module, with the exception of a larger cushion and a larger inflator to inflate the larger bag to the desired level. Both the driver and passenger airbag materials are often manufactured with a heat shield coating to protect the fabric from scorching,

especially near the inflator assembly, during deployment. For car occupants who are protected by airbags and their seatbelts, leg injuries are the most frequent problem in frontal crashes. Autoliv estimates that leg injuries account for 40% of the moderate to severe injuries to these occupants, of which 60% are below the knee (Belwafa et al., 2015).

2.2.1.3 Lower-body protection airbags

The lower-body protection airbags are still not well established compared to driver and passenger airbags. However, there is an increasing demand for lower-body protection airbags (knee airbags and anti-sliding airbags) to prevent fatal leg injuries and ensure that people not only survive a crash but also are able to walk and lead a normal life after a crash (Goldhaber and Sampson, 2019). Therefore, preventing a passenger's head or neck from suffering secondary injuries (Choi et al., 2013).

2.2.2 Side-Impact Airbags

Side-impact collisions account for a quarter of all injuries to car occupants, but they account for more than one third of the serious and fatal injuries according to Autoliv. One major reason is that the side of the vehicle is a thin crumple zone and the space between the occupant and the side of the vehicle is small (Wipasuramonton et al., 2018). Side-impact airbags can be subdivided into 5 categories:

1. Inflatable Curtain
2. Thorax Bag
3. Head Thorax Bag

4. Pelvis-Thorax Bag

5. Door Mounted Inflatable Curtain

2.2.2.1 Inflatable curtain airbags

Inflatable curtains are stored in the headliner above the doors and are used to absorb the energy of a direct side impact, often known as the “first impact” and to provide energy absorption in roll-overs, often known as “second impact”. The US federal law has made it mandatory for all new vehicles of 2013 model sold in the US to contain this kind of airbag. Side-impact crashes at intersections account for approximately 22% of all major crash types where people are killed or seriously injured, the curtain airbag are widely utilized to enhance the protection performance in the case of a side impact (Yun et al., 2014).

2.2.2.2 Thorax airbags

Thorax airbags are stored in back rests of the front seats or in the front doors. These airbags are meant to protect the occupant from serious chest injuries from side-impact collision by pushing the occupant away from the impact zone, thus dampening the blow. These bags usually have a small volume to keep the force on the occupant as gentle as possible while providing sufficient protection. This class of airbags was designed to deploy from a compartment within the door (Roberts and Kaprelian, 2005).

2.2.2.3 Head thorax airbags

Head Thorax airbags are used in vehicles where inflatable curtains cannot be used, for example in convertible cars. The module is usually located in the seat frame and works to protect the occupant very much similar to that of inflatable curtains.

The side airbag systems designed to protect both the head and torso reduced the risk of death in near side impacts by close to 50% (D'Elia et al., 2013).

2.2.2.4 Pelvis-Thorax airbags

Pelvis-Thorax airbags are used to increase side impact restraint performance by increasing the coverage area with the help of an added cell which is inflated to a higher pressure in order to distribute load over the thorax (abdomen area) and pelvis (area between the abdomen and the lower limbs) parts of the occupant's body more efficiently. This concept takes advantage of the pelvis' ability to take higher loads, while it limits pressure on the sensitive thorax area. To achieve improved protection, the airbag's coverage area is extended by adding a cell, which is inflated to a higher pressure in order to distribute the load more efficiently over the thorax and (D'Elia et al., 2013). pelvis parts of the occupant's body. The pelvis airbags are positioned on the seat frame such that in the event of an accident or crash, the pelvic airbag will inflate and prevent the occupants' pelvis from harmfully impacting a portion of the vehicle (Yoshida et al., 2006).

2.2.2.5 Door Mounted Inflatable Curtains (DMICs)

DMICs provide a large side coverage area in vehicles which have no roof, such as convertibles. It has a chamber design which offers even protection and real inflatable curtain (IC) performances, including improved ejection (situation where the seat belts of the driver or passengers are released) protection in roll-over accidents. The door mounted retention mechanism includes a retention strap and a tensioning device (Welch et al., 2003). All these types of airbags illustrated in Figure 2-3.

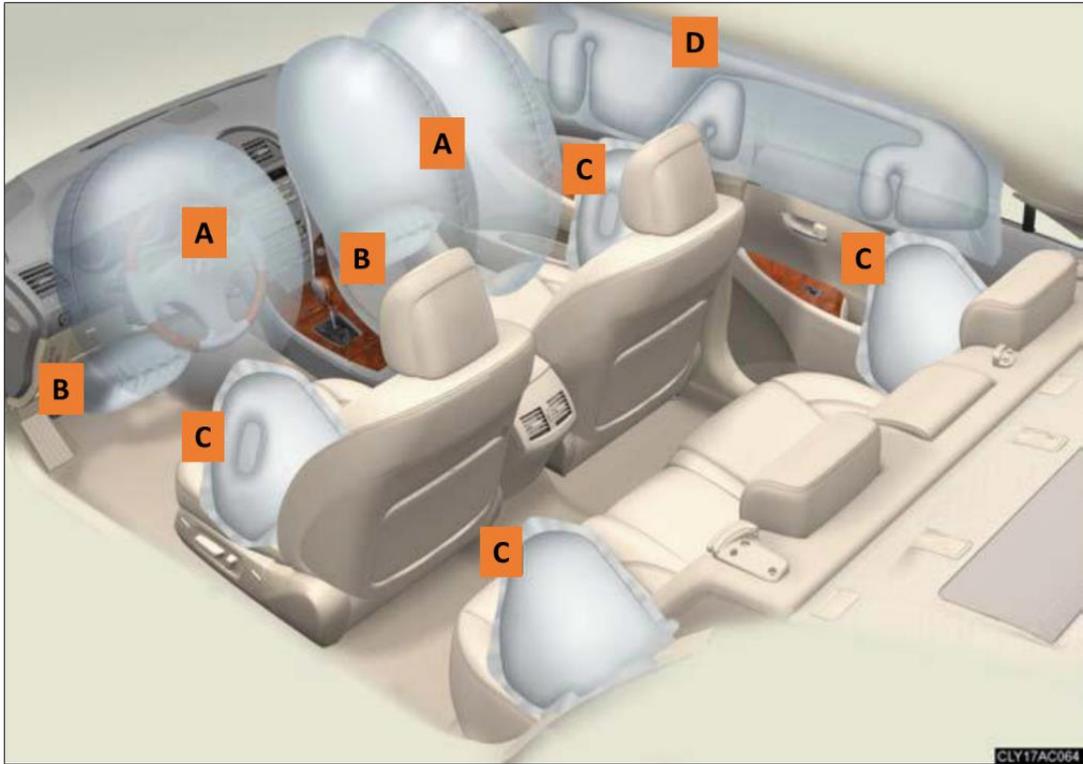


Figure 2-3: Different types airbag in the lexus ES 350. (A. driver airbag/Front passenger airbag, (B. knee airbag,(C. side-impact airbag,(D. inflatable curtains (Rokan, 2013).

2.2.3 Other Airbags

2.2.3.1 Rollover airbags

Rollovers are crashes involving vehicle rotation of at least one-quarter turn (90°) about a lateral or longitudinal axis although about 3% of all the crashes are rollovers, they account for 33% of the crash-related deaths. During rollovers, Vehicle movement involves deceleration along a horizontal plane, vertical acceleration and deceleration combined with rotational acceleration and deceleration. After rollovers, the vehicle may come to rest either on the side or upside down, on the roof or upright on all four wheels (Conroy et al., 2006).

2.2.3.2 Center airbags

Automobile manufacturers around the world have made great efforts to address the safety issues of the occupants, first focusing on the front seat and subsequently on the back seat. Recently, Toyota has introduced the first rear-center airbag. The new front-center airbag, co-developed with Takata Corporation, Tokyo, Japan, is a tethered tubular airbag located between the two front buckets. The airbag will deploy from the right or left side of the driver's seat to protect the driver in side impacts. The Center airbag for a vehicle may be installed in a center console of the vehicle so as to prevent the heads of neighboring passengers from colliding with each other (Choi and Choi, 2013). The center airbag as shown in Figure 2-4.



Figure 2-4. The center airbags (Nayak et al., 2013)

2.2.2.1 Pedestrian protection airbags

Recently, Volvo introduced the first airbag engineered to protect pedestrians. A pedestrian protection airbag system for a vehicle includes an airbag that is adapted

to be deployed along a windscreen and/or A-pillars of the vehicle, is inflatable to a deployed state and has projected periphery (Bergenheim et al., 2015). Figure 2-5 showed the pedestrian protection airbags.



Figure 2-5. Pedestrian protection airbag (Maki et al., 2003).

2.3 Manufacturing of airbags

The manufacturing process of airbags involves several steps starting from the appropriate selection of raw materials to the final assembling of the whole airbag module. Figure 2-6 demonstrated. Process sequence for the manufacturing of airbag module assembly(Nayak et al., 2013).

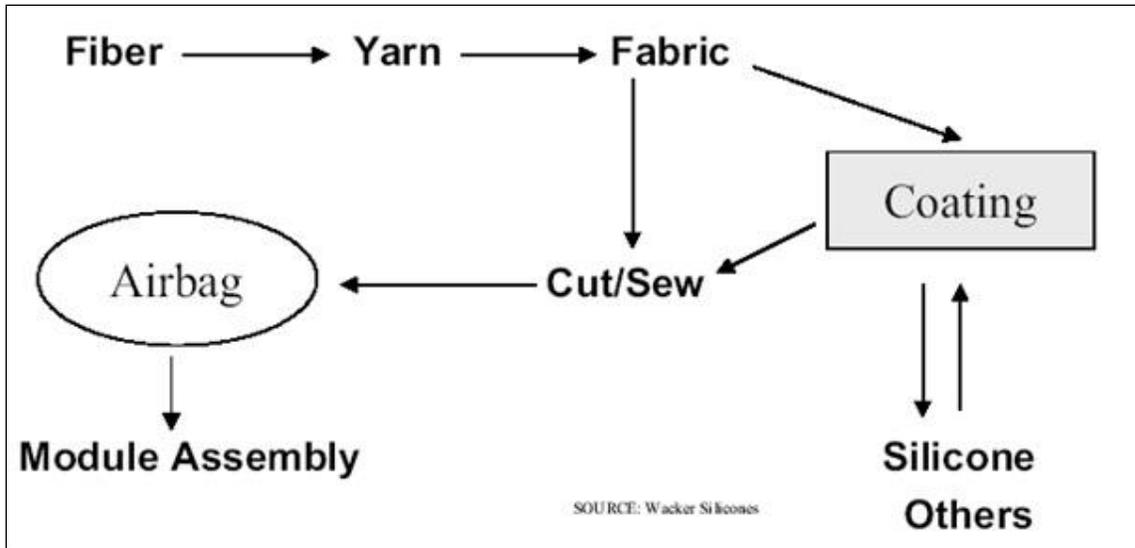


Figure 2-6: Process sequence for the manufacturing of airbag module assembly(Nayak et al., 2013).

2.4 Fibers

The fibers used for airbag fabrics should possess high strength, thermal stability and energy absorption capability, good ageing characteristics, coating adhesion and functionality under extremely hot and cold environmental conditions, a fiber for forming the textile may be selected from aliphatic polyamide fiber obtained with nylon 6, nylon 66, nylon 46, nylon 610, nylon 612, polyester fiber obtained with polyethylene terephthalate, polytrimethylene terephthalate, polybutylene terephthalate, polyethylene naphthalate, copolymer, and mixture thereof; aramid fiber obtained with paraphenylene terephthalic amide and copolymer of paraphenylene terephthal amide and aromatic ether; aromatic polyester fiber; vinylon fiber; ultrahigh-molecular-weight polyethylene fiber; fluorocarbon fiber including polytetrafluoroethylene; polysulphone fiber; polyphenylene sulfide (PPS) fiber, polyether etherketone (PEEK) fiber; polyimide fiber; polyether imide fiber; cellulosic fiber including high tenacity rayon; acrylic fiber; carbon fiber; glass fiber;

silicon carbide (SiC) fiber; and alumina fiber (Kanuma, 2009). There are three main types of fiber selection for airbag, polyamide (nylon 66 nylon6) and polyester.

2.4.2 Nylon 66

Nylon used for airbags are mostly from nylon 66 but other kinds of nylon are being used such as nylon 6, nylon 66 and nylon 46 (Kami and Fukumori, 1992) The most commonly used nylon 66 nylon is the generic name of a long-chained polyamide with many amide lined together, however the amide linkages shall be less than 85 % to two aromatic rings, above 85% is considered an aramid fiber. These linkages give the molecular chains a linear, zigzag configuration making them easier to pack closely together and create a fiber with high crystalline content, as in Polyamide which is usually about 65-85 % crystalline see Figure 2-7. and 15-35 % amorphous simply packing the molecular chains together do not give polyamide its properties, the molecular chains are also held together by strong hydrogen bonds (Nyström and Olsson, 2013).

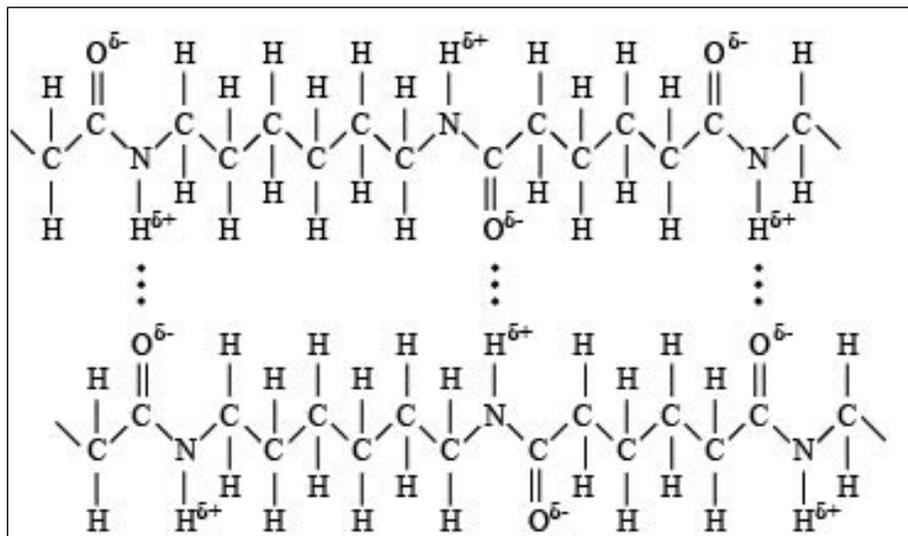


Figure 2-7: The chemical structure of Polyamide (Nyström and Olsson, 2013).

The structure of the molecular chains in polyamide also gives the fiber good tenacity together with the ability to elongate and recover. The fiber is produced in two types of tenacity, regular and high tenacity. Where the regular is mostly used for apparel and high for carpets and industrial use. Tenacity of the fiber is due to how the structure is in the crystalline parts of the polyamide fiber, not depending on the degree of polymerization the molecular zigzag structure is the first to take any stress in the material as force is subjected in longitudinal direction. As long as the force is not greater than the force of the hydrogen bonds, the chain can recover to its original zigzag configuration. This makes the polyamide fiber to withstand up to 8 % of extension and still recover fully also the zigzag configuration gives the fiber good abrasion resistance and high flexibility(Lewin, 1984) . When polyamide fiber is extruded into round cross-sections, they can easily be woven tight together making a fabric that has low water vapor and low air permeability and still have low weight. Nylon 66 has the most superior capability in energy absorption. The balance between the strength and elongation gives it unmatched suitability for airbag cushion materials although nylon 66 and polyester have similar melting points, the large difference in specific heat capacity causes the amount of energy required to melt polyester to be about 30% less than that required to melt nylon 66 (Sun and Barnes, 2010) Table 2-1 showing comparison of key properties of nylon 66 and polyester.

Table 2-1: Comparison of key properties of nylon 6 6 and polyester (Sun and Barnes, 2010).

Properties	Nylon 66	Polyester
Density (kg/m ³)	1140	1390
Specific Heat Capacity (kJ/kg/K)	1.67	1.3
Melting Point (°C)	260	258
Softening Point (°C)	220	220
Energy to melt (kJ/kg)	589	427

2.4.3 Polyester

Polyester is the most used synthetic fiber of all man-made fibers and has bigger production volume than cotton (Aizenshtein, 2009). Polyester fibers have a wide generic group definition, since any long-chained polymer composed of an ester containing at least 85 % of esters are considered to be a polyester. However, the ester shall be formed from a dialcohol reacting with an aromatic carboxylic acid or hydro-benzoate. The most common type of polyester is polyethylene terephthalate or more known as PET, which is created by a reaction between ethylene glycol and terephthalic acid the molecular chain is shown in Figure 2-8.

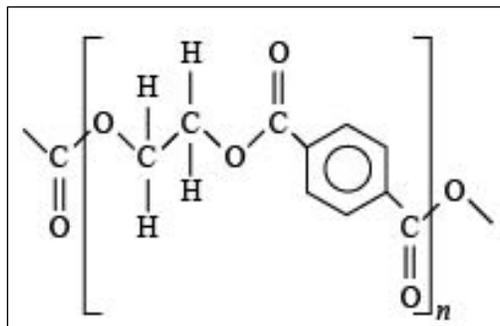


Figure 2-8: The molecular chain of polyester.

Polyesters molecular chain is linear, making the polymer easy to pack close together, are up to 35 % crystalline and up to 65 % amorphous and highly oriented. The chain is not very polar and will therefore not have hydrogen bond, instead a cloud of electrons in the benzene ring is created, a dipole-dipole interaction. This structure together with molecular chains being highly oriented gives the polyester fiber properties of high tenacity and good resilience. But at the same time the fiber does not have good ability to recover when subjected to stress. Any elongation more than 2 % will make a deformation to occur due to polyesters smooth surface and lack of hydrogen bond makes the fiber have a low moisture regain at 0,4 % (Goodman, 1988). This gives the fiber good wicking properties and easy to wash but also makes the polyester fabric to accumulate static electricity (Nyström and Olsson, 2013).

2.4 Yarns

The basic building blocks for the airbag fabrics are yarns. Continuous filament yarns (false twisted and air textured) are generally used for the airbag fabrics. The airbags in the most modern cars are being manufactured from finer nylon 66 filament yarns (from 50 to 850 dtex). The number of individual filaments in the yarn is important for achieving the desired properties. The use of finer filaments in the yarn results a fabric with lower air permeability. The important yarn parameters for airbag fabrics are yarn strength, elongation and uniformity (Tanaka and Yamada, 2017). The multi-filament yarns used for airbag fabrics should have high tensile strength with low coefficient of variation (CV) to improve the strength of airbags.

2.5 Fabric

Almost all of the airbags manufactured worldwide are made from woven fabrics consisting of two sets of threads interlacing at right angles to each other composed of nylon 66 yarns. Airbag fabrics need to be strong enough to withstand high stresses during inflation of the airbag (Johansson, 2014). Traditionally fabrics used for "airbag" usage have been of a plain weave, rip stop, or basket weave construction. At certain densities or yarn sizes these constructions can have other than desired properties of stiffness, tear strength, or gas permeability. Fabrics made from twill constructions are more flexible, tear resistant, and have higher gas permeability than a plain weave fabric (Sollars Jr, 1994). In the past, many air bags were made from a woven fabric containing multifilament yarns. The air bag fabrics were made using various different weaving systems (Ise, 2017). For instance, in some applications, the fabrics were woven on a Rapier weaving machine (Bowers et al., 1995). Recently, various attempts have been made to produce air bag fabrics on water jet weaving machines. In a water jet loom, the weft or pick yarns are moved in the cross-machine direction through a shed formed by the warp yarns using jet streams of water. Of particular advantage, water jet weaving machines are much faster and have a higher throughput than conventional Rapier weaving machines (Manley, 2009). In addition to rapier and water-jet looms, air-jet looms are also used for airbag fabric production, not least because the productivity of air-jet looms can be higher than the rapier looms. The major requirements for airbag fabrics include low thickness, high tensile strength, high resistance to tear, high anti-slip properties of the seam, strong, lightweight, thin, good dimensional stability, and resistance to ageing, defined and uniform air permeability and product reliability at least for 15 years all characteristics which can be achieved with appropriately constructed woven fabrics. (Thornton et al., 1991, Rink and

Green, 2001, Rink et al., 2001) There are two types of airbag fabrics available commercially: coated and uncoated.

2.5.2 Coated airbag fabric

Coatings have been applied to fabrics, intended for use in automotive airbags, to resist the unwanted permeation of air through the fabric and, to a lesser extent, to protect the fabric from detriment by the hot gases used to inflate the bags (Parker, 2005). Most driver side airbags are coated whereas the passenger side airbags are generally uncoated. This is related to the larger size of the passenger side-impact airbag generally longer and of a different shape so that it retains the inflation gas for a longer period of time, with the gas cooling during the inflation (Menzel et al., 1992), that a coated fabric has a volume when folded at least 10% higher than that of an uncoated fabric. The space required for accommodating the air bag, for example in a steering wheel, is thus greater for a coated fabric than for an uncoated fabric (Krummheuer et al., 1996) Polychloroprene such as neoprene was selected as the first elastomeric coating for airbag fabrics for several reasons such as neoprene-coated fabrics fulfilled the requirements for the airbag fabrics, neoprene was environmentally and chemically stable, the flame retardancy of neoprene is higher than the most competitive products and it was readily available in the commercial market at low prices. By the end of 1980s, almost all the North American and European automobile manufacturers had adopted neoprene coatings for driver side airbag fabrics (Crouch, 1994, Nayak et al., 2013). There are weaknesses with the chloroprene coated fabric in that it is difficult to produce light-weight air bags using this fabric and the physical properties of it deteriorate with time (Honma et al., 1993). Furthermore, when it is folded into a compact module, it is hard to fold (Schmitt, 2010). There are many types of coating

compositions used to produce such coated fabrics, but one class of coating composition that is becoming quite popular in the airbag industry is based on silicone elastomers. Silicone elastomers provide a great degree of flexibility in modifying the gas permeability of the fabric. Silicone elastomers also provide appreciable heat protection, which is beneficial given the high amount of heat to which the airbag can be exposed during its life in the automobile and the heat that is produced by the gas generator when the airbag is deployed. Despite these benefits, silicone elastomer themselves tend to be very weak. Therefore, they are frequently reinforced with fillers in order to produce a coating having the desired degree of tensile strength (Keshavaraj, 2015). The coating of airbag can be applied by methods such as knife coating; knife-over-roll coating, spray coating, impregnation coating, curtain coating, screen coating, reverse roll coating and transfer roll coating. They can also be used with one or more additives such as heat stabilizers, antioxidants cross-linking agents, flame retardants, rheology modifiers, thickeners, ant blocking agents, UV stabilizers, adhesion promoters, fillers and colorants. Some of the anti-blocking agents used can promote the flame retardant properties of the fabrics (Barth et al., 2018, Keshavaraj and Yu, 2010)

2.5.3 Uncoated airbag fabric

The coated base fabrics are heavy and do not have satisfactory flexibility. The manufacturing cost is high and the base fabrics are not recyclable. Therefore, the base fabrics have such drawbacks when each of them is used as a base fabric for an air bag (Kitamura and Konishi, 2005). Airbags may also be formed from uncoated fabric which has been woven in a manner that creates a product possessing low permeability or from fabric that has undergone treatment such as calendaring to reduce permeability. Fabrics which reduce air permeability by calendaring or other

mechanical treatments after weaving are disclosed uncoated fabrics fray during trimming and cutting operations (Li and Arnott, 1999). Coating the fabric material will often allow the fabric to be cut without the fabric fibers fraying but the prior art coatings often add unnecessary bulk and thickness to the fabric. Additionally, there is a need for a coated fabric that is light weight, strong, flexible, foldable and impermeable so that the coated fabric may be used in the construction of air bags for either the passenger side or driver's side of an automobile. Uncoated fabric could cause secondary injury due to permeation by hot gases through the fabric or by particulate matter which bypasses the inflator filter system (Menzel et al., 1992) . Table 2-2 shows some differences between the coated and uncoated fabrics (Damewood, 1995).

Table 2-2. Difference between coated and uncoated fabrics.

Property	Coated	Uncoated
Air permeability	Precisely controlled	Variable
Packability	Bulky	Smaller package
Stiffness	Stiffer	Pliable to moderate
Pattern cutting	Easily cut	More difficult
Sewing	Easy to handle	More difficult
Burn thru	Good resistance	Poor
Deployment	Excellent control	Edge combing effects
Cost	High	Low
Recyclability	Difficult	Easy

2.6 Cutting

Airbags International Limited (AIL) supplies airbag safety devices to the major European automotive manufacturers.. AIL's product range encompasses many different types and sizes of airbag devices, ranging from standard driver and passenger products found in most vehicles, to highly specialized curtain airbags which require advanced design and manufacture facilities (Dal et al., 2000). The increase in the use of airbags in automobiles have led airbag manufacturers to determine the most cost-effective and flexible methods of cutting and the airbags. Recently, the demand of consumers for more frequent model changes of the cars and hence the airbags have necessitated flexibility in high quality cutting. Cutting systems which can meet all the above requirements are in high demand. There are different cutting methods used for airbag fabrics. The major methods used for coated fabrics are mechanical (such as dies or reciprocating knife cutters) and for uncoated fabrics are based on the use of lasers Laser-based cutting systems are faster and more accurate than mechanical-based cutting systems (Gaebler and Clark, 2009). The airbags in automobiles are prepared in different shapes such as circular spherical and oblong. The driver side airbags are circular in shape, formed by joining/sewing two similar circular panels face to face. During their deployment, circular airbags are subjected to substantial tensile stress that can cause seam failure. To avoid this problem, polygon-shaped (hexagon and octagon) airbags were designed by Keshavaraj (Keshavaraj, 2004).

2.7 Joining of panels.

After the panels are cut into shape, they are joined together by appropriate methods. The methods of joining the panels involve sewing, welding joining by adhesives airbags are mostly joined by sewing (Nayak et al., 2013). The sewing machine

needs to be able to stitch the airbag panels without damaging the airbag fabric or the sewing thread. This can be achieved by suitable selection of sewing machine, sewing threads and proper adjustment of sewing parameters such as needle type, stitch length, stitches per min and machine speed. The sewed airbag made by a common automatic sewing machine is short of the seam strength and elongation of the seam parts for providing effective expansion performance and unfolding performance when the airbag operates (Kwak et al., 2017, Hosaka and Yokoi, 2018). Sewing thread is an engineered material, which holds all the cut panels together (Fan and Leeuwner, 1998), it joins the fabric components by forming a seam that is intended to provide uniform stress transfer from one fabric piece to the other (Geršak and Knez, 1991). An airbag construction utilizing welds, reinforced with sewn seams, to adhere two fabrics together to form an inflatable airbag cushion. Although welded seams provide better and more easily produced attachment points between multiple layers of fabrics (Kanno, 2010). As existing sewing threads for an airbag, a polyamide fibers (nylon 66 and nylon 46) sewing thread and an aramid (p-aramid) sewing thread are widely used, however, they are disadvantageous in view of a cost as compared to a sewing thread for an airbag to which a polyester yarn is applied (Kim et al., 2018).

2.8 Folding

The air bags are often stored in the dashboard or steering wheel of the vehicle with restricted space for the placement of the air bag. In the event of an accident, the air bag is inflated. The characteristics of the air bag's deployment are determined by the method of folding the air bag (Dennis, 2003). Different airbags are folded with different numbers and types of fold by numerous methods. A number of folds such as simple fold, open fold, rolling fold, tuck fold, accordion fold, reversed accordion

fold, pleated accordion fold, Leporello fold (L-fold), raff fold, stochastic fold, ring fold and overlapped fold can be selected for this purpose, The method also includes guiding the airbag end portions around the outer circumference of the gas generator and/or of the airbag-retaining metal sheet in opposite directions toward each other up to a folding zone in which the end portions of the airbag at least almost contact each other (Hepp, 2018).

2.9 Injuries caused by airbags

Half a million persons are injured on the roads worldwide every year and road accidents are becoming one of the top three causes for premature death. Airbags and associated safety devices have become one of the largest growth areas in technical textiles over recent years. Although, airbags significantly reduce the risk of serious or fatal injuries in accidents, there exist some risks of their deployment(Yetisen et al., 2016). The vast majority of injuries (96%) are minor injuries categorized as bag slap injuries such as grazing, bruises and abrasions to the face, neck and upper limbs, burn by hot gasses due to leakage (Menzel et al., 1992)and additional problems causes un-proper folding of airbags(Moscatelli, 2016). Proper folding of airbags nevertheless, it has been shown that airbags cause potential hazards to children and small stature occupants in the front seat(Yetisen et al., 2016). The other airbag injuries to adult occupants include periorbital fracture, head injuries, eye injuries, hearing loses due to noise of bursting, internal organ lacerations, cervical spine injuries and otologic injuries(Yetisen et al., 2016). In the recent year, there are some solution points such as un-proper folding was manual in the past but now a days changed to computer simulation is playing an increasingly important role in the design, development and application of airbag safety system. As the folding patterns and airbag structure become more and more

complex. Users are turning to simulation based folding solution to generate accurately folding modules in a short space of time. Furthermore, to meet this demand, a new software tool called JFOLD has been developed by JSOL Corporation to enable successful airbag folding using LS-DYNA (Taylor and Hayashi, 2015, Gray, 2016). Pink noise which Mercedes calls “Pre-Safe Sound” in its marketing is unique in that its power is inversely proportional to the signal. When it hits the ear, it triggers muscles in the ear to contract by reflex, automatically bracing the inner ear and eardrum for the extremely loud noise of the crash by reflecting some of the sound before it reaches the point where it could cause problems.(Li et al., 2018) That the system reduces the possibility of hearing damage result to the explosive deployments of airbags.

2.10 Research problems (Key points need to be solved)

Film bonding is unfavorable for airbag fabrics, because it leads to increase in fabric thickness and decrease compactness in packing. The uncoated fabric fabricated with a high density but it still have hot gases leakage problems.

2.11 Research Objectives

This research aims to the following objectives:

1. Reduce the thickness of the coated nylon 66 airbag fabric by using combination of silica nanoparticles (SiO_2) and low-density adhesion polyvinyl alcohol (PVA) material to make air bag easy to fold in small space.
2. Decrease the number of injuries due to the hot shock, by improving the thermal properties of the airbag fabric by using PVA/ SiO_2 thermal insulating coating material.
3. Reduce the burns caused by the leakage of hot gases by reduction of air permeability.
4. Enhancing the mechanical properties of air bag fabric coated with different concentrations of silica nanoparticles.
5. Obtain an eco-friendly airbag by easy separation of coated bio-materials (SiO_2 and PVA) from nylon 66.

CHAPTER 3

MATERIAL AND METHOD

3.1 Nylon 66 fabric

The nylon 66 fabric used in this research was supplied from Easy Composites Company China, with higher tear-strength operating temperatures and an easier release from curd, during product the nylon 66 is rinsed and heat treated to eradicate any surface contamination. Specification as given in Table 3-1 and in (Figure 3-1).

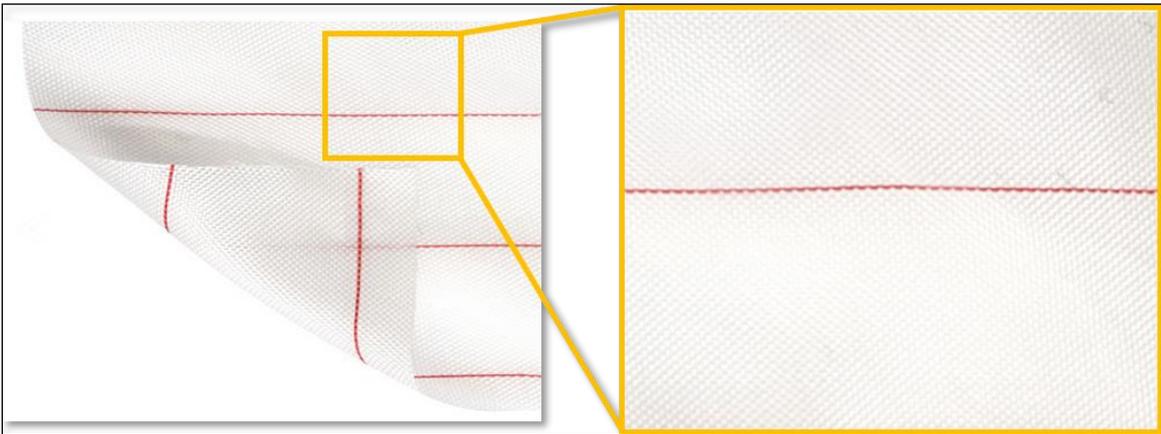


Figure 3-1: Nylon 66 fabric.

Table 3-1: Specification of nylon 66 fabric.

Specification	Count/Denier		Ends/inch	Pick/inch	Weave	Weight (g/m ²)	Thickness (μ m)
	Warp	Weft					
Nylon 66 fabric	260	260	50	40	plain	9.5	140.52

3.2 Polyvinyl alcohol (PVA)

Polyvinyl alcohol (PVA) the most common synthetic water-soluble polymer produced in the world has valuable properties, biocompatibility, chemical resistance, and good mechanical properties (Panaitescu et al., 2015). In textile

industries PVA has widely used as sizing agent because of good film- forming properties (Chen et al., 2016).

Polyvinyl alcohol (PVA) used in this research is a hydrophilic linear polymer which forms copolymers of vinyl alcohol and vinyl acetate. Hence, the structural properties of polyvinyl alcohol polymers depend on the extent of polymerization and hydrolysis. Such changes cause both chemical and physical modifications such as esterification, etherification, crystallization, ion-polymer complexation in the polymer. Modified- PVOH structures are useful in biomedical application. The PVA powder supplied from Sigma-Aldrich, China. Table 3-2 showed specification of polyvinyl alcohol, Figure 3-2 presented PVA powder.



Figure 3-2. Polyvinyl alcohol (PVA) powder.

Table 3-2: Specification of polyvinyl alcohol (PVA).

Appearance (Color)	Appearance (Form)	Hydrolysis	pH	Mw	Loss on Drying	Residue on (Ash)
White to Off-White	Powder	99.0	5.0-7.0	89 000	<-5 %	<-0.7 %

3.3 Silica nano particles

Fumed silica, SiO₂ (CAS number 112945-52-5), also known as pyrogenic silica because it is produced in a flame, consists of microscopic droplets of amorphous silica fused into branched, chainlike, three-dimensional secondary particles which then agglomerate into tertiary particles. The resulting powder has an extremely low bulk density and high surface area. Its three-dimensional structure results in viscosity-increasing, thixotropic behavior when used as a thickener or reinforcing filler. Silica nanoparticle obtained from Macklin Biochemical Co., Ltd. China. Specification as given in Table 3-3. The silica nanoparticles powder as shown in Figure 3-3.



Figure 3-3: Silica nanoparticles.

Table 3-3: Specification silica nanoparticles

Specification	Size nm	Surface area m ² .g ⁻¹	Density kg/m
SiO ₂	5–50	50–60	160–190

3.4 Methods

3.4.1 Preparation of PVA/SiO₂ solution

Silica nanoparticles (SiO₂NP) and polyvinyl alcohol (PVA) has been used for coating nylon 66 fabric. Used different concentration of PVA 0.3-3wt.% observing the changes in physical properties of the fabric handle as shown in Figure 3-4. As the result, the nylon 66 fabric coated with PVA is gradually changed from flexible to hard with different concentrations by using handle. Therefore, its found that optimal concentration of PVA is 0.3wt%. The PVA immersed in water for 12hrs, then prepared in a beaker by continuously stirring using magnetic stirrer at 80°C for 2hrs. The 0.3, 0.6, 0.9wt. % silica nanoparticles were added to dissolve PVA and ultra-sonicated 18000rpm for 5min by direct sonicator (sonicator probe) at 40°C for 5min . Figure 3-5 illustrated the magnetic stirring of PVA and Figure 3-6 showed sonication of silica nanoparticles in PVA solution.

3.4.2 Nylon 66 fabric coating

The fabric was coated by dip-coating method at 70°C for 10 min followed by drying under tension at 27°C for 1hr. The dip-coated nylon 66 by PVA/silica nanoparticles as in Figure 3-7. Figure 3-8 presented Nylon 66 coated by 0.3wt.% PVA and silica nanoparticles of (a) 0.3wt.%, (b) 0.6wt.%, and (c) 0.9wt.%.

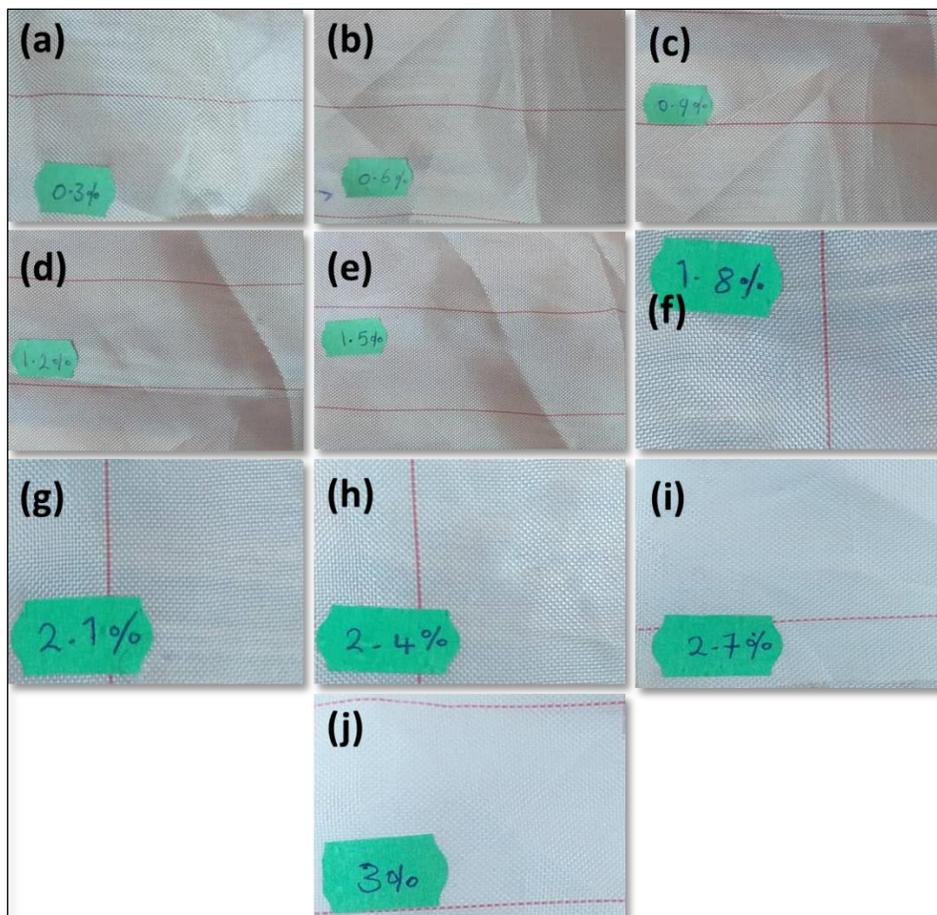


Figure 3-4: Nylon 66 coated by PVA with different concentration (a-j) 0.3-3wt.%



Figure 3-5: Magnetic stirring of PVA.



Figure 3-6: Sonication of silica nanoparticles in PVA solution.

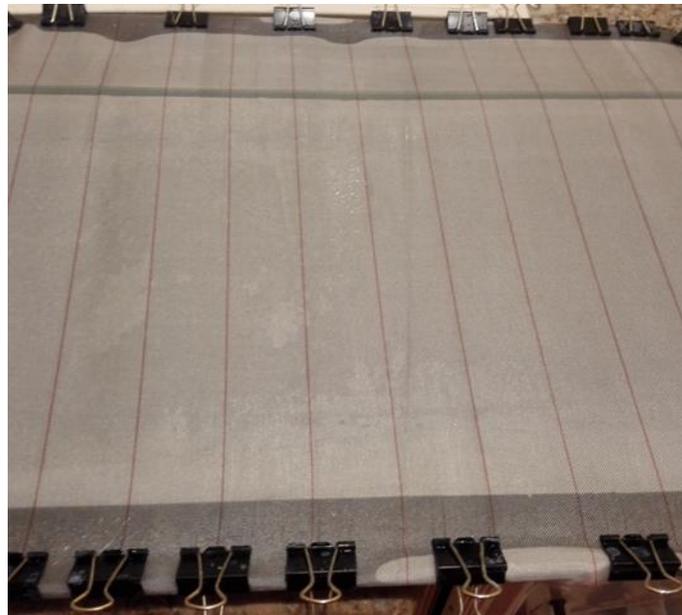


Figure 3-7: Dip-coated nylon 66 by PVA/silica nanoparticles.

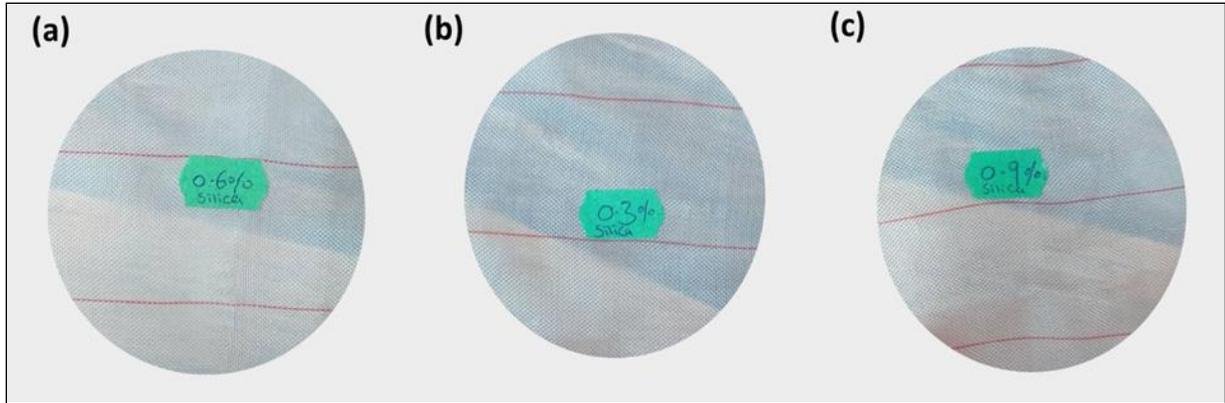


Figure 3-8: Nylon 66 coated by 0.3wt.% PVA and silica nanoparticles of (a) 0.3wt.%, (b) 0.6wt.%, and (c) 0.9wt.%.

CHAPTER 4

EXPERIMENTAL WORK

In this chapter, the nylon 66 fabric, nylon 66 coated with PVA, nylon 66 coated with PVA/silica nanoparticles at different concentrations of silica nanoparticles have been tested using the Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FT-IR), Differential Scanning Calorimetry (DSC), Thermogravimetric Analysis (TGA), Tensile Strength tester, Water Contact Angle analysis (WCA) and air permeability tester.

4.1 Scanning electron microscopy (SEM)

A scanning electron microscope (SEM) scans a focused electron beam over a surface to create an image. The electrons in the beam interact with the sample, producing various signals that can be used to obtain information about the surface topography and composition. The surface morphology of the silica/PVA nylon 66 composite fabrics were characterized by scanning electron microscope (SEM) instrument (Model JSM5610LV, version 1.0, Jeol, Japan) and the presence of silica in composite fabric was confirmed on scanning electron microscope using Oxford-Inca software. In the preparation of the fabric, the fabric was coated by a layer of gold using the coating machine Figure 4-1 (a). Figure 4-1 (b) showing the scanning electron microscope (SEM).

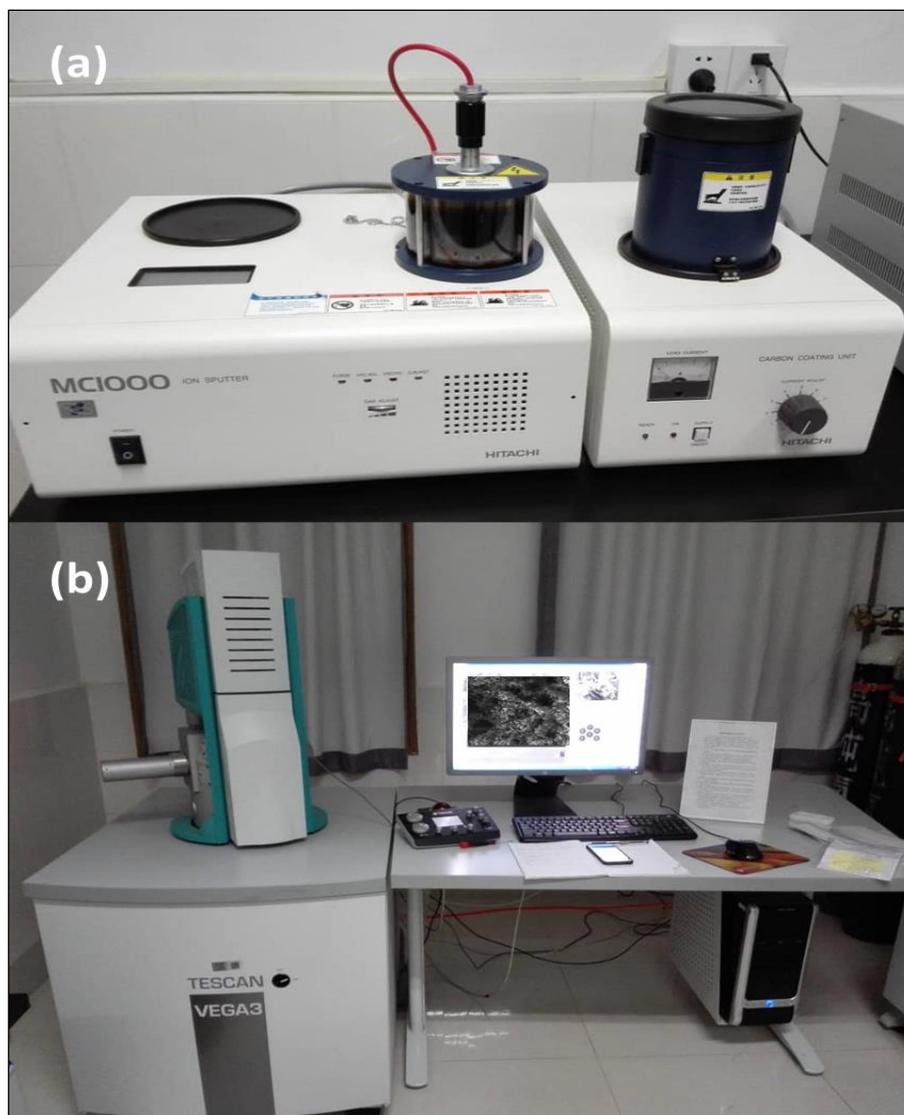


Figure 4-1: (a) coating machine and (b) scanning electron microscopy (SEM)

4.2 Fourier Transform Infrared Spectroscopy (FT-IR)

The FT-IR Analysis or FT-IR Spectroscopy, is an analytical technique used to identify organic, polymeric, and, in some cases, inorganic materials. The FT-IR analysis method uses infrared light to scan test samples and observe chemical properties such functional groups of the materials.

The nylon 66 fabric coated with PVA/silica nanoparticles was characterized by (FT-IR, 8400 S SHIMADZU) spectrophotometer as in Figure 4-2.



Figure 4-2: Fourier Transform Infrared Spectroscopy (FT-IR)

4.3 Differential Scanning Calorimetry (DSC)

The differential scanning Calorimetry (DSC) was carried out at heating rate of $10^{\circ}\text{C min}^{-1}$ up to $800^{\circ}\text{C min}^{-1}$ under air atmosphere via TA instruments (DSC SDT Q600, USA). As in Figure 4-3, during the test an empty DSC pan was then weighed. The nylon 66 fabric, nylon 66 coated with PVA, nylon 66 coated with PVA/silica nanoparticles were placed inside the pan and weighed again (9.5, 11.0 and 12.5 mg). The difference between the two gave the mass of the nylon 66 coated fabric being used. Once the coated fabric mass was measured, a lid was placed on the pan and the pan was sealed.

4.4 Thermogravimetric Analysis (TGA)

Thermogravimetric analysis (TGA) is an analytical technique used to determine a material's thermal stability and its fraction of volatile components by monitoring the weight change that occurs as a sample is heated at a constant rate. The thermogravimetric (TGA) was carried out at heating rate of $10^{\circ}\text{C min}^{-1}$ up to $800^{\circ}\text{C min}^{-1}$ under air atmosphere via TA instruments (DSC SDT Q600, USA). This instrument confirmed the comparison of thermal stability of the samples (Figure 4-3).



Figure 4-3: Thermogravimetric Analysis (TGA)

4.4 Tensile strength

The tensile properties were examined at room temperature with a tensile tester (OTU-2, Oriental TM Co Korea). ASTM D5035 Specimen 200m in length, 50 mm in width Figure 4-4 the tensile strength tester.



Figure 4-4: Tensile strength tester.

4.5 Water contact angle (WCA)

Water contact angle measurement has been broadly accepted for material surface analysis related to wetting, adhesion, and absorption. The dynamic contact angle of the water droplet placed on the of nylon 66 fabric, nylon 66 coated with PVA and nylon 66 coated with PVA/silica nanoparticles were measured using a water contact angle measuring instrument. Digital Goniometer (Kino SL200B) used for water contact angle (WCA) analysis. In order to evaluate the adhesion at the PVA/SiO₂ nanoparticles in the room temperature condition (Figure 4-5).



Figure 4-5: Water Contact angle (WCA) tester.

4.6 Air permeability

The air permeability of the coated fabric was measured using an Air Permeability Tester (PRO WHITE AIRTEST II) Instruments according to ASTM D 737. A test pressure of 125 Pa and the size of specimen as illustrated is 38 cm² (Figure 4-6).



Figure 4-6: Air permeability tester.

CHAPTER 5

RESULTS AND DISCUSSION

This chapter includes all the results from the experimental work described in the previous chapter. The chapter also includes detailed discussions and explanations of the results obtained.

The Table 5-1 showed the comparison for thickness of nylon 66 fabric, nylon 66 fabric coated with PVA, nylon 66 fabric coated with 0.3wt.%PVA/0.3wt.%SiO₂, nylon 66 fabric coated with 0.3wt.%PVA/0.6wt.%SiO₂ and nylon 66 fabric coated with 0.3wt.%PVA/0.9wt.%SiO₂ which indicated that layer thickness increased with increasing the amount of silica nanoparticles as coating material. In the results, even the higher concentration sample (0.9wt.%) has a reasonable thin layer (0.009mm) compared to silicone-coated airbags with a thickness layer (0.5mm), and this issue was required for folding the airbag in small package size (Akechi, 2017). Furthermore The final dry weight of the coating (PVA/SiO₂) material for higher concentration silica is 0.4 gram per square meter. Table 5-2 presented the dry weight per meter square of nylon 66 fabric and nylon 66 fabric coated with PVA and different amount of SiO₂ nanoparticles.

Table 5-1: The thickness of nylon 66 fabric and nylon 66 fabric coated with PVA and different amount of SiO₂ nanoparticles.

Nylon 66	Nylon 66 +PVA	Nylon 66+ 0.3wt.% PVA/0.3wt.%SiO₂	Nylon 66+ 0.3wt.% PVA/0.6wt.%SiO₂	Nylon 66+ 0.3wt.% PVA/0.9wt.%SiO₂
0.140mm	0.142mm	0.145mm	0.147mm	0.149mm

Table 5-2: The weight per square meter of nylon 66 fabric and nylon 66 fabric coated with PVA and different amount of SiO₂ nanoparticles.

Nylon 66	Nylon 66 +PVA	Nylon 66+ 0.3wt.% PVA/0.3wt.%SiO ₂	Nylon 66+ 0.3wt.% PVA/0.6wt.%SiO ₂	Nylon 66+ 0.3wt.% PVA/0.9wt.%SiO ₂
9.5g/m ²	9.6g/m ²	9.7g/m ²	9.8g/m ²	9.9g/m ² w

5.1 Scanning electron microscopy (SEM)

The Figure 5-1 showing SEM images of nylon 66 fabric, nylon 66 fabric coated with PVA/silica nanoparticles, nylon 66 coated with PVA and cross-section morphology of nylon 66 fabric coated with PVA. The joining process between the warp-weft yarn on plain weave nylon 66 fabric is due to the PVA/silica which were used as coated materials and even between the fibers in single yarn as shown in (Figure 5-2 a and b) . The SEM magnification images presented the morphology of nylon 66 fabric coated with 0.3wt.% silica, nylon 66 fabric coated with 0.6wt.% silica and nylon 66 fabric coated with 0.9wt.% silica illustrate in Figure 5-3(a ,b ,c). The Figure 5-3(d) displayed cross-section morphology of nylon 66 coated with PVA/0.9wt.% silica and display the good distribution of the PVA/silica on the surface of nylon 66. Figure 5-4 explained the SEM images of nylon 66 coated with constant 0.3wt.% PVA and different concentrations of silica nanoparticle, observed that the surface area of nylon 66 fabric gradually increased with increasing the amount of silica nanoparticles and distribution of the silica are denser on the surface of the nylon 66 fabric (fume shape). Figure 5-4(a ,b ,c) demonstrated the bigger sizes of the silica nanoparticles (20.48, 20.30 and 18.76nm) respectively, which refer to a better sonication of the silica in the PVA solution and good dispersion without aggregation.

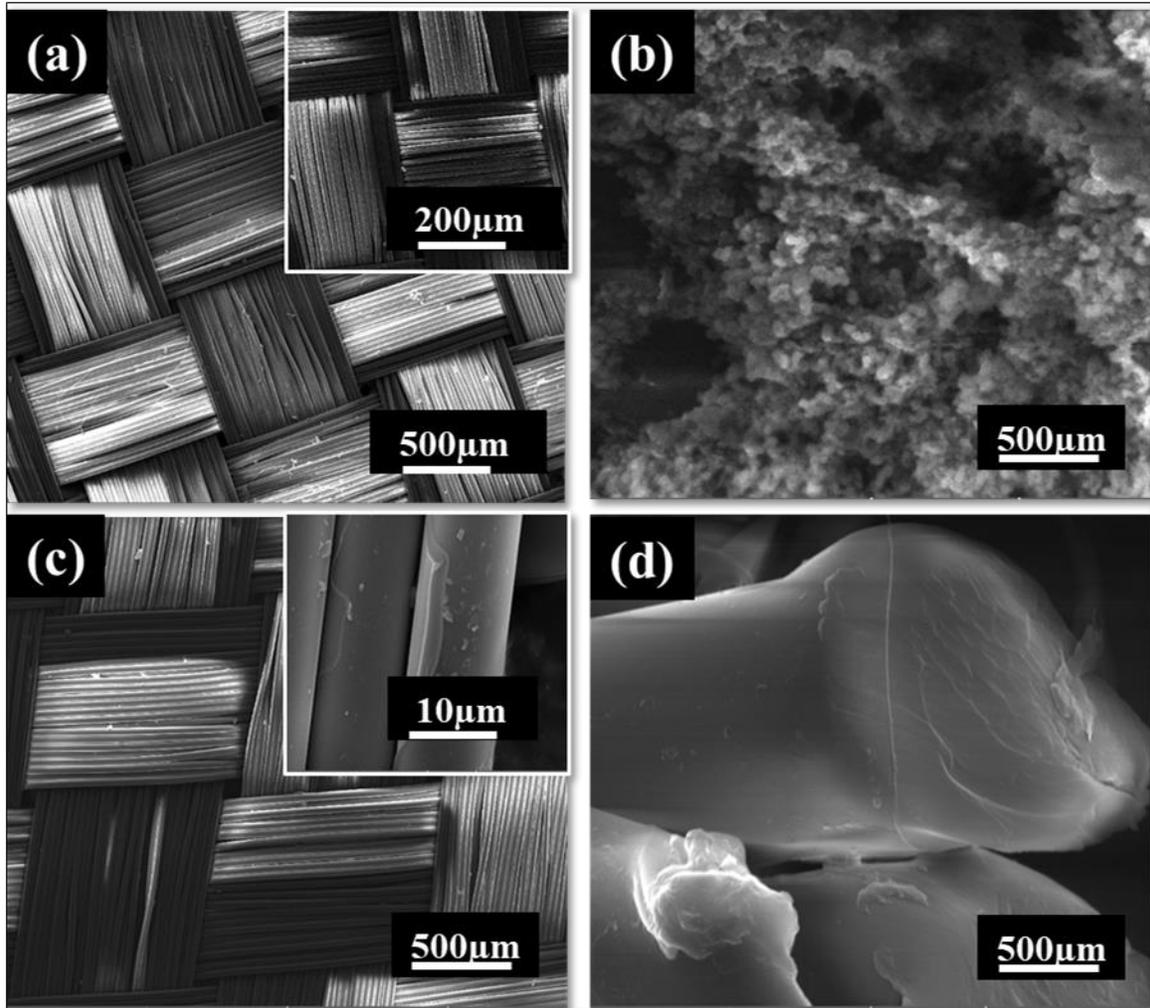


Figure 5-1: SEM images of (a) nylon 66 fabric, (b) nylon 66 fabric coated with PVA/silica nanoparticles, (c) nylon 66 coated fabric with PVA and (d) cross-section morphology of nylon 66 fabric coated with PVA.

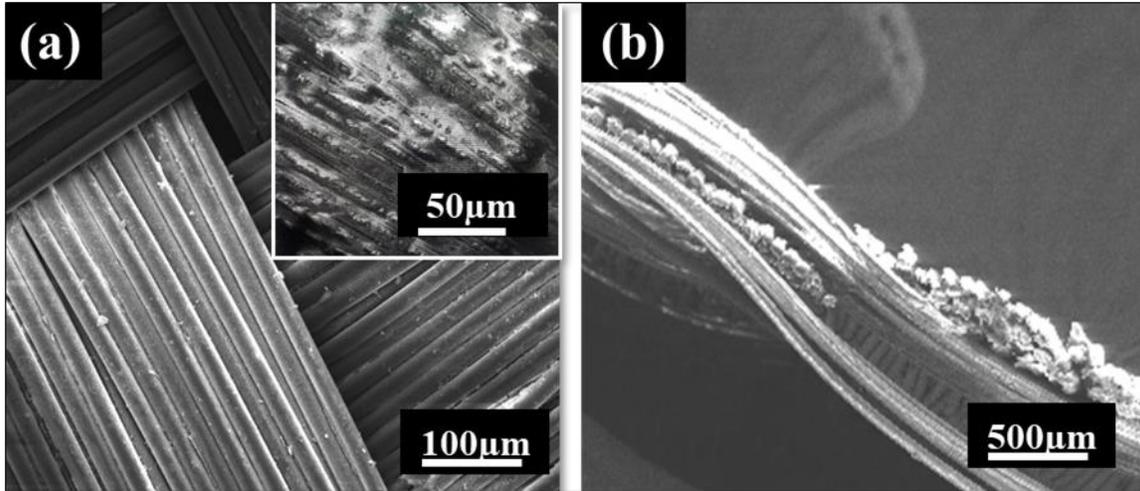


Figure 5-2: (a ,b) SEM and cross-section images explain the joining process between the warp-weft yarn in nylon 66 fabric by PVA/silica nanoparticles.

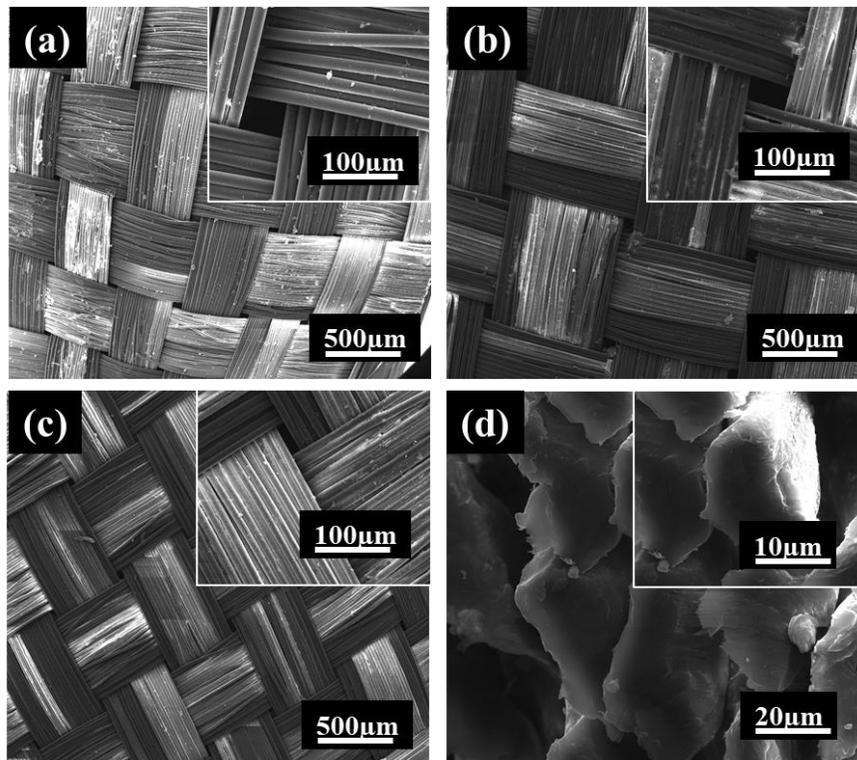


Figure 5-3: SEM magnification images of (a) nylon 66 fabric coated with 0.3wt.% silica, (b) nylon 66 coated with 0.6wt.% silica, (c) nylon 66 fabric coated with 0.9wt.% silica and (d) cross-section morphology of nylon 66 fabric coated with 0.9wt.% silica.

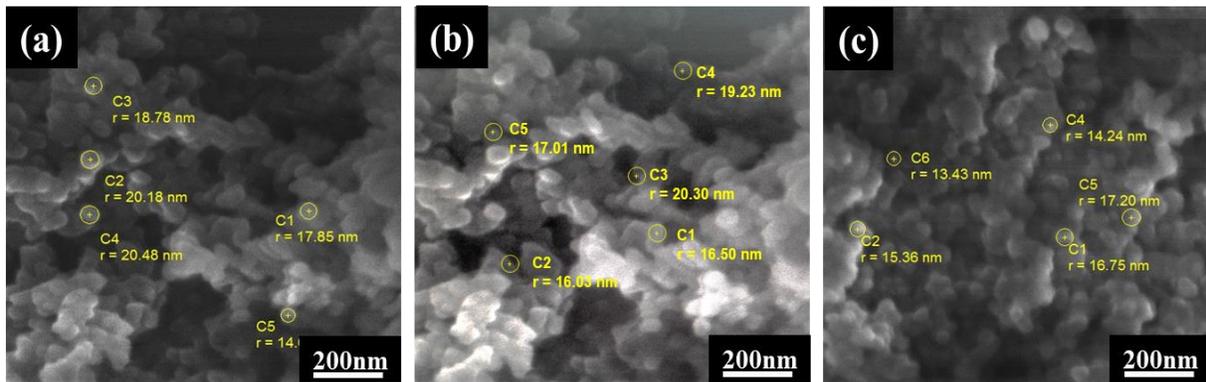


Figure 5-4: SEM images showed the dispersion of silica on the surface of (a) nylon 66 fabric coated with 0.3wt.% silica, (b) nylon 66 fabric coated with 0.6wt.% silica, (c) nylon 66 fabric coated with 0.9wt.% silica. (Fume shape).

5.2 Fourier Transform Infrared Spectroscopy (FT-IR)

The Fourier transform infrared spectroscopy (FT-IR) used to obtain an infrared spectrum. Herein, the FT-IR characterized the functional group of the fabric. FT-IR spectra of nylon 66 fabric, SiO₂ nanoparticles, nylon 66 fabric coated with PVA and nylon 66 fabric coated with PVA/SiO₂ nanoparticles as shown in Figure 5-5. Comparing between pure nylon fabric and fabric coated with PVA/SiO₂ nanoparticles, pure nylon 66 clearly indicate peaks at 1708 cm⁻¹ which are assigned to symmetric (C=N). The SiO₂ nanoparticles curve has peak of 1114cm⁻¹ which indicates presence of Si-O-Si. The peak at 1240 cm⁻¹ which indicate -(C-O)-C-OH in nylon coated with PVA. Finally, nylon 66 fabric coated with PVA/SiO₂ nanoparticles consist of the peaks of nylon 66, SiO₂ and PVA that means sample successfully deposited the coating materials.

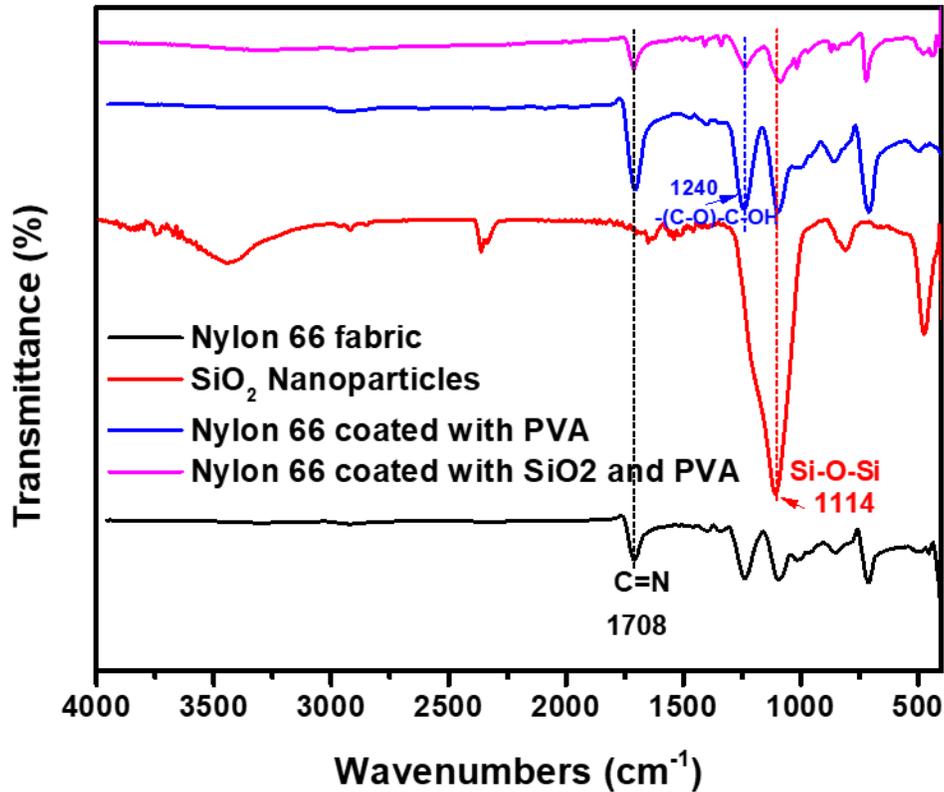


Figure 5-5: Fourier Transform Infrared Spectroscopy (FT-IR) of nylon 66 fabric, SiO_2 nanoparticles, nylon 66 fabric coated with PVA and nylon 66 fabric coated with PVA/ SiO_2 nanoparticles

5.3 Thermal Study

Thermal tests were conducted at coated fabric level using techniques Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA).

5.3.1 Differential Scanning Calorimetry (DSC)

The DSC is a thermal analysis technique that looks at how a material's heat capacity (C_p) is changed by temperature. A sample of known mass is heated or cooled and the changes in its heat capacity are tracked as changes in the heat flow. This allows the detection of transitions like melting, glass transitions, phase changes, and curing. Change in heat capacity is also important in determining the

glass transition of the polymeric fiber (Gaisford et al., 2016). Herein, the nylon 66 fabric coated with PVA/silica nanoparticles Figure 5-6 demonstrated the DSC curve of the nylon 66 fabric, nylon 66 fabric coated with PVA and nylon 66 fabric coated with PVA/SiO₂. The peak is seen to shift the right with the samples from nylon 66 to nylon 66 coated with PVA and nylon 66 coated with PVA/SiO₂ nanoparticles. Nylon 66 fabric coating with PVA improved the thermal properties of the fabric. The main issue of using the silica nanoparticles here is enhancement of thermal insulation and reduce leakage of hot gasses. The shift in the peaks detected in curves is the best indicator of material properties different degrees of polymerization, and physical change by additives (PVA and silica).

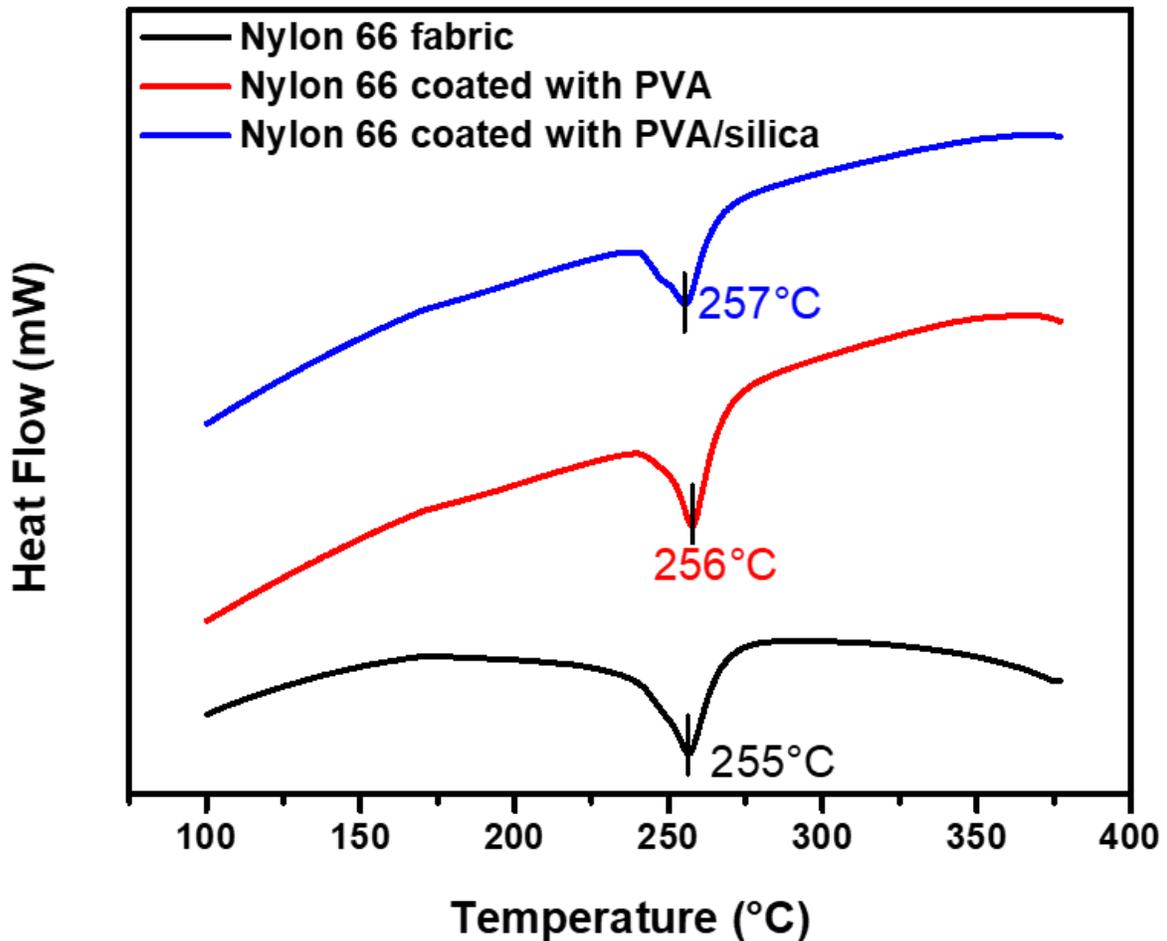


Figure 5-6: DSC heating curves of nylon 66 fabric, nylon 66 fabric coated with PVA and nylon 66 fabric coated with PVA/silica nanoparticles

5.3.2 Thermogravimetric Analysis (TGA)

Thermogravimetric (TG) analysis provide direct and instant evidence of polymer thermal decomposition, composition, and purity. Figure 5-7 presented (TGA) of nylon 66 fabric, nylon 66 fabric coated with PVA and nylon 66 fabric coated with PVA/silica nanoparticles. Plateau from 10°C to 350°C a region of no mass change indicates the thermal stability of nylon 66 fabric, nylon 66 fabric coated with PVA and nylon 66 fabric coated with PVA/silica nanoparticles. Initial temperature (350°C) at which the cumulative mass change reaches magnitude that the

thermobalance can be detected. final temperature(500°C) at which the cumulative mass change reaches a maximum. Thermal stability of the samples which are gradually thermal stabilized (9.5, 15.9 and 17.6wt.%) respectively.

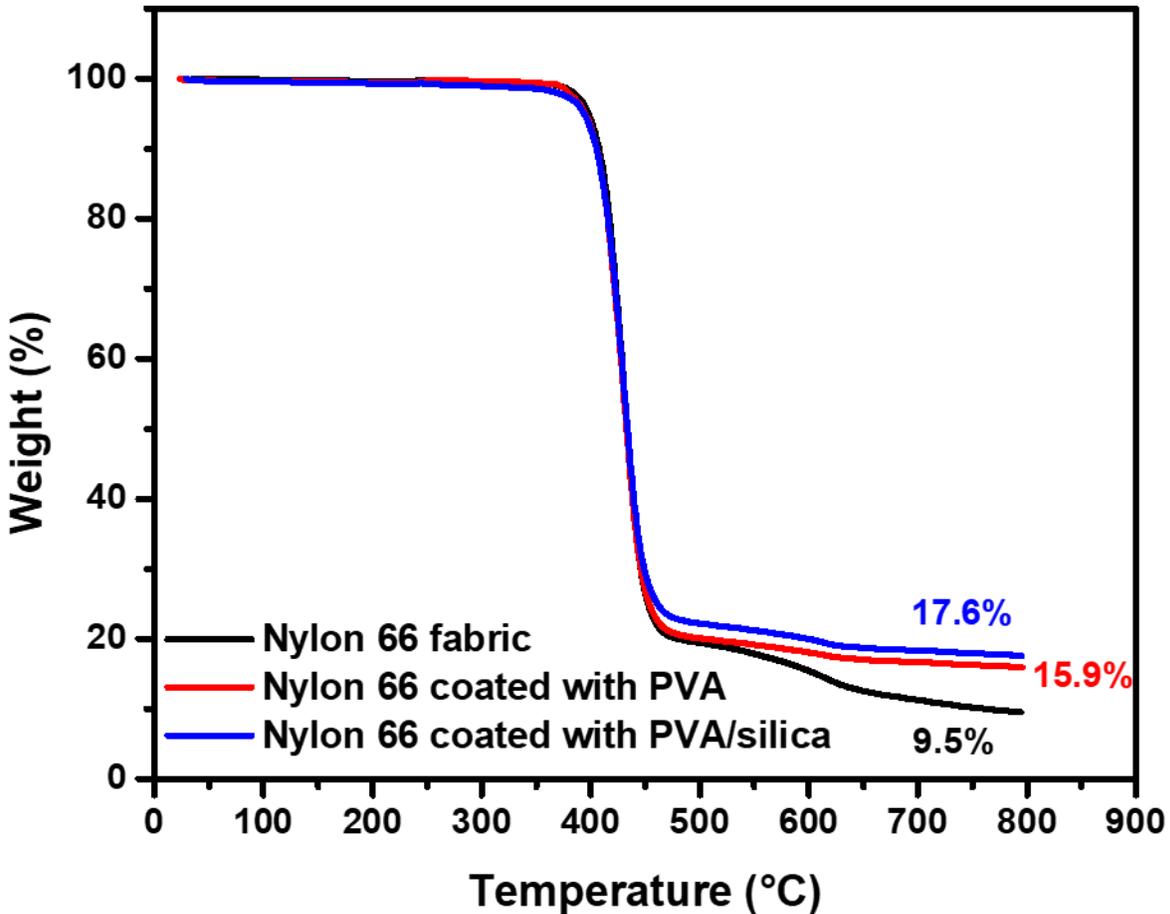


Figure 5-7: TGA nylon 66 fabric, nylon 66 fabric coated with PVA and nylon 66 fabric coated with PVA and different concentrations of silica nanoparticles.

5.4 Tensile strength

Figure 5-8 stress-strain showing curves of nylon 66 fabric, nylon 66 coated with PVA and nylon 66 coated with PVA/silica nanoparticles. Figure 5-8 showing the stress-strain curves of nylon 66 fabric, nylon 66 fabric coated with PVA and nylon 66 fabric coated with PVA and different concentrations of silica nanoparticles. In

this characterization instrument, it is observed that stress of nylon 66 coated with PVA and nylon 66 coated with PVA/silica nanoparticles have been increased and also observing significant amount of elastic deformation. Nylon 66 coated with PVA/silica nanoparticles showing higher Young's moduli. A degree of freedom at which the warp and the weft move is limited to restrain the yarn even between each fiber in the single yarn, and the whole yarn is broken at a time at an ordinary tensile test of a base fabric. due to gentle bonding between the warp/weft yarn resulting from the adhering material (PVA) and filling material. The Figure 5-8 showing the stress is gradually increased according to increase of silica nanoparticle amount as a coating material. Tensile strength for nylon 66 coated with (PVA) /silica (0.9wt.%) according to commercial guidelines airbag FMVSS (Houraiya, 2018).

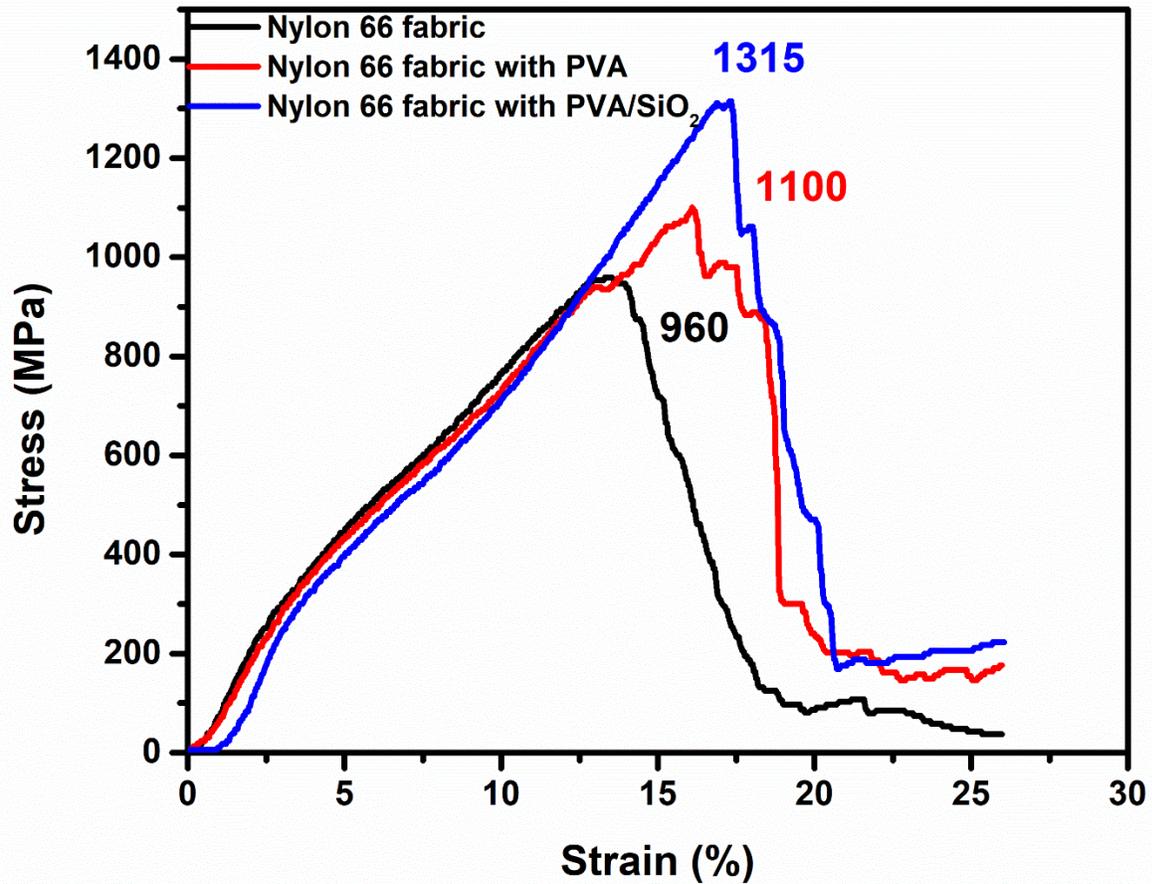


Figure 5-8: Stress-strain curves of nylon 66 fabric, nylon 66 fabric coated with PVA and nylon 66 fabric coated with PVA and different concentrations of silica nanoparticles.

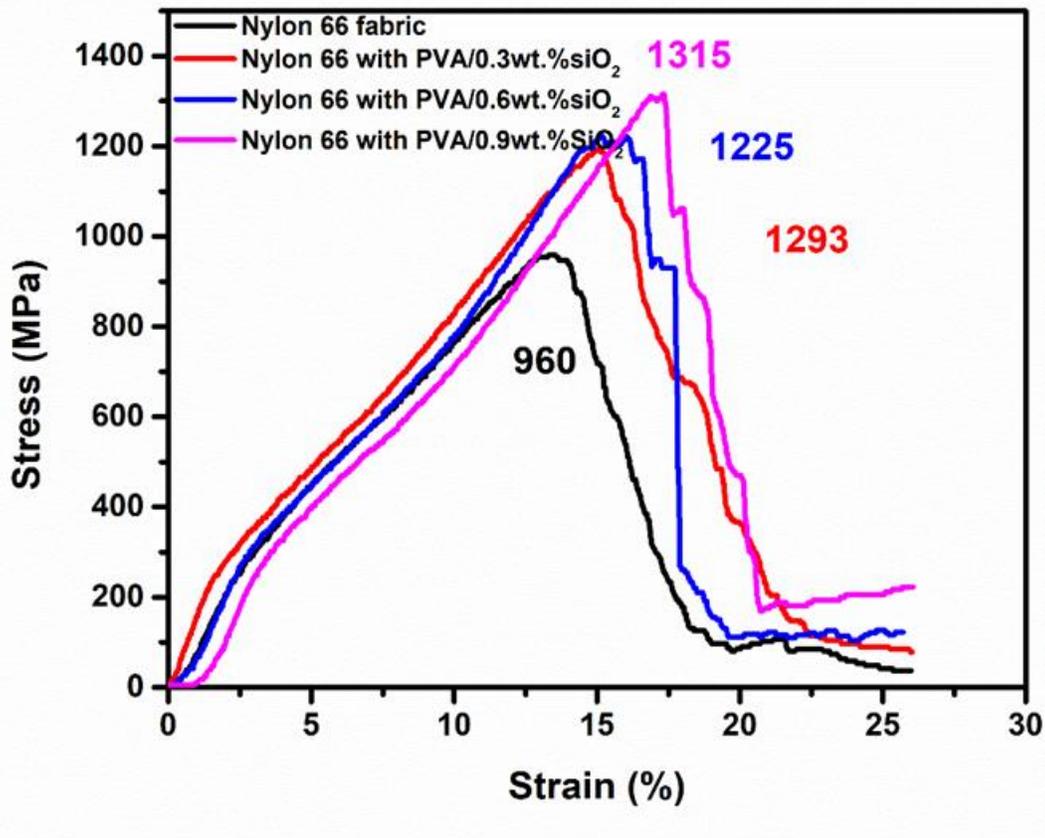


Figure 5-9: Stress-strain curves of nylon 66 fabric and nylon 66 coated with (0.3wt.% PVA and different concentrations of silica nanoparticles (0.3wt.%, 0.6wt.% and 0.9wt.%)).

5.5 Water contact angle (WCA)

When water beads are into distinct droplets it is a demonstration of hydrophobic properties, when the contact angle, greater than the range of 90°- 120° they are designated as hydrophobic, Super-hydrophobic 150° (Zhao and Jiang, 2018). Results in Table 5-3 and Figure 5-9 showing water contact angles of (a) nylon 66 fabric, (b) nylon 66 fabric coated with PVA and (c) nylon 66 fabric coated with PVA/Silica nanoparticles. As in the water contact angle results in the Figure 5-9 (a,b,c), Figure 5-9 (a) with low water contact angle which designate to uncoated

nylon 66 fabric. The nylon 66 coated with PVA (Figure 5-9 (b)) with water contact angle of 73° showing to improvement the sample capillary because of good properties of coated material (PVA). Herein, the PVA used in this work as stabilizer materials to improve the distribution of the silica and avoid the silica aggregation during the coating process, beside adhering to silica on the surface of the nylon 66. Finally, the nylon 66 coated with PVA/silica nanoparticles gave water contact angle of 131° showed a respectable capillary compared with the previous two samples owing to the silica which was used in the coating process in the nano-size. Additionally, the smaller size of the silica enhancing by the increaseing the surface area of nylon 66 fabric. It is found that PVA/silica nanoparticles coated on the surface filing the gap between the warp and weft yarns and even between single fibers in nylon 66 fabric, this is a better indicator of reduction of air permeability of the fabric and reduction of leakage of airbag fabric. Table 5-3 shows the water contact angles of these samples.

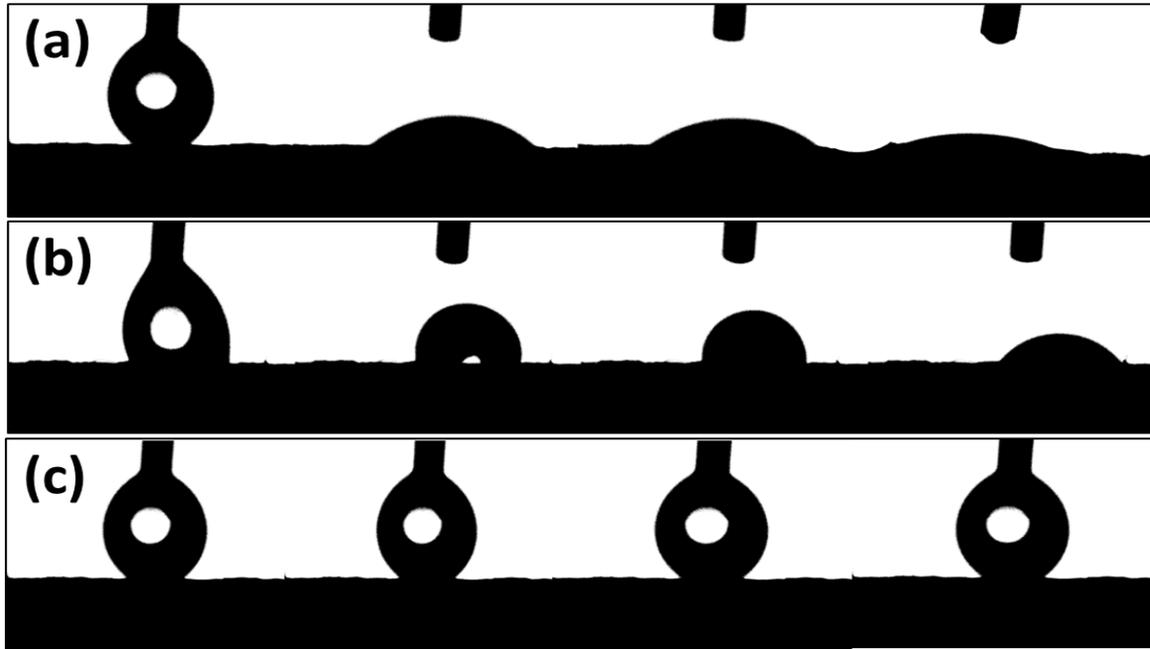


Figure 5-10: (a) Water contact angles of nylon 66 fabric, (b) nylon 66 coated with PVA and (c) nylon 66 coated with PVA/Silica nanoparticles.

Table 5-3: Water contact angles of nylon 66 fabric, nylon 66 coated with PVA and nylon 66 coated with PVA/Silica nanoparticles.

Sample	Water contact angle
Nylon 66 fabric	13°
Nylon 66 coated with PVA	73°
Nylon 66 coated with PVA/Silica nanoparticles	131°

5.6 Airpermeability

The air permeability of nylon 66 fabric has decreased due to two effective factors such as coated material (PVA) as adhering material and (silica nanoparticles) as filling material. The air permeability decreased by increasing the amount of silica

nanoparticles in the composite as presented in Table 5-4.

Table 5-4: Air permeability of nylon 66 fabric, nylon 66 coated with PVA and nylon 66 coated with PVA/Silica nanoparticles.

Sample	Air permeability CFM
Nylon 66 fabric	51
Nylon 66 with 0.3wt.% PVA	35
Nylon 66 with 0.3wt.% PVA/0.3wt.% Silica nanoparticles	27
Nylon 66 with 0.3wt.% PVA/0.6wt.% Silica nanoparticles	26
Nylon 66 with 0.3wt.% PVA/0.9wt.% Silica nanoparticles	25

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions:

In conclusion, nylon 66 airbag fabric has successfully coated with PVA/silica nanoparticles. Nylon 66 fabric coated with PVA and nylon 66 fabric coated with 0.3wt.%PVA and different concentration of SiO₂ (0.3, 0.6 and 0.9wt.%). the higher concentration sample (0.9wt.%) has thin layer (0.009mm) and the final dry weight of the coating(PVA/SiO₂) 0.4 gram per square meter.

The fabrics were characterized by different instruments such as scanning electron microscopy (SEM), Fourier Transform Infrared (FT-IR) spectroscopy , Differential Scanning Calorimeter (DSC), Thermogravimetric Analysis (TGA), Water Contact Angle (WCA) tensile strength tester and air permeability.

The (SEM) showed surface topography and (FT-IR) characterized the functional group of nylon 66 fabric coated with PVA and nylon 66 fabric coated with 0.3wt.%PVA and different concentration of SiO₂ (0.3, 0.6 and 0.9wt.%). (FTIR) The DSC confirmed that the shift in the peaks which detected in the curves is the best indicator of material properties and different degrees of polymerization, and physical change by additives (PVA/ SiO₂). The sample with higher concentration of silica nanoparticles as coated material is thermally stabilized reached 17.6wt.%. The sample of nylon 66 coated with PVA/SiO₂ nanoparticles established the hydrophobicity properties with water contact angle of 131° and its air permeability also has been enhanced by decreasing from 51CFN to 25CFM.

Finally, the thickness of nylon 66 airbag fabric coated with PVA/SiO₂ nanoparticles has a thin layer which helps in folding the airbag in small package

size. The thin layer from PVA/ SiO₂ improve the thermal insulation and reduce leakage of hot gasses to avoid the injuries.

6.2. Recommendations:

- Fabrication of airbag fabric coated with smart coatings by using nanotechnology.
- Control of the influencing factors during manufacturing .
- Improvements in sensing, propellant type, airbag designs and technology of deployment can avoid injuries, and improving airbag's effectiveness in saving lives .
- Future research should focus on recyclability of airbags to meet demanding environmental specifications.

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