Plant Fibers: The Next Generation of Environmentally Friendly Automobiles.

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Abstract— Automobile companies employed the use of biodegradable materials such as nonwoven hemp fibers in the manufacture of its cars. Nonwoven hemp fibers are renewable, cheap, light weight and thus can reduce fuel consumption in automobiles, thereby reducing the amount of CO_2 emitted into the environment. At the end of its life cycle, car components manufactured from these nonwoven hemp fibers can be biodegraded. Hence, this study investigated the length of time it took these fibers to degrade. The rate of degradation of the fiber was analyzed by soil burial test and the changes in tensile strength loss of the fiber over weeks of burial were analyzed by using a Hounsfield Tensometer. The results revealed a significant loss in the mean tensile strength of Dry non –woven Hemp Fiber [DHF], Moist nonwoven Hemp Fiber [MHF], Dry untreated Cotton calico [DC] and Moist untreated Cotton calico [MC]. The DHF had an initial mean tensile strength loss of 31.8KN while MHF had 30.09KN at the first week. At the end of the 6th week, this was significantly reduced to 0.14KN [99.68% was degraded] and 0.08KN [99.74% was degraded] for DHF and MHF respectively. The mean tensile strength for DC and MC reduced significantly from 14.82KN and 16.46KN respectively to 0.05KN [99.66% of dry cotton was degraded] and 0.1KN [99.39% of moist cotton was degraded] after 12days. The analysis of the results using a student's t-test at 95% confidence interval revealed that there is a significant difference between the mean experimental values and the control. If all the conditions necessary for biodegradation of a material are present, the degradation of hemp fiber will occur at six weeks. Therefore, it can be concluded that the use of hemp fiber in the manufacture of vehicular components can not only help to reduce emission of CO_2 [reduced fuel consumption due its lightweight nature] but can be effectively biodegraded at the end of its lifecycle.

Index Terms— Automobiles, Biodegradation, Hemp fiber, Lightweight, Plant fibers, Soil burial test,Tensile Strength Loss

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1 INTRODUCTION

OVER the past century, there has been an increase in the earth's atmospheric temperature by 0.6 ± 0.2 °C. This change is mainly caused by increased carbon dioxide [CO_2] and other human-made emissions into the atmosphere [1]. Global warming occurs when carbon dioxide [CO_2] and other air pollutants and greenhouse gases collect in the atmosphere and absorb sunlight and solar radiation that have bounced off the earth's surface. Normally, this heat radiation would escape into space but these pollutants, which can last for years to centuries in the atmosphere, trap the heat and cause the planet to get warmer[2]. This results in an increase in sea level, flooding, warming of the oceans, elevated global temperatures, drought, declining artic sea ice and extreme weather conditions [3]. The major source of greenhouse gas emission is the combustion of fossil fuels from our power plants, automobiles, homes and industries. According to [4] the transportation sector alone generates about 1.7 billion tons of CO_2 emissions a year.

In order to minimize this environmental pollution from the transportation sector, the European Union [EU] and other developed countries have enacted laws and regulations on the production and disposal of automobiles with the aim of reducing the amount Co_2 emitted into atmosphere [5]. In addition, scientists have developed alternatives to the use of fossil fuels in automobiles. These alternatives such as; hybrid cars, biofuels and electric vehicles aim to reduce carbon emissions and fuel consumption. Further research are also been carried out to increase the battery capacity of these hybrid and electric vehicle thus leading to an increase in mileage [5]. However, one of the disadvantages of fossil fuel alternative car is that the car is very heavy due battery weight and body structure and this ultimately reduces the vehicle mileage. According to [6], the weight of the vehicle is an important factor in how much fuel or battery it will consume. The heavier the automobile, the more energy it will require to move thus increasing the fuel/battery consumption.

Similarly, government policies and market pressure on the use of sustainable materials has triggered automobile manufacturers such as Bavarian Motor Works [BMW] to examine the environmental impacts of their products throughout its life cycle [i.e from its production to the final stage of disposal [7]. This process begins with the development of fuel efficient and lightweight vehicles that are relatively cheap environmentally friendly and safe drivers as well as commuters. Furthermore, the disposal of End of vehicles [ELVs] made from non-renewable raw materials have resulted in various environmental issues and thus have impelled the automobile industry to produce cars made from sustainable materials which can lower fuel/energy consumption. This strategy involves the use of green materials such as natural fibers which helps to reduce environmental issues such as landfill and groundwater contamination which may result from the disposal of ELVs [7].

Natural fibers are bio-based fibers that originate from vegetables, mineral and animals, which be spun into yarns, rope or thread [8]. They can be classified according to their plants, animals and minerals origins. Plant fibers are made up of cellulose whereas animal fibers for example; wool, silk and hair are composed of proteins such as collagen and keratin [8]. Examples of plant fibers are; Hemp fibers, flax, Jute, sisal. The nonwoven plant fiber can be utilized as both reinforcement and fillers for automobile vehicles [9].

The history of plant fibers in the automobile industry can be traced back to the 1930s when Henry Ford analyzed an array of plant species such as carrots, cornstalks, and onions in the hope of finding a suitable material for the development of an organic automobile body [10],[11]. He created a prototype of the organic car body made from hemp fiber, however due to economic constraints; mass production of the car was not successful. Subsequently, the interest in the use of plant fibers declined until late 1940's when ford scientists discovered that soybean oil could be molded to make fiber based plastic and good quality paint enamel [10],[11]. The result of the research revealed that soybean oil had approximately 10 times more shock resistance than steel [10], [11].

Over the next few years, natural fibers were used to make seats, bearings, fuselage for aircrafts and ships [9], [10].The breakthrough for the development of a vehicle made from plant fiber came in the late 1950s. The East German Trabant car was the first automobile to be developed from plant fibers; the car was made from cotton embedded in a polyester matrix [13].The first application of plant fiber in commercial automobiles was developed in the 1990s by Diamler-Chrysler [14], [10]. Coconut fibers were combined with latex and used to make backrests, head restraints and sun visors, this application demonstrated the process by which non-food crops can be employed in the automobile industry [14],[10]. Similarly, due to the emergence of stricter environmental legislation on the disposal of ELVs, there has been an increase in the use natural fibers in automotive application. Presently, majority of automobile manufacturers such as BMW, Ford, Opel, Mercedes and Daimler-Chrysler use plant fibers in the manufacture of cars.

The nonwoven plant fiber can be utilized as both reinforcement and fillers for automobile vehicles [9].For an average automobile vehicle approximately 1.2-1.8kg of plant fibers are used to make front door liner, 0.8-1.5kg for rear door liners, 1.5-2.5kg for boot liners and 2.0kg for parcel door shelves [9].Similarly, approximately 2.5 kg of fibers are used for headliners and 0.4kg for sun roof sliders per car [9],[10]. Since the 1990's approximately 24kg of plant fibers were used as components of BMW 3, 5 and 7 series models [7],[10]. In 2001, approximately 4000 tonnes of natural fibers comprising 80% flax and 20% sisal were used in BMW 3 series alone [10]. In addition, wood fibers are used as components of seatback and also, cotton fibers are employed as materials in sound proofing [7],[10]. In Germany and Austria, approximately 21,000 tonnes of hemp fiber were used in the automobile industry between 1999 and 2000 [15].

BMW currently uses 80:20 flax/sisal for improved performance and strength [10]. Other types of nonwoven fibers or felt used in this industry includes jute, hemp or flax bonded with polypropylene which acts as a binder to form thermoplastic composite and LoPreFin which consists of kenaf fiber mixed with Polypropylene [10]. Nonwoven plant fibers are also utilized by other automobile manufacturers for various applications such as; seat backs, headliners, door panels and boot linings [14].

Natural plant fibers such as hemp fiber used in BMW car component can only be biodegraded at the end of their life cycle. This research will therefore investigate the length of time required for the biodegradation of nonwoven hemp fiber found in BMW cars. It will also compare the rates of degradation between moist and dry nonwoven hemp fiber.

2 MATERIALS AND METHOD

2.1 Materials

Nonwoven Hemp Fiber

The material is found in boot linings, noise insulation panels, seat backs, headliner panels, door panels of BMW 3, 5, 7 Series. The fiber was cut into strips measuring 20cm long and 3cm wide.

Untreated Cotton Calico

This serves as a control and it is also used to compare the rate of degradation between moist and dry nonwoven hemp fiber.

Soil Compost and Poultry Manure

The three types of commercial soil used in this experiment, namely; new horizon organic and peat free multi-purpose compost, garden compost, and poultry manure. These commercial soils are used to increase the organic matter, moisture content, microbial activity and nutrients of the compost bed [16] .

In the preparation of compost soil, twenty trowels of multi-purpose organic and peat free were mixed with three trowels of garden compost and half trowel of organic pelleted poultry manure. The Poultry manure was added to the soil to increase the carbon/nitrogen (C/N) ratio thus improving microbial activity.

Warm Experiment Box

The box used in this experiment is a multi-compartment warm experiment box made of aluminum sheet. It comprises of four sections which are bolted together with aluminum nuts and bolts. It is made of aluminum because other metals, such as iron would corrode more easily when it comes in contact with the soil. The box consists of a soil heating cable which passes through all the compartments of the box and a thermostat that helps to regulate the temperature of the compost bed and creates a favorable condition for microbial activity. The soil heating cable is laid on a bed of gravel and sharp sand. In addition, the box has a water reservoir fitted with capillary matting which is located at the edge of the box. This capillary matting supplies moisture to the soil bed and this is required for biodegradation to occur. The lid of the box is made up of a wooden framework with a perspex top which helps to reduce evaporation.

2.2 Experimental Procedure

Soil burial test and tensile strength loss are the methods used in carrying out this research. Hounsfield tensometer is used to measure tensile strength loss of strip.Tensile strength loss test is a method used to determine the biodegradability by measuring the tensile strength loss of the test strips buried in soil compost[18]. For this experiment, the tensile load at break is the maximum force required to break the test strip [18]. This experimental procedure is based on studies carried out by [17], [19], [20] & [21].

2.3 First Experiment

The nonwoven hemp fiber and untreated cotton calico was cut into strips. For this experiment, a total of 160 test strips containing 80 nonwoven hemp strips and 80 untreated cotton calico strips were used and buried at once in the warm experiment box [17]. 24 controls strips each of nonwoven hemp and untreated cotton calico were cut with the same measurement as the experimental strips but they were not buried.

The test strips were buried half way through the soil and approximately 2 cm of each of the strip was left protruding above the soil surface. The duration of the experiment was nine weeks and during that period ten test strips were unburied every three weeks. The unburied test strips were wrapped and frozen to stop further microbial activity. Hounsfield tensometer was used to measure tensile strength loss of strip

2.4 Second Experiment

The setup of this experiment was modified as four additional water reservoirs were added to the warm experiment box. A total of 320 strips were buried in the experiment box comprising 80 strips of [MHF] and 80 strips of [DHF] as well as 80 strips of moist [MC] and 80 strips of dry untreated cotton calico [DC]. 24 control strips each of nonwoven hemp fiber and untreated cotton calico were not buried however they were used as a control to compare the speed of degradation of both test samples.

The test strips were all buried at once in the warm experiment box [17].The experiment was conducted for a period of six weeks and within that period ten strips each of dry and moist hemp fiber where unburied every week while ten strips each of moist and dry untreated cotton calico were unburied every two days. Subsequently, the unburied strips were wrapped in a foil and frozen to stop microbial activity. These were later evaluated using tensometer to measure the changes in tensile strength loss of the strip.

3 RESULTS

Soil burial test method was used to investigate the biodegradation of non- woven hemp fiber. The biodegradability of the fiber was evaluated by measuring the changes in tensile strength loss of strip over weeks of burial. As mentioned earlier, two experiments were carried out, the results are as follows

3.1 First Experiment

The maximum force in Newtons required to break the strips was obtained from the tensometer and used in calculating the tensile strength loss. The summary of the mean values of the tensile strength loss of the test and control samples are shown in Table 1 and Fig. 1

Table 1: Mean values of the tensile strength loss of test and control strips

Sample	3 weeks	6weeks	9weeks
Non- woven Hemp fiber [HF]	7.85KN	2.26KN	1.54KN
Control	41.6KN	45.6KN	49.37KN
Untreated Cotton Calico [CC]	-	-	-
Control	14.16	-	-

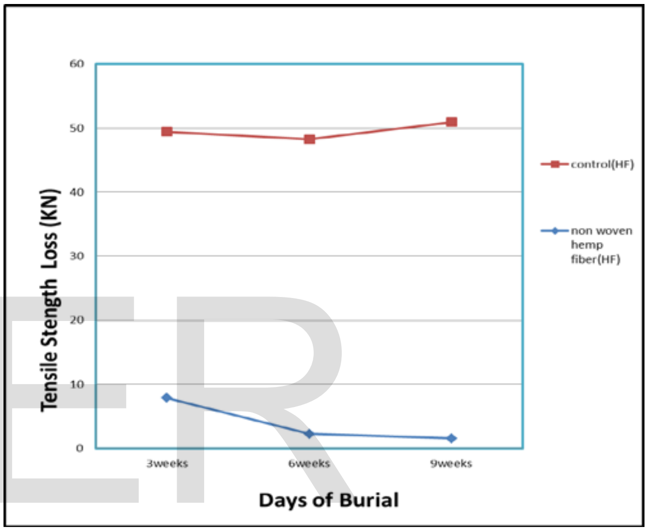

Fig. 1: The Changes in tensile strength loss of nonwoven hemp strips over nine weeks of burial

The results of the experiment [Table 1], [Fig. 1] revealed that after three weeks of covering/burial the tensile strength loss of the fiber was 7.85KN and at the ninth week it reduced further to 1.54KN. This indicates that at the end of nine weeks, 80.13% of nonwoven hemp fiber was degraded. Similarly, the untreated cotton calico degraded before the three week mark set for the uncovering of strips hence no results for weeks 3, 6 and 9. The results were analyzed using a student t-test, and it revealed that there is significant difference at 95% confidence level between the rate of degradation between the nonwoven hemp fiber and the control.

3.2 Second Experiment

The strips of dry and moist nonwoven hemp fiber as well as strips of moist and dry cotton calico were analyzed to determine compare the rate of degradation between the test samples. The results of the tensile strength loss of the two test samples are shown in the tables 2 and 3;

Table 2: Mean values of tensile strength loss of moist and dry non- woven hemp fiber

Sample	0 week	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks
Control [KN]	43.66	44.6	45.57	51.67	61.68	55.15	49.16
Dry hemp fiber [KN]	43.54	31.8	15.79	5.54	3.34	0.15	0.14
Moist hemp [KN]	31.00	30.09	14.64	5.12	2.78	0.1	0.08

Table3: Mean values of tensile strength loss of moist and dry untreated cotton calico

Sample	2 days	4 days	6 days	8 days	10 days	12 days
Dry Cotton [KN]	14.82	4.4	0.82	0.2	0.17	0.05
Moist Cotton[KN]	16.46	5.62	0.85	0.26	0.08	0.1
Control [KN]	17	15.5	15.98	15.04	16.58	16.08

It was observed during the first experiment that the test strips buried close to the water reservoir degraded faster than strips buried further away from it. This indicates that moisture was a limiting factor in the first experiment hence the modification of the second experiment with the addition of four water reservoirs.

The result from the second experiment revealed that nonwoven fiber degraded in six weeks [Table 2], [Fig. 2]. At the end of week six, 99.68% of dry hemp nonwoven fiber and 99.74% of Moist Nonwoven Hemp fiber was degraded. Similarly, untreated cotton calico degraded in 12 days [Table 3], [Fig. 3]. In addition, at the end of day twelve, 99.66% of dry cotton was degraded while 99.39% of moist cotton was degraded. The analysis of results using a student's t-test revealed that there is a significant difference at a 95% confidence level between strips of moist untreated cotton calico and the control as well as between the dry untreated cotton calico and control. However, there is no statistical difference at a 95 % confidence level between the moist and dry nonwoven hemp strips.

4 DISCUSSION

4.1 Comparison of the Rate of Degradation between Moist and Dry Nonwoven Hemp Fiber

The gradual reduction in the tensile strength loss of the hemp and cotton strips over weeks of burial can be attributed to the microbial degradation of highly crystalline cellulose polymer present in the lignocellulose fiber [22]. According to [23], the chemical structure of the polymer is the main factor that determines the degradability of the polymer and how long it will take to degrade. This finding can be used to explain the reason for the slow degradation of nonwoven hemp fiber as compared to untreated cotton material.

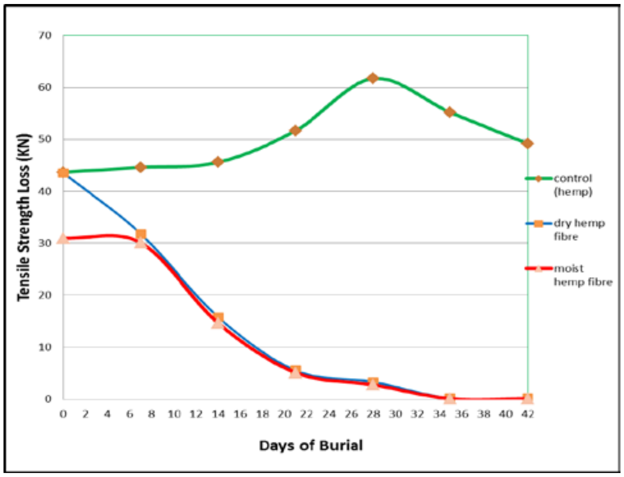

Fig. 2: The changes in tensile strength loss of dry and moist nonwoven hemp strips over six weeks or 42days of burial

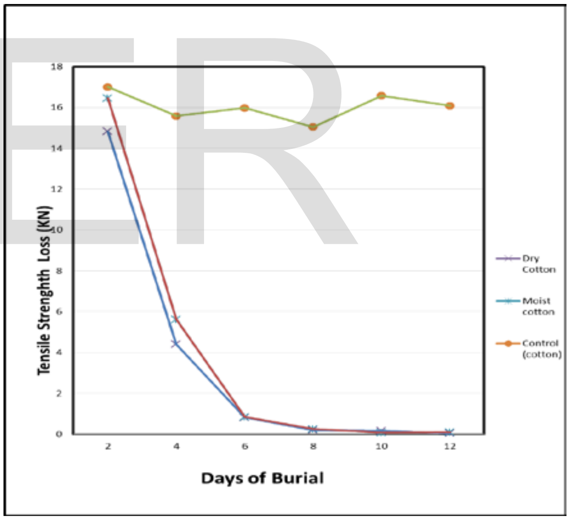

Fig. 3: The changes in tensile strength loss of dry and moist untreated cotton strips over twelve days of burial

The chemical structure of hemp fiber is well organized and highly crystalline. This highly crystalline nature is as a result of the 68.1% of cellulose present in the fiber cell wall [24] .The high cellulose content makes the material less susceptible to hydrolysis reactions and limits microorganisms access to water thus reducing microbial activity and rate of degradation [23].The fast degradation of cotton may be attributed to the presence of more amorphous cellulose regions within the polymer. These regions are pliable and easily accessible to microbes and moisture thereby increasing rate of polymer degradation [25].

The result of the experiment was analyzed using a t-test and it revealed that there is no significant difference at a 95%

confidence level between the rates of degradation of moist and dry nonwoven hemp fiber as well as between moist and dry untreated cotton calico. Similarly, [26] analyzed the water absorption and tensile properties of soil buried Kenaf Fiber Reinforced Unsaturated Polymer Composites [KFRUPC]. The result of this research reveals that the there is no significant difference in mechanical properties of degradation of KFRUPC after absorption of moisture. KFRUPC is a composite material which contains a mixture of Kenaf bast fiber and an unsaturated polymer that is resistant to microbial degradation [26]

Therefore, it is suggested that the absence of significant difference between moist and dry test samples may be due to fact that the soil compost was well saturated therefore microbial action on the strips of moist and dry test samples did not have any significant effect on the rates of degradation of both sample.

4.2 EFFECT OF MOISTURE ON THE RATE OF DEGRADATION

The result of the first experiment [Fig. 1] revealed that the degradation of nonwoven hemp fiber occurred at nine weeks. It was visually observed that strips nonwoven hemp fiber buried close to the water reservoir degraded faster than those buried farther away from the water reservoir. Thus, it is evident that moisture was a limiting factor in the first experiment.

The strips of nonwoven fiber degraded faster in the second experiment due to the addition of four water reservoirs which elevated the moisture content of the soil compost thereby increasing the rate of degradation. According to [25], moisture is one of the factors that can affect the hydrolysis and rate of degradation of a polymer material. Moisture enhances hydrolysis reactions and rate of polymer degradation by increasing the availability of sites for microbial action [25], [27].

In addition other abiotic factors such as temperature, moisture, soil pH can influence the rate of hydrolysis and biodegradation of a polymer chain [25] .These factors are very important and their absence can stall the degradation process [27]. In order to increase the rate of degradation of the material, three types of compost, namely organic and peat free multipurpose compost, garden compost and poultry manure were used. The soil compost helps to improve soil nutrients, organic matter, C/N ratio and water holding capacity, thus creating a suitable environment for microorganisms to rapidly degrade the material [16]. The temperature of the box was kept constant at 20^{o}C throughout the duration of the experiment thereby creating a favorable condition for microbial activity.

5 CONCLUSION

The disposal of ELVs in landfills is associated with a number of environmental issues, such as the rise in waste disposal, and contamination of surface and groundwater Environmental legislations such as the European Union ELVs Directives and EU Directive on the landfill of waste were enacted to minimize the use of non- biodegradable materials in the manufacture of cars so as to reduce the quantity of ELVs disposed into landfills. Based on this, the following conclusions can be drawn from the study.

Firstly, the result of this research supports the finding that nonwoven hemp fibers are biodegradable. It also proves that the fiber degrades in six weeks while untreated cotton degrades in twelve days. The strips of nonwoven hemp fiber degraded faster in the second experiment due to increase in moisture content. Moisture is one of the factors that can affect the hydrolysis and rate of degradation of a polymer material.
Finally, the use of biodegradable nonwoven hemp fiber in the manufacture of light weight vehicles can impact positively on climate change not only in reduction of CO_2 emission during the use of the car but also as ELV in disposal of the components. Little or no amount of CO2 is released into the environment as the car components are not combusted but rather degraded in the soil and completely harmless.

It is therefore suggested and advised that BMW and indeed other car manufacturers should not restrict the use of nonwoven hemp fibers to countries within the EU /developed countries, where a directive regulating the disposal of ELVs into landfills is in place. The use of these biodegradable materials in cars should also be encouraged in third world countries such as where there is no legislation guiding the disposal of ELVs.

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