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Application of Epoxy Resin and Glass Fiber Composites in Cricket Bats

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ABSTRACT

The sports industry predominantly makes use of wood for manufacturing equipment such as cricket bats. However, the equipment has to be replaced often as it gets worn out and damaged. This has led to increased wood consumption, which is rapidly becoming scarce, contributing to environmental issues. The objective of this work is to provide a protective composite layer on the face of the bat to enhance its life without affecting its performance. This work also aims to find a solution to reduce the wood consumption in the cricket industry in the form of a protective composite layer. The layers on the bats are prepared using two different resins, namely HSC 7600 and General Purpose resin with 400 GSM glass fibers as the reinforcement. The specimens are prepared using the hand-layup process and then cured in the oven. The composite materials are then subjected to tensile tests and impact tests. Properties such as Young's modulus and impact stress are obtained. When compared with willow wood, the specimens prepared using HSC 7600 exhibit similar properties and can be used in practical applications. The layer once applied on the bat, is subsequently tested under traditional match-like conditions wherein more than 2000 shots are played with a standard leather ball. Regular willow bats are tested similarly, and cracks begin to appear after approximately 1700 shots. Testing of the bats that are reinforced with the composite layer shows that the layer is intact with negligible damages. It is concluded that this material is more resistant to the impact of the ball and also does not provide the batsman with an unfair advantage. With proper implementation, the application of such a layer is a promising solution to be put to use in the cricket industry that tackles the challenge of excess wood consumption.

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Introduction

Willow wood is the predominant material used for making cricket bats. Generally, bats incorporate a wooden spring design where the handle meets the blade. Today's bats have a design of a cane handle spliced into a willow blade through a tapered splice. The game of cricket has been governed by a series of Codes of Laws for over 270 years. The Marylebone Cricket Club (MCC) is the authority that decides the laws of the game [1]. Law 5 of the Laws of Cricket states the dimensions that the bat should have.

English willow is generally used at the professional international levels, whereas at the lower levels of cricket, such as state or domestic tournaments, Kashmiri willow is used as a substitute. Predominantly found in the Kashmir valley of India, this type of willow is slightly harder than the English Willow due to different grain structures and also different climatic conditions. English willow takes around 15 years to harvest and has a medium grain that is desirable [2]. It is soft but durable at the same time. It reacts remarkably well to the impact of the ball and is resistant to splitting and tearing over time compared to its Kashmiri counterpart.

Over the course of a year, a large number of willow trees are felled to produce the starting material for these bats. Willow trees require around 15 years to mature before they can be used to produce optimal quality bats. The trunk of the tree is sawn and split into sections called clefts. One cleft can produce a single bat blade. A single willow tree can yield 30 to 40 internationally accepted clefts [3].

The global market demand for cricket bats is more than 4 million units [4]. The number of trees that are cut annually for this cause amounts to a figure of at least 1.1 lakh. Clearly, this will have a damaging impact on the environment. The rise in global warming has also led to a change in the moisture content in wood. A Jalandhar-based bat manufacturing company found that when moisture content drops, the wood tends to become brittle and leads to more incidents of failure on the pitch [5]. The entire bat can be made using the composite material but this will not be an economically viable option at the local level. The alternative to this is applying a layer of the composite material on the front face of the bat. The objective of this research work is to use a composite layer to extend the lifespan of a cricket bat, which will in turn reduce the amount of wood that is consumed in manufacturing bats. The purpose of turning towards composite material as a way to prolong the life of a cricket bat is due to the fact that the layer which is applied on the bat will save the wood from getting damaged. The properties of composite materials will help in strengthening the willow wood and increasing the overall lifespan. However, a situation should not arise wherein the composite material gives an unfair advantage to the user of the bat. This should also not hamper the performance of the bat while in play, and hence a material with properties similar to the traditional willow wood is selected. This is a novel idea and there has been no prior research done that makes use of such a composite layer applied on the front face of a cricket bat.

Literature Review

Tong [6] studied the possibilities and application of different composites made of materials such as graphene, epoxy resins, nylon, carbon fiber, etc., and found that the use of such materials will lead to a better quality of sports technology and development. Yadvinder et al. [7] studied the applications of fiber-reinforced epoxy and concluded that they can be used in safety and sporting goods. Chen and Ji [8] elaborated the applications and advantages of fiber reinforced composites materials in sports equipment. Wang [9] studied the applications of fiber reinforced composites in sports and has shown that the composites are environment friendly.

Smith and Singh [10] studied the performance of the bat with this thin layer and found that the skin stiffens the blade and improves durability. Tinkler-Davies et al. [11] conducted a series of tests and found that laminated bamboo can be used as a replacement for willow. However, the weight of the bat is significantly higher. Allen et al. [12] studied the validity of a finite element analysis of the impact of the ball on a cricket bat. It is found that the cricket bat had a Young's modulus of 6 to 6.5 Gpa. A comparison of the ball rebound characteristics of bats made of wood and composites was carried out by Stretch et al. [13]. They found that bats made out of composites will not give the batsman any advantage when compared with traditional bats [13]. Eftaxiopoulou et al. [14] compared bats made of different materials and found that with a composite reinforced handle, the vibrational and stiffness characteristics of the bat improved. Chimmat [15] carried out fatigue analysis on a cricket bat at different points on blade of the bat by applying fatigue load obtained from the different ball speeds. The toe edge is the weak spot in the cricket bat. It was also found that fluctuating loads proved to be more dangerous than a constant load at high speeds.

Linkov [16] conducted a study on the effectiveness of using composites to strengthen wooden structures. Based on this study, composite materials can be used to reinforce and strengthen the willow if needed. Some cricket manufacturers make use of a thin composite skin on the rear surface of the bat to improve it structurally. Gribanov et al. [17] studied the change in the strength of wood when modifiers such as ED-20 epoxy resin are used. The strength after testing had an increase of 46 percent. The major requirement is to use a material that has properties similar to that of wood. Based on available data of the mechanical properties of willow wood, a fiber-reinforced epoxy resin composite is taken as a prospective choice. Adekomaya and Adama [18] studied the effect of loading and orientation of fibers on the tensile and impact strength. They used a glass fiber reinforced epoxy resin ED-20 that had properties similar to our requirements.

The work done in references 6-9 demonstrates the application and advantages of composites in the sports industry. The work carried out in papers 10-15 is based on the testing and experimentation on cricket bats. The research work in papers 16-18 revolves around epoxy resin composites and their properties. After this review, it is concluded that the use of composites in sporting goods can prove to be beneficial to the industry as well as the end-user. Hockey sticks make use of composites such as carbon fiber sheets impregnated with resins. Sports such as baseball have also experimented with use of composites to produce their equipment [19]. However, the idea of applying a composite layer on the face of a cricket bat is a novel one. The application of such a layer to existing bats will extend their life and delay the time for failure. This will also mean that bats will have to be replaced less often and in turn reduce the consumption of wood. It is also concluded that using a fiber-reinforced composite with epoxy resin as the matrix will be optimal for the research work. Hence it is intended to manufacture a protective composite layer over the face of a cricket bat and test it to examine its lifespan.

Materials and Methods

Materials used for experiment

In this research work, woven glass fibers mat (400 GSM) are used as reinforcing materials and two types of epoxy resins, namely HSC 7600 and General Purpose (GP) resin with hardener HSC 8210 are used as matrix material. The mixing ratio for the resin and hardener is 10:1. The required materials are obtained from Vega Auto Accessories Pvt. Ltd. The manufacturing of specimens and application of the layer on the cricket bats is also done in the same industry. The properties of the materials used are given in the tables below.

Table 1: Properties of epoxy resin HSC 7600

Epoxy Resin HSC 7600	**Value**
Appearance	Clear Liquid
Viscosity at 25° C (mPas)	10000-12000
Epoxy Equivalent Weight (g/Eq)	180-190
Pot life (100 gm.@ 25° C, in minutes)	20-25
Mixing Ratio by weight (Resin: Hardener)	10:1

Table 2: Properties of hardener HSC 8210

Hardener (HSC 8210)	Value
Appearance	Clear Liquid
Viscosity at 25° C (mPas)	20
Amine Hydrogen Equivalent Weight (g/Eq)	23

Table 3: Properties of general-purpose resin

General Purpose Resin	Value
Appearance	Pale Yellow
Viscosity at 25° C (mPas)	600-800
Epoxy Equivalent Weight (g/Eq)	180-190
Pot life (100 gm.@ 25° C, in minutes)	15-25
Mixing Ratio by weight (Resin: Catalyst)	50:1

Preparation of composite samples

The composite specimens that are used for our research are prepared using the conventional hand lay-up method. A rectangular slab is utilized, and the required dimensions of the specimens are outlined on it. The composite glass fiber-epoxy layers are placed alternately on the rectangular slab on which the dimensions are outlined.

The specimens are prepared using a ratio of 60:40 by weight (glass fiber: epoxy resin). The orientation of the glass fibers is 90 degrees. Increasing the percentage of fiber being used will improve the strength, but also leads to decreased homogeneity [20]. This in turn leads to some regions being weaker than others, a characteristic that is undesirable for application in bats. A total of twelve specimens are prepared, six specimens for the tensile test and six specimens for the Izod impact test are prepared. The specimens are then placed in the oven for 12 hours at an average temperature of 30-35 degrees Celsius.

Tensile test specimens: The standard followed for the specimens is ASTM D3039 for which the required thickness is 3 mm. The layers of glass fiber are added and resin is applied in between the glass fiber layers which are thoroughly rolled over by a roller to spread uniformly and a thickness of 3 mm is achieved which forms a rectangular piece by hand layup process. The standard size is then cut off from the rectangular sheet. The dimensions of the obtained specimen are gauge length of 220 mm, width of 25 mm, and thickness of 3 mm [21].

Impact test specimens: As done for the tensile specimen preparation, the two above-mentioned resins and woven mat glass fibers are used for making the specimens and able to achieve a required thickness of 10 mm in the rectangular sheet as per ASTM standard D256 [22]. The sheet is then cut into the required size of the specimen i.e. 12.70 x 12.70 x 63.5 mm. A V-notch is made at 2.5 mm depth and at the center.

Results and Discussion

A series of tests are conducted on the composite specimen following which the material is selected and the layer is applied on the bat.

Tensile test

The composites for the test are made following the ASTM D3039 standards which are the most commonly used standard in the industry for determining the tensile properties of composite materials. A gauge length of 220 mm is chosen. The tensile tests are conducted on a Universal Testing Machine (UTM TUE-C-400) which yields a load vs. displacement/cross head travel diagram, which is used to determine the desired characteristics such as Young's Modulus, tensile strength, etc. The sample plots of the same are mentioned in Figures 1a and 1b.

Three specimens of each type of material are tested and the values obtained are averaged out. Based on the tests, it is seen that the specimen with epoxy resin HSC 7600 and glass fibers exhibited higher values for Young's modulus. On taking the average, the composite with HSC 7600 had a value of 6.28 GPa, which is close to the desired value of 6.65 GPa [18]. The sample after testing on the UTM is shown in Figure 2. The GP resin had values that are slightly lower, with the Young's modulus being 5.78 GPa.

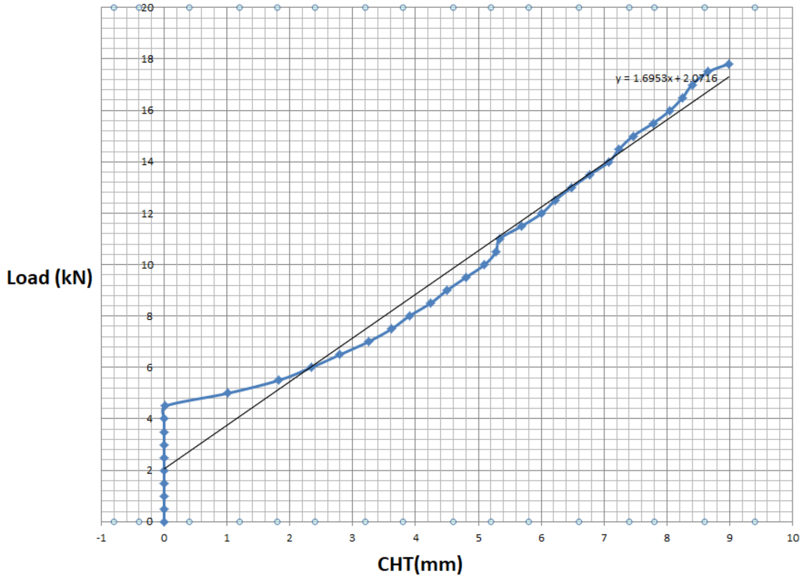

Figure 1a: Load vs. Cross head travel plot for HSC 7600 composite

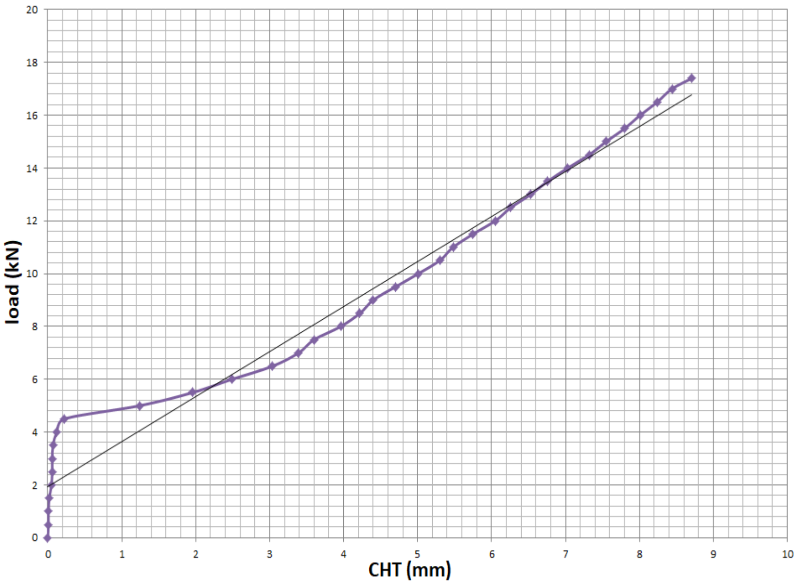

Figure 1b: Load vs. cross head travel plot for GP Resin composite

Izod impact test

As done for the tensile specimen preparation, three specimens of each material are utilized for impact testing. The impact testing machine used is ATT-300N and the values obtained are averaged out. On conduction of the tests and calculations, it is observed that the specimen with GP resin as the matrix has a significantly higher average value of impact bending strength, which is 200 MPa. The impact bending strength of the HSC 7600 specimen is 126 MPa. The expected value is 122 MPa [15]. The specimens after impact testing are shown in Figure 3.

On-field testing

For this work, three bats are prepared having 6 layers, 4 layers, and 2 layers. One layer of the composite material is approximately 1.5 mm in thickness. The layer is applied to the bat using the hand lay-up process. The glass fiber sheet is cut according to the dimension of the bat and then placed over it.

Alternate layers of this sheet and resin are applied on the bat and then cured in the oven at 30-35 degrees for 8-10 hours, once the desired thickness is achieved. The bats complete with the layer are shown in Figure 4. Bats have a weight that usually lies in the range of 1.2 to 1.45 kg, although there are heavier bats that have been used by cricketers in the years gone by. The weights of the bats prepared are 1.9 kg, 1.64 kg, and 1.41 kg respectively. For optimal weight balance, the 2 layered bat is preferred as it is both durable and comparatively light weight. Hence there will be less fatigue felt by the batsman when playing for an extended amount of time. Real-time testing is carried out on three regular bats (SS Group) at a local cricket academy using a leather ball. Balls are bowled at varying speeds from 20 ms^{-1} to 40 ms^{-1}.

Figure 2: Tensile test specimen after failure on UTM

Figure 3: Impact test specimens after testing

Out of the three bats that were initially tested, cracks appeared on one specimen which had a manufacturing defect after 300 shots and material chipped off. The crack propagation observed was also relatively faster. The other two sustained approximately 1700 shots.

After the application of the composite layer on the three bats with different thicknesses as mentioned above, real-time testing is carried out similarly. 2000+ shots are played to check the performance. Defensive as well as attacking strokes were played, with various shot types such as pull shots, hook shots, and drives. On comparing with the regular bat, the layered bat sustains more shots and is a promising solution. The bat sustains more shots when compared to the regular bat and also has a longer life span. The composite layer used has impact strength of 126 MPa (refer to section 4.2).

The probable reason for the extended lifespan of the cricket bat is attributed to the absorption of the impact energy by both layers leading to an energy distribution that gives rise to a synergetic effect. A regular bat with longitudinal wooden fibers will be more susceptible to failure when compared to the composite specimens. The surface roughness value (Ra) of the bats is also measured before and after the impact of the ball on them. The Ra value of the layer before testing is found to be 1.72 and that after testing is found to be 2.05. Surface roughness increased slightly, indicating negligible damage. All three bat specimens sustained more than 2000 shots, but due to the excess weight, the 4 and 6-layered bats are not a suitable option, and hence the bat with 2 layers is selected as the most optimal.

Figure 4: Side view (top) and front view (bottom) of the composite layered cricket bat

Discussion

The driving force behind this work is recognizing the need to reduce wood consumption in the cricket bat manufacturing industry. Cricket bats are predominantly made out of willow wood and have to be replaced often. Our aim is to make use of a protective composite layer on the front face of the bat which will increase the life span of the bat and protect the base material, i.e willow wood. In this research work, the composite layer applied on the bat is found to be satisfactory after real-time testing. The mechanical properties such as the impact stress and Young's modulus of the reinforced composites are investigated according to the ASTM standards.

In regards to the Young's Modulus, HSC 7600 displayed superior values when compared to GP resin. However, the impact bending stress for GP resin is considerably higher than HSC 7600. When compared with the actual desired property values of willow wood, HSC 7600 exhibited similar values and is hence more suitable to be put to use practically. For example, the composite specimen prepared using HSC 7600 has a Young's modulus of 6.28 GPa whereas the General Purpose resin specimen has a Young's modulus of 5.78 GPa. Given that willow wood used for making bats has a Young's modulus of 6.65 GPa, the former specimen is preferred.

Overall, the obtained property values are found to be well in accordance with the desired values seen in willow wood. The real-time testing is done where the bat is tested for more than 2000 shots against a standard leather ball. The bats are tested at a wide range of ball speeds ranging from 20 ms^{-1} to 40 ms^{-1} at a local cricket academy. Both regular willow bats and the bats reinforced with composite layers are tested. The composite bat easily sustains the leather ball impacts with negligible damage on the surface when compared to the regular willow bats. The layer does not hamper the ball-striking off the face of the bat and there is no significant advantage to the batsman. Further improvements in the tensile and flexural strengths of the composite can be achieved by using additives such as Cobalt [23].

With the increase in the rate of global warming and deforestation rising steadily, the application of such a layer on the bat will reduce the consumption of wood resulting in the sport becoming more environmentally benign. The future scope of this research work will be to develop a layer that is light in weight and easily replaceable. The entire cricket bat can be made from the same material, but it is not an economically viable option. Local cricket bats are consumed more than at the international level, so the primary focus should be on the composite layer being cheap and environmentally friendly.

Conclusion

The proposed research work aims to address the wood consumption for producing cricket bats and reduce its detrimental effects. This research demonstrates the feasibility of using a composite layer that can be applied on a cricket bat to protect the willow. A glass fiber-reinforced epoxy resin composite is chosen. The composite specimens are fabricated using hand–layup techniques using two different types of epoxy resins (HSC 7600 and general-purpose resin). Mechanical testing such as tensile test and impact test is conducted on the samples and the values obtained are found to be in accordance with the desired values seen in willow wood. HSC 7600 has a Young's Modulus of 6.28 GPa, and an impact bending strength of 126 MPa which is satisfactory. Regular willow bats and three bats having varying thickness of the composite are utilized to carry out real-time testing with the leather ball. While the regular willow bats fail after close to 1700 shots, all three bats reinforced with the composite layer sustain more than 2000 shots. No significant damage is seen on the surface of the layer. As the property of the material used is quite similar to that of willow wood, the use of such a layer does not provide any advantage to the batsman. Hence it is concluded that the novel idea of applying a composite layer over a cricket bat to extend its life is accomplished successfully. It is concluded that the composite layer used is a viable option to be put to use in the cricketing industry. The protective layer enhances the energy absorption capacity of the bat due to a synergetic effect and absorbs impact well. As the bats lifespan is significantly increased and the willow remains intact, the bat will have to be replaced less often, eventually leading to reduced consumption of wood. The issue of global warming due to this excess consumption in the cricketing industry can certainly be addressed by the utilization of such a composite layer, as exhibited in this research work.

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