Optimization of bio-composite material constituents for developing yak saddle

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ABSTRACT: The design of traditional implements fulfilled the farming purpose with long exposure and understanding. However, there is plenty of scope to amend the design predicated on animal-machine-environment interaction so as to have more output, incremented efficiency and preserving the environment by avoiding deforestation without endangering the animal health. Superseding of wooden component with bio-composite materials is the better option. The optimization of bio-composite material has been done to ascertain the strength, durability and cost efficacy of the equipment. The density of the bio-composite material was observed as 1.02 g/cm3 whereas, maximum flexural, tensile, and compressive strength of bio-composite saddle were obtained as 47 N/mm2, 24.62 N/mm2 and 28.58 N/mm2 which is 262 %, 37 % and 30 % higher than the wooden saddle respectively. Field testing of bio-composite yak saddle showed that the animal could take 30 % more pack load as compared to the traditional wooden saddle. The bio-composite yak saddle costs 50% less compared to traditional saddle. The developed composite material yak saddle covers all the advantages which consummate the desideratum of the farmer.

Key words: Bio-composites, composite material, draft animal power, pack load transportability, wooden saddle, yak saddle

Draught animal Power is a reliable and important source of farm power in most of the developing countries. Millions of small and marginal farmers (especially in hills) consume (DAP) for the cultivation and transportation purpose. With increased farm mechanization and power operated machinery, there has been a decrease in the population of draft animal, but still animal power play a vital role to perform various agricultural operations. The live stock population has reduced from 720 million in 1971-72 to 512.8 million in 2011-12. The bovine population in India is estimated about 299.9 millions out of which Bullock are 38.07, male buffalo are 13.2, camel are 0.52, horses and poneys are 0.62, yak are 0.29, donkey are 0.32 millions used as a draught animal power (*19th Indian live stock census*). The harnessing system and animal drawn farm an implement utilizes wood as a material of construction which estimates the tons of wood requirements. In general, the demand of the wood for such work and other house hold activity is met from the forest leading to indiscriminate cutting of trees which badly affect our climate and environment. Also poor and old design of harnesses and farm implements causes several constraints which adversely affect the productivity and the physiological parameters of the animals. So keeping above points in view, it is important to develop an alternative material from the waste bio mass which replaces wood effectively. Hence, a study on bio-composite material has been carried out to optimize its mechanical properties to use as an alternative material for replacing wooden components from different animal drawn implements, harnessing system and various utilities.

This study is basically carried out for biomass fiber reinforced composite materials. They are renewable, cheap, completely or partially recyclable, and biodegradable. Plants, such as flax, cotton, hemp, jute, sisal, pineapple, ramie, bamboo, banana, etc., as well as wood, used as a source of lignocelluloses fibers and are applied as the reinforcement of the composites material. Their availability, renewability, low density and price as well as satisfactory mechanical properties make them an attractive ecological and environment friendly alternative to glass, carbon and man-made fibers used for the manufacturing of composites (*Kulkarni et al.,* 2014).

Yak is the main-stay for the highlander's dwellings in mid and higher reaches of Sikkim providing transport. Due to their unique ability to survive in extreme cold climates, Yak is an important animal in high hills and snow bound areas. It has been felt to be appropriate to utilize efficiently to these animals by developing suitable harness, saddle and other required fixtures. There appeared great potential for harnessing Yak energy effectively which would help the dependent users in other North East Hill regions having Yaks. The improved design of yak saddle may provide higher work output besides comfort to the animals. Keeping in view the cost-effectiveness, light weight, cushioning effect with lower body surface friction and easy availability and affordability replacement of saddle materials may be considered.

MATERIALS AND METHODS

Material used

Matrix material

a. ***Resin:*** Epoxy resin is an odorless, tasteless and completely non-toxic liquid solvent free resin which has versatile applications in technical and industrial applications due to its excellent mechanical, electrical properties. It is highly resistant to chemical and atmospheric attack with good ageing characteristics. Araldite CY 230 purchased from M/s Fine Finish organics Pvt. Ltd. Mumbai, India has been used as matrix material in the present investigation.

b. ***Hardener:*** Hardener HY951 purchased from M/s Fine Finish organics Pvt. Ltd. Mumbai, India, is used as curing agent. In the present investigation 9 % wt/wt have been used in all material developed. In the present investigation, optimized volume of hardener has been used in all composite material developed as per the recommendation of *(Singh, 2012*).

Reinforcing element: Reinforcing agents are added to the resin to improve the physical and mechanical properties of the composites material.

a. ***Silica:*** Induction of silica in the matrix material has been taken into consideration. Silica particles improve the physical and the mechanical properties significantly. Silica flour is directly mixed in to the resin and stirred mechanically.

b. ***Glass wool:*** Glass wool is produced in rolls or in slabs, with different thermal and mechanical properties. These are taken as a binding material for enhancing the adhesive property of the models. The glass wool purchased from M/s Fine Finish organics Pvt. Ltd. Mumbai, used as in sand-witched form, between every other two sets of jute net layers.

c. ***Jute net:*** Jute net is biodegradable matting manufactured from jute fiber. It is light in weight and widely used for housing and commercial purposes. It is considered as a waste material which is a main constituent here for developing a yak saddle.

d. ***Bagasse and paddy straw:*** Bagasse is a fibrous residue of cane stalks left over after the crushing and extraction of juice from the sugar cane which was collected from nearby Kichha Sugar Mill, Uttarakhand, India. Paddy straw was collected after the harvesting. Bagasse and paddy straw can be considered as waste biodegradable material. These are light in weight and don't add much to the density of the samples. The main chemical constituents are cellulose, hemicelluloses and lignin. Hemicelluloses and cellulose are present in the form of hollow cellulose, which contributes about 70 % of the total chemical constituents present in bagasse and paddy straw. Lignin acts as a binder for the cellulose fibers and also behaves as an energy storage system.

Sugarcane bagasse and paddy straw were dried in sun for a week and subsequently cut into small pieces. It was then washed, dried and grounded in a hammer mill up to the powdery form. Two sieves of required (ASTM-30 & ASTM -60) size were used to get the final fiber size for casting.

Method of fabrication: The solution is kept in the oven at a temperature of 85˚c after that silica and biomass were mixed with the resin. When proper mixing is done, the whole solution is again kept for cool down to obtain 45˚C of temperature. When the desired temperature is obtained, hardener is mixed immediately. Due to addition of hardener high viscous solution will been obtained which is again stirred at high speed (mechanical stirrer recommended). Lubricating material (grease) was put into the inner surface of moulds so as to avoid the contact between solution and mould surface. The viscous solution was poured in to the moulds of saddle with desired percentage of jute net layers. A single layer of glass wool was introduced in part b of the yak saddle, shown in Figure 1. After proper adjustment of jute net and glass wool with desired ply rating, rest of the solution was poured on to the surface of molds, so that each layer absorbs solution and get adhered with each other for imparting the desired strength. This whole process was carried out at room temperature. The prepared composite saddle is shown in Figure 2. The constituent in the

Fig. 1: Different components of the Yak saddle

Fig. 2: Developed bio-composite yak saddle

different composite materials samples are given in Table 1.

Optimization of reinforcing material

Reinforcing material:

Silica: 10 wt % of silica with particle size 60 to 120 mesh on weight basis of resin was observed more efficient and selected as reinforcing agent for composite material.

Jute net: Jute net almost has wood like properties. It has high weight to strength ratio, insulation properties and often considered as a waste material. Varying number of plies of the jute net effects significantly on the Physical and Mechanical properties of the composite materials. Jute net was optimized up to 12 ply or maximum 10 % on weight basis of the resin to get the desired output.

Bagasse and paddy straw: On the basis of the results obtained with 5, 10 and 15 wt % of biomass, 14 % oven dried bagasse, and paddy straw in equal proportion were taken as in milled form to mix with the resin as a filler material. This amount reduces the density as well as increased mechanical properties of the composite material.

Hardener: Less quantity of hardener cases slow reaction rate and stickiness is observed, whereas, more quantity is caused fast reaction rate, since mixing of hardener is an exothermic reaction so more quantity causes abrupt heat releasing which is resulted as cracks formation on the surface of saddle. So it has been optimized as 9 % on weight basis of resin and found more agreeable.

RESULTS AND DISCUSSION

The design of the yak saddle was opted from traditional yak saddle (weight: 6.7 kg, tensile strength; 22.1 N/mm^2, unit price: Rs 2000/-) designed and developed in *AICRP on UAE Centre of CAE&PH,T Gangtok (Sikkim)* for a yak animal (weight: 40 kg, age: 4 years, unit price: Rs 18000/-).

The study was conducted for standardizing different parameters of composite material for the development of

Table 1: Constituents for different composite materials sample

Treatments	Constituents							
	Jute net (Number of plies)	Wire mest (Number of plies)	Glass wool (Number of plies)	Bagass (Weight %)	Paddy straw (Weight %)	Silica (Weight %)	Hardener (Weight %)	Resin (Volume ml)
T_1	12	4	-	-	-	4	9	750
T_2	12	4	-			10	9	750
T_3	12	4	-			16	9	750
T_4	16	5	-			10	9	750
T_5	12	4	3			10	9	750
T_6	12	-	-	5	10	10	9	750
T_7	12	-	-	10	5	10	9	750
T_8	12	-	4	7.5	7.5	10	9	750
T_9	Wood used for developing Yak saddle (weight : 6.7 kg)							

yak saddle. The effect of silica, bagasse, and paddy straw on weight percentage and the variations of number of jute net and glass fiber layers on physical and mechanical properties were evaluated and compared with wood. The results and analytical interpretation of various composite materials samples are presented in Table 2.

Wood is fibrous in nature that delivers significant mechanical strength. It is clear from the Table 2 that sample T_9 (wood) has the tensile, compressive and flexural strength of 18, 22.21 and 13 N/mm^2 respectively. Sample T_1 has tensile strength of 15.5 N/mm^2 which is 50% lower than T_9, but sample T_2 and T_3 had shown mechanical strength almost close to the sample T_9 that suggests that silica percentage must be fixed between 10 to 16 wt percent. Also, addition of 16% silica makes the specimen brittle in nature, which resulted in reduced compressive strength of the sample. Thus, introducing 10% silica with different percentage of bagasse, paddy straw and glass wool provides more strength as compared to other models.

The compressive strength of the treatment T_1, T_2, T_4, T_5, T_7, T_8, and T_9 were found 32.91, 33.52, 29.46, 27.58, 22.21, 25.93, 24.08, 28.58 and 22.21 Nmm^{-2} respectively (Table 2). It is also clear that the value of compressive strength for T_1, T_2, T_4, T_5, T_6,T_7 and T_8 was 48.17, 50.92, 16.11, 32.64, 24.17, 16.74, 8.41 and 28.68 % higher than T_9. It is evident from the results, that number of plies radically affects the mechanical properties of the treatments. However, T_5 contains wire mesh reinforced with silica and cellulose material, which does not increasing strength considerable as compared to the sample T_4 of 16 jute plies. In addition to it, wire mesh plies were increasing undesired weight to the samples.

After optimizing the silica up to 10 wt %, tests were performed for analyzing the effect of ply on flexural strength with intention behind increasing more strength and lower the weight by reducing the density of the samples.

The flexural strength of models T_2, T_4, T_5 and T_6 were found 32, 44, 37 and 13 N/mm^2 respectively with 10 wt % of silica (Table 2). The value of flexural strength for T_2, T_4, T_5, T_8 and T_9 are 146.15, 238.46, 184.61, 223.07 and 261.53 % higher than T_{10}. It is evident that more plies impart more strength to the samples however, T_5 consists of wire mesh together with other reinforcing material which does not increase the strength considerably as compared to the sample of more plies i.e. T_4, but increasing undesired weight. Besides these the glass wool used in T_9 effectively increasing the strength nearer to the sample T_{10} without affecting the density of the sample.

Densities of the sample plays crucial role in designing of any animal drawn implements and keep the gadgets light in weight. Wood used for developing traditional yak saddle has the density of 0.72 g/cm^2. The experimental densities of the sample T_1, T_2, T_4, T_5, T_7 and T_8 were obtained as 1.11, 1.11, 1.24, 1.21, 1.33, 1.09, 1.03 and 1.02 g/ cm^2 respectively, which are 54.16, 54.16, 72.22, 68.05, 84.72, 51.38, 43.05 and 41.66 % higher than the required density for developing a yak saddle. Treatment T_7 and T_8 has the lowest density, which is desirable for the development of yak saddle and very close to the density of the wooden saddle. Physical and mechanical properties of the treatment T_7 and T_8 were very close to the desired value of wood to develop yak saddle. The tensile compressive and flexural strength of the sample T_8 were 19.41, 15.74, and 10.63 % higher than $T_{7.}$ Thus the sample T_7 and T_8 proves itself as the most

Table 2: Physical and mechanical properties of different composite material samples

Material Properties	Density (g·cc^{-1})	Tensile Strength (N-mm^{-2})	Compressive Strength (N-mm^{-2})	Flexural Strength (N-mm^{-2})
T_1	1.11	15.7	32.91	41
T_2	1.11	24.5	33.52	32
T_3	1.24	21	25.79	26
T_4	1.21	26	29.46	44
T_5	1.33	19.2	27.58	37
T_6	1.09	17.63	25.93	27
T_7	1.03	19.84	24.08	42
T_8	1.02	24.62	28.58	47
T_9	0.72	18	22.21	13

Table 3: Cost analysis of the developed yak saddle

Jute net		Glass wool		Silica		Bagass		Paddy Straw		Resin		Hardener		Miscellaneous
Mass 6.1g ply-1	Rate Rs. 40 kg-1	Mass 13.9 g ply-1	Rate Rs. 140 kg-1	Mass/g (10% of total)	Rate Rs. 25 kg-1	Mass (7.5% of resin) (g)	Rate Rs. 3.5/kg	Mass (7.5% of resin) (g)	Rate Rs. 6/kg	Mass/g (85% of total	Rate Rs. 320 kg-1	Volume /ml (2% of resin)	Rate Rs. 100 lit-1	(Labour etc.)
251.1	10.04	147.60	20.664	320	8.00	24	0.84	24	1.44	2496	798.72	32.00	3.2	157.0

suitable sample then rest of the others. However T_8 could not be used for the parts which comes directly in contact with the animal skin as the glass wool is being used, which causes sore or itching to the animal. To avoid severe irritation and gal to the animal skin, lower part of the saddle, as shown in Figure 1 was molded with the treatment T_7 which do not contain glass wool.

Cost analysis

The cost analysis of developed saddle is given in Table 3. Table indicates that the cost of yak saddle developed from composite material is about Rs.1000/- whereas the cost of existing wooden saddle is about Rs. 2000/-. Thus the cost of developed yak saddle is 50% less as compared to wooden saddle.

CONCLUSION

The test trial of developed saddle was performed at Thangu region (altitude 4270 – 4880 m above msl) in north Sikkim. The maximum pack load of 120 kg (three bags of potato each of 40 kg weight) on yak could be used to travel 5.5 km distance at a speed of 2.62 km/h in two hour duration on steep slope of 60 degree. This indicates that newly developed saddle was able to take 30% more load over traditional saddle.

On the basis of the study, it is found that the developed saddle of composite material (weight: 3.2 kg, tensile strength: 24.8 N/mm^2 and unit price: Rs 1000/-) using samples T_7 (constituent: resin 87 % w/v, silica 10 % w/w, 12 numbers of jute net plies 2.5 % w/w) for the part (b and c) in Figure 1 and T_8 (constituent; resin 87 % w/w, silica 10 % w/w, 12 numbers of jute net plies 2.5 % w/w, 2 numbers of glass wool plies w/w) for Part (a) in Figure 1 is more suitable. The animal could carry 30% more pack load using saddle made from composite material than the traditional wooden saddle.

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Received: June 4, 2015
Accepted: August 9, 2016