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Effect of Mechanical, Thermal Properties and Drilling Parameters on Groundnut Shell-Broom Fibre-Reinforced Epoxy Composite

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Abstract.

In this preliminary study, the potential of ground nut shell and broom fiber as a reinforcement material for polymer bonded composites was investigated. Ground nut shell and broom fiber (fiber strands extracted from broom grass) are easily available in the market at low cost. Ground nut and broom fiber reinforced epoxy resin matrix composites have been developed by hand lay-up technique with different volume fraction of fibers as in 1:1 ratio (30%, 40% and 50%). The mechanical characterization of these composites was carried out by standard tensile, compressive and flexural tests on a Universal Testing Machine with appropriate setups. Thermo gravimetric analysis was performed to compare the thermal characteristics of conventionally cured and microwave cured composites. Microwave cured samples exhibited higher thermal stability indicating a better extent of cure. Drilling parameters were performed by experiments using a CNC drilling machine with drill tool dynamometer. Two input parameters, cutting speed and feed rate and the one output parameter, thrust force, were used for the drilling process. Solid carbide and HSS drills were employed in the drilling experiments and a comparative study was made based on the output parameters. Solid carbide resulted in lower thrust force values and feed rate proved to be the most influential parameter on thrust force. SEM analysis on the composite materials was performed. The fracture surface of the composite shows that pull out and de bonding of fiber is occurred.

Keywords: Natural fibre, Hand layup method, Mechanical and Thermal properties, Solid carbide tool, Drilling, SEM.

1 Introduction

Recently, the research attempts in natural fibre reinforced polymer composites have greatly increased. Natural fibre reinforced polymer composites involve simple processing techniques, easily procurable raw materials and high biodegradability levels among all the engineering materials. Apart from researchers, manufacturers have also shown increased interest in natural fibre composites from the past decade. To substantiate this claim, the increased in the use of the natural fibres in German cars from around 10000 tonnes in the year of 2000 to 19000 tonnes in 2005 could be mentioned [1]. Hemp, sisal, kenaf, and bamboo are the natural fillers which have undergone many evaluation procedures and declared fit for a good number of applications. The mechanical properties of natural fibers and the composites developed by incorporating them in different polymer matrices and various processing techniques for fabricating them have been studied by many researchers [2–4]. In a majority of the research attempts on natural fibre reinforced polymer composites, the filler phases used were in the form of fibres. Natural filler phases in other forms like shell (eggshell), powder (sawdust) were very rarely experimented. This research work is an exploratory attempt on composite containing shell

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type and fibre type fillers. Groundnut shell is highly rigid, non-edible portion of groundnut and is usually discarded which makes it easily procurable. Broom fibre, which is in the form of thin, long and flexible strands, is also an economic material which is commercially sold in large quantities. Consequently, a combination of these two fillers could presumably account for a suitable reinforcement phase in an epoxy matrix.

The evaluation of preparation techniques is a vital part in the research regarding composite materials. Wet hand layup is the widely used technique for manufacturing polymer composites, mainly because of its simplicity and cost effectiveness [5]. Additionally, compression moulding of the hand lay-up, aids in elimination of the air bubbles present in the resin which reduces the porosity of the composite. Experiments were conducted to study the microwave processing of epoxy adhesive joints and their results stated that curing of epoxies using microwaves reduces curing time and could improve the mechanical properties. Their results also highlighted the high bond strength exhibited by MW cured epoxies as compared to ambient cured ones [6]. The dielectric properties of the materials involved should be considered before experimenting. Research carried out in the past reveals that in microwave processing of fibre reinforced epoxy composites, the heating of matrix takes place prior to the heating of fibres. This is mainly because, the dielectric loss factors of matrix resins are high compared to most of the fibres [7].

Drilling is the most important machining operation performed in fibre reinforced composites for joining in assembly operations. At present, conventional drilling involves material removal from contact with a rotating metallic drill tool (mostly twist drill) is the widely used drilling process because of its simplicity and low cost involved. A lot of research on the drilling of fibre reinforced composites (FRPs) has been carried out in the past. Experiments were conducted as early as 1985 to study the effect of feed rate on drilling of FRPs. In one of those early experiments, the results revealed that high feed rates resulted in crack formation around the exit edge of the hole [8]. The influence of various parameters on peel-up and push-out delaminations was analysed. The results indicated that increase of the fiber volume fraction increases the thrust force which in turn leads to increase in delamination [9]. The study of the material removal mechanism established that the cutting process in epoxy composites is entirely based on fracture mechanics, unlike shearing in the case of metals [10]. Experimental analysis to determine the cutting load distribution along the work-piece thickness and tool radius by analyzing the thrust and torque curves in drilling of carbon-fiber) and glass-fiber reinforced composite plates. The highest loads were found at the tool tip in the vicinity of the chisel edge (in case of a twist drill) and it was recommended that a smaller chisel edge could result in lower delamination [11]. A very few research attempts were made to study the drilling characteristics of natural fibre reinforced polymer composites. The effects of drilling parameters on delamination of hemp fiber reinforced composites were studied to find out conditions for minimum delamination using Taguchi and ANOVA methods [12]. The drilling characteristics of sisal/GFRP hybrid composite were studied by employing drills made of different materials among which solid carbide proved to be the best tool material as it resulted in the lowest thrust force values [13]. In an attempt to study the delamination characteristics of bamboo-polyester composite it was observed that low diameter of drills and low feeds resulted in low delamination and better hole quality [14]. In the machining study of coconut meat husk reinforced polyester composite the delamination of this material was found to be lower than GFRP [15]. This is a rare instance in which the machinabilty assessment of a composite with natural filler in a non-fibrous form has been performed and the results indicate a potential for low delamination.

In this research work, broom fibre-groundnut shell reinforced epoxy composites were fabricated by hand layup followed compression moulding and the mechanical characterization was carried out by standard tensile, compressive, flexural and impact tests and the effect of microwave curing on the thermal properties of ground nut and broom fibre reinforced epoxy composite, its efficiency in terms of energy and time, and thermal characteristics in comparison with those of conventionally cured composite and SEM analysis of fractured surfaces of the composite were performed. Machinability was evaluated by a study of drilling process parameters. Input parameters, cutting speed and feed rate and an output parameter thrust force were employed to study the drilling process. The tool and input parameter value, selection were done based on the literature stated above.

2 Experimental procedure

Materials

The raw materials used for manufacturing the composites were epoxy LY 556 resin long with hardener HY 951, broom grass fiber, groundnut shell and mansion wax. Broom grass fibers with Groundnut shell fiber composite.

Fabrication Process

The ground nut shells were broken into small pieces and thin strands of fibre were extracted from a household broomstick. These two natural fillers were subjected to alkaline treatment by immersing in NaOH for 12 hours and then washed using distilled water. This chemical treatment was carried out to enhance the fibre-matrix adhesion which can improve the mechanical properties of the composite. Then, three hand lay-up, each containing 30%, 40% and 50% of these fibers by volume were made in a compression mould made up of GI (gauge 25) sheet of dimension 300x300x3mm. The specimens were prepared in varying fibre volume fractions 30%, 40% and 50%. Later the specimens were cut from the prepared casting.

Microwave curing of composite

A multimode microwave (MW) furnace with a maximum heat output of 1200W was used. The epoxy DGEBA resin and TETA hardener were mixed in the ratio 10:1 and ground nut and broom

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fibres were introduced into this mixture such that the fibres accounted for 40% of the weight of the mixture. Initially, epoxy (250 gm) taken in an earthen container was heated in the MW furnace at a power of 220 W for 3 mins. This was followed by the addition of hardener and fibres in the proportions mentioned above, to the heated resin in a rectangular PPE container and the mixture was left at room temperature for 4 mins. Then it was heated for 30 mins in the furnace at a power of 110W. The temperature was maintained close to 90^0C using a thermometer (refer fig. 1) as the hardener belongs to the family of Aliphatic amines, which produce a maximum reaction rate at 90◦ C [20]. Later, the container was removed from the MW furnace and the composite was obtained.

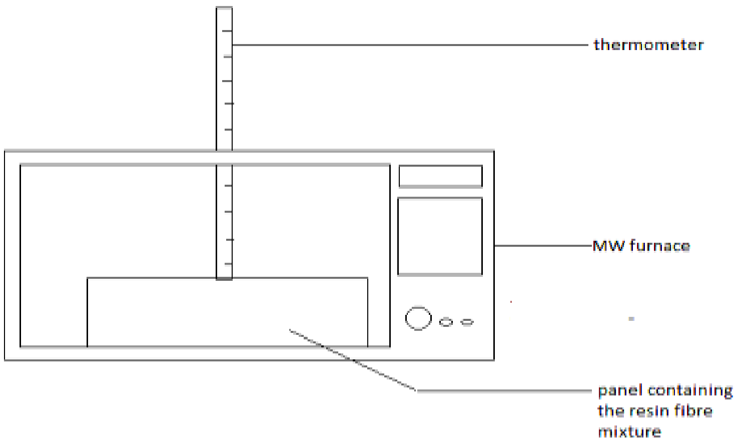

Fig.1. Experimental Setup for MW curing

Thermo gravimetric analysis (TGA)

TGA was used to determine the degradation temperatures of natural fibre composites. The decomposition characteristics of the composites were used to compare the extent of cure between the conventionally cured and microwave cured samples. All the samples were heated in a TA Instruments TGA to 600^0C at a heating rate of 10^0C/min in an N_2 atmosphere.

Mechanical characterization

The tensile and compressive property values of composite samples (ASTM D 3039/D 3039M) were determined using a Universal Testing Machine (Instron 3369). Test samples were prepared as per ASTM standard EN ISO 14125 (1998) to determine flexural property using three-point bending. The standard charpy impact test was used to determine the impact strength.

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Scanning electron microscopy (SEM)

The morphological characterization of the composite fracture surface was carried out using SEM. The samples were gold sputter coated to improve electrical conductivity.

Machining

Rectangular plates of these materials, measuring 5mm in thickness were prepared for drilling. A high speed steel (HSS) twist drill of point angle 118 and diameter 5 mm, which is a commonly used inexpensive drill and a solid carbide twist drill (WC) of point angle 140 and diameter 5 mm were employed for the drilling operation. The HSS 118 twist drill was chosen as it is conventionally used for many applications because of the low cost and availability. The WC drill was chosen as it had recorded thrust force values lower than HSS while drilling sisal–GFRP composites [13]. The laminate was sandwiched between the front and back plates of the machining fixture. The high speed drilling tests were conducted on a CNC drilling having spindle speed of 60-5000rpm and a maximum feed rate of 4000mm/min. Machining tests were conducted under dry conditions and the cutting forces was recorded using a Kistler Quartz 3-Component dynamometer (type9257B).

Process parameters

The combinations of input process parameters cutting speed and feed rate were formed. Plan of experiments is shown in Table 1.

Table 1. Plan of experiment

S.No	Feed rate (mm/rev)	Spindle speed (rpm)
1	0.05	900
2	0.05	1500
3	0.05	2100
4	0.20	900
5	0.20	1500
6	0.20	2100
7	0.35	900

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8	0.35	1500
9	0.35	2100

3 Results and discussion

Mechanical Properties

The variation of tensile tests was conducted according to ASTM D 3039-76 standard on a computerized Universal Testing Machine. This variation in tensile and flexural strength of the composites with 30%, 40% and 50% of fibre content are shown in fig 2 and 3 respectively. These figures clearly indicate the gradually increase in both tensile strength and flexural strength of 30% and 40% fibre content. However, there is a decrease in both tensile and flexural strength of the composite with 50% fibre content. Similar observations were reported by Noorunisa Khanam et al. When they experimented with Sisal/Silk reinforced hybrid poly-ether-ketone composite [23].

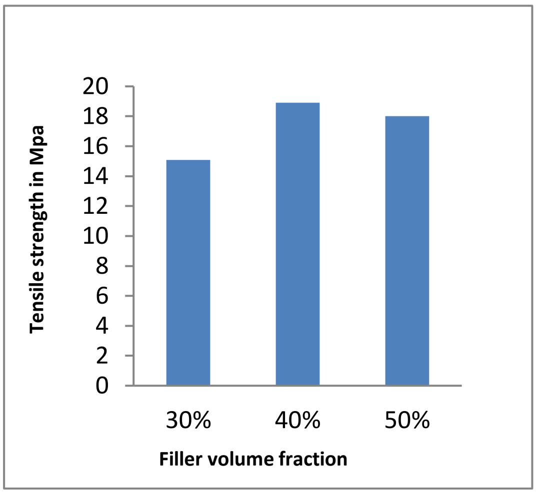

Fig.2. Tensile strength

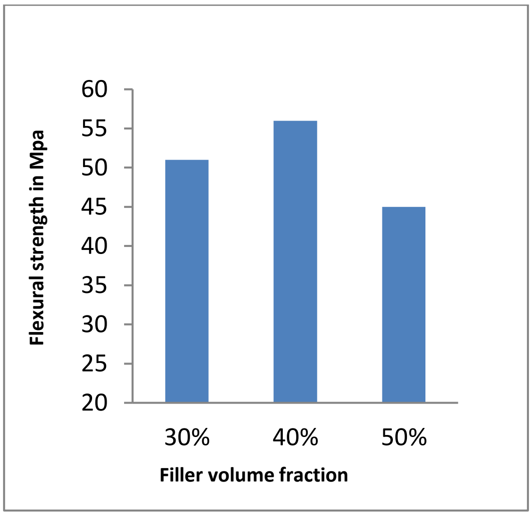

Fig.3. Flexural strength

The variation of compressive strength with the fiber content on the alkali treated composites is shown in Figure 4. The broom-ground nut fiber composite material was tested and the compressive strength was found. Five specimens are tested, with different fiber volume fractions and average compressive strength was reported. The compressive strength was increasing steadily up to 30% and beyond that the change was very marginal.

The variation of impact strength with the fibre content, in case of groundnut and broom fiber composite is presented in Fig 5. The impact strength increases with increasing volume fraction of fibres, reaching a maximum value of 30%. Beyond 30% the impact strength shows a decreasing trend.

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The maximum impact strength of the composites varies between 0.9 to 1.3 Joules. Alkali treated broom fibers and groundnut shells showed improved impact strength. This result was in line with the findings of Varada Rajulu et al. and Ramachandra reddy et al., the researchers with whom characterization of bamboo composites was carried out [21-22].

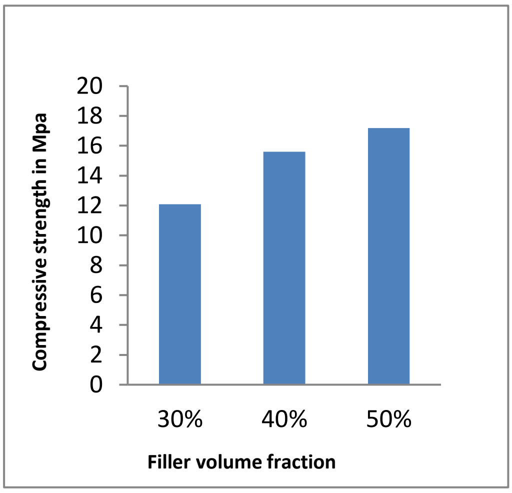

Fig.4.Compressive strength

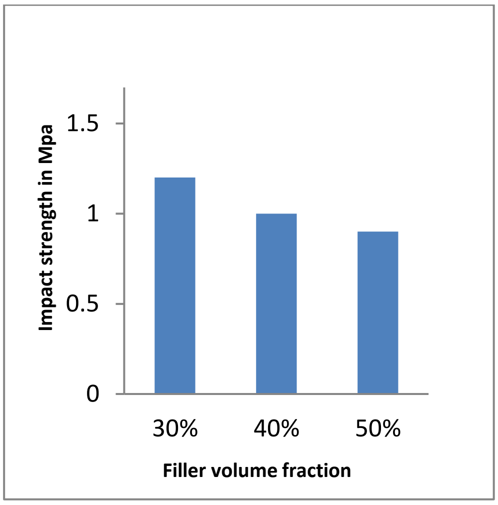

Fig.5. Impact strength

Time and energy consumption

The MW curing proves to be a highly rapid method of curing a polymer resin and in this experiment, it consumed 35 minutes to complete curing of the composite. The rapid curing is mainly because of the frictional heat generated at the intermolecular level due to MW heating of the epoxy resin leading to increased reaction with the curing agent. Among the conventionally used methods in the curing of composites, curing at room temp takes 24 hours and thermal curing by autoclave heating involves a minimum of 2 hours [20]. In the MW curing of groundnut and broom fiber epoxy composite, heating was carried out for 2 mins (120s) at a power of 220W and for 30 mins (1800s) at a power of 110W.

Energy consumption= Power (W) x Time(s)

=220x120 + 110x1800 =198 KJ

Therefore, MW curing seems to be energy efficient. More importantly, it is highly time saving compared to room temperature curing.

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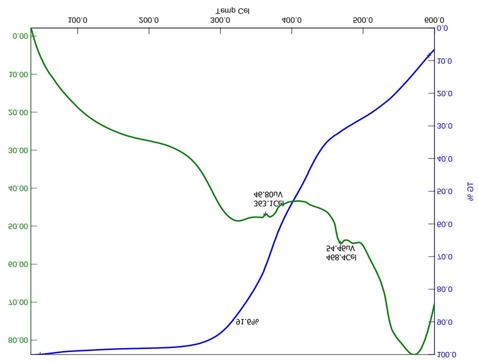

Fig.6. TGA curve for MW cured composite

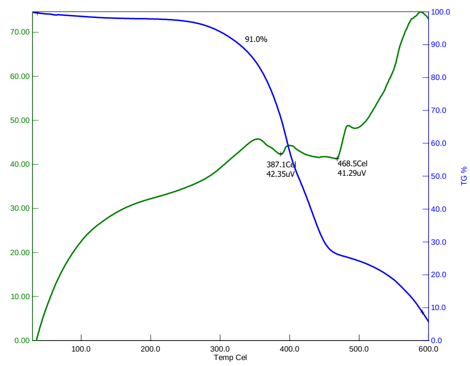

Fig.7. TGA curve for conventionally cured composite

Cure and Thermal characteristics

In this work, TGA was used to cure and thermal characterization. The thermal degradation characteristics can be used to confirm the presence of cured networks. The thermal degradation of cured epoxy-amine networks start roughly at 390ºC [9, 20] and the MW cured groundnut and broom fiber-epoxy sample, the matrix of which contains the same network started degrading at 388^{0}C, indicating the attainment of cure. A similar approach was adopted in the work done by Amanda L. Higginbotham et al [19].

Table.2. Thermal properties of the composites

Material	Initial Decomposition Temperature (℃)	Decomposition Temp at 50 % weight loss (℃)	Final Decomposition Temp (℃)
Groundnut and broom fiber epoxy composite cured at room temp	364	468.6	600
Microwave cured groundnut and broom fiber epoxy composite	387	469.2	600

In case of the conventionally (room temp) cured and MW cured composites (see fig 6&7), it is seen that the start of decomposition of MW cured composite is prolonged. The delay in the decomposition start by 25^{0}C compared to the room temperature cured composite indicates the presence of higher cross link density or improved cure and also higher thermal stability in the microwave cured sample. Therefore, it is evident that, as a result of volumetric heating, MW curing results in a better extent of cure. The initial degradation temperatures of both the conventional and MW cured composites fall between the initial degradation temperature of neat epoxy(cured) and the groundnut and broom fibre. A similar trend was observed in the experiments carried out on curing of natural fibre composites by Nikki Sgriccia and M.C. Hawley [11].

Machining performance

The thrust force was recorded using the drill tool dynamometer, as presented in Table 2.

Table 2. Thrust force values of the drilled composite

S.No	Feed rate (mm/rev)	Spindle speed (rpm)	Thrust force (N)	
			HSS	CWC
1	0.05	900	18.89	20.45
2	0.05	1500	24.37	19.73
3	0.05	2100	23.04	19.82
4	0.20	900	71.84	40.94
5	0.20	1500	74.76	43.38
6	0.20	2100	60.69	42.00
7	0.35	900	111.5	65.98
8	0.35	1500	105.7	73.57
9	0.35	2100	59.63	77.61

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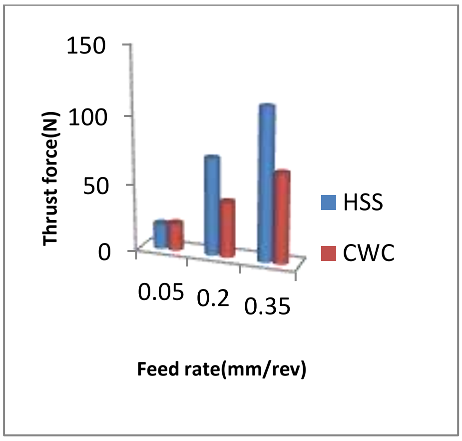
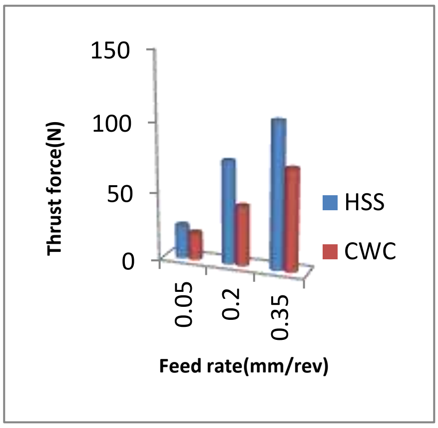
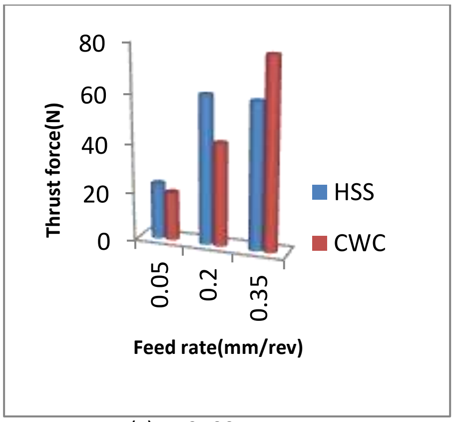


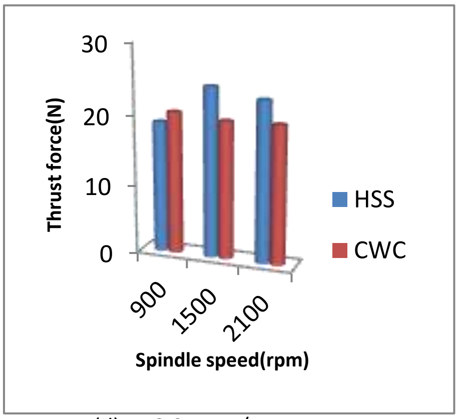
(a) At 900rpm



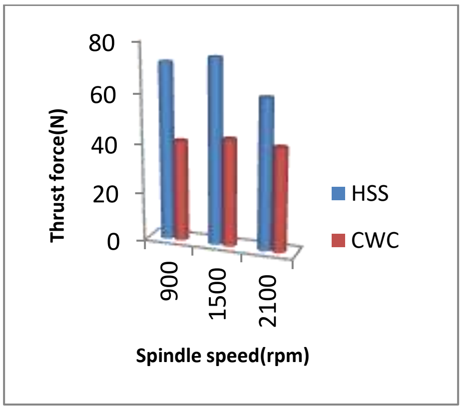
(b)At 1500rpm



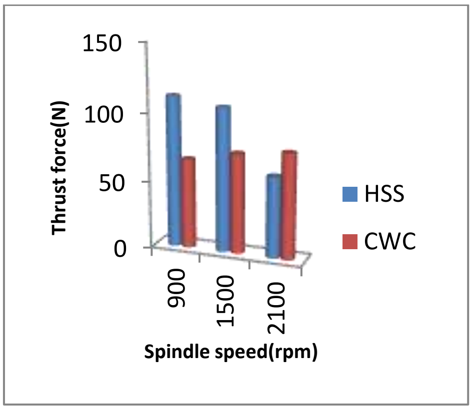
(c) At 2100rpm



(d) At 0.05 mm/rev



(e) At 0.20 mm/rev



(f) At 0.35 mm/rev

Fig.8. (a),(b),(c)-Thrust force vs feed rate (d),(e),(f)-Thrust force vs spindle speed

From the graphs presented in fig.5, it is very clear that feed rate is

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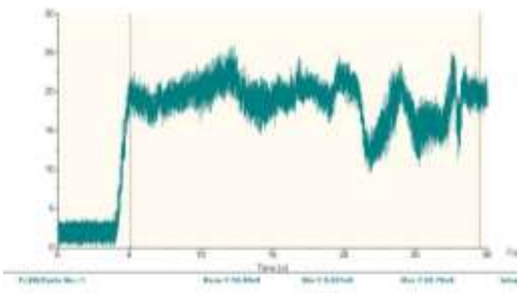
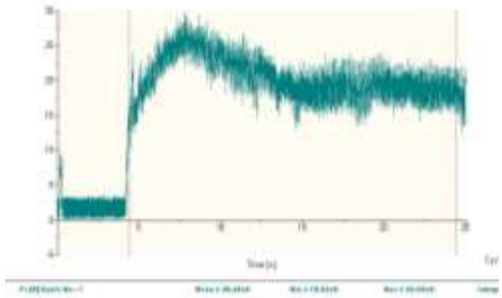
For all the three spindle speeds, the thrust force increases with increasing feed, a trend that agrees to many of the previous research attempts of this type. This phenomenon occurs because, increase in feed rate results in the increased cross sectional area of the uncut chip which increases the resistance to chip formation and, eventually, the thrust force [16].

Feed rate has proved to be the more influential parameter than spindle speed. This is in agreement with the findings of Davim and Reis [17]. In most of the cases, the CWC drill has resulted in lower thrust force values. Exceptionally, the HSS drill has recorded thrust force values lower than the solid carbide drill for the highest feed and spindle speeds (Fig.8. c and f). The TiAlN coated solid carbide drill tool seems to be better for drilling at normal speeds and feeds. At the thrust force vs time signals shown below, a sudden increase in the thrust force is observed in a time close to 5 seconds. This trend is similar for all the input parameter combinations. The reason for this sudden increase could be the transition of the chisel edge of a layer of resin matrix to the reinforcement layer.



(a)



(b)

Fig.9. Thrust force(N) vs time(s) (a-HSS drill, b-Solid carbide drill)

The thrust force variation with respect to the machining time for a fibre reinforced composite with distinct plies is given in Fig.10 [18]. The maximum thrust force characterized by peak 3 occurs when the drill starts cutting the bottom most ply and it is to be noted that this thrust force value exceeds the values at all other positions by a huge difference. This is the cause of push out delamination (the most frequently observed type than peel up). In case of the groundnut shell broom fibre composite the difference between the maximum value and the average value doesn't appear to be high (as the graphs in fig.9 show no very high peak). The obvious reason for this is the absence of distinct plies and the chances for delamination are very low. The results favoured this conceptualization as the delamination observed was very negligible.

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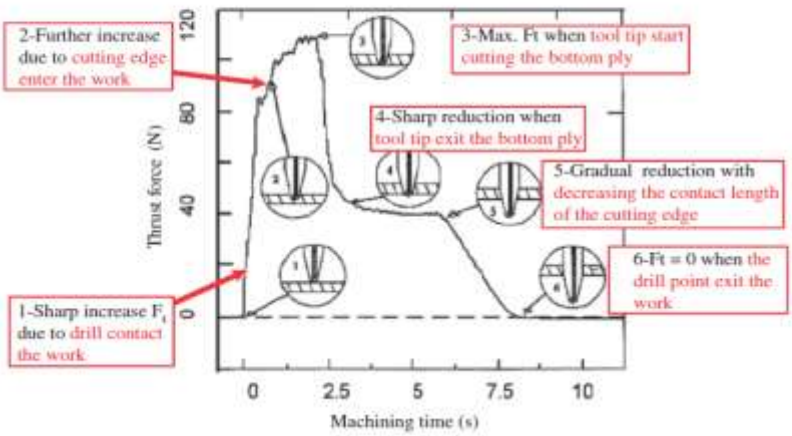

Fig.10. Typical thrust force versus time plot for a single drilling operation on CFRP

After all the holes were drilled in the composite plate, the drills showed no signs of tool wear. This is because of the absence of an abrasive nature in the natural fillers unlike glass fibres which are abrasive enough to cause high tool wear comparable to that caused in the drilling of hard metallic materials.

Morphology Test on Cross Sections of Fractured Surface

The analysis of the micrographs of the composites prepared under the fractography of alkali treated groundnut and broom fiber reinforced polymer composites are presented in Fig. 11. These fractography was recorded at two different regions at x35 and x300 magnifications. From these micrographs, it is clearly evident that the surface of the fibers becomes rough after alkali treatment. The elimination of hemi-cellulose from the surface of the groundnut and broom fiber may be responsible for the roughening of the surface. As a result of improvement in fibre matrix adhesion, fibre pullout is reduced.

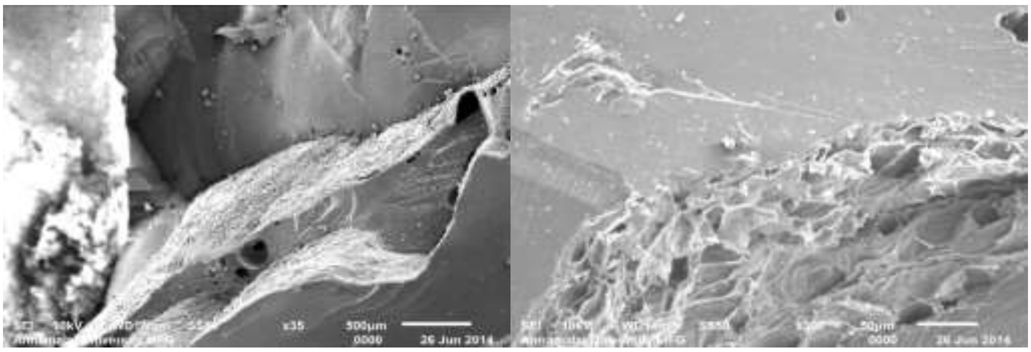

Fig.11. SEM image of drilling fractured surface of Ground nut and broom fiber composites

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Comparison for mono poly with hybrid polymer composites

It clearly shows that broom with groundnut polymer exhibited higher mechanical properties when compared to Groundnut and broom polymer composites. These figures clearly indicate that there is a marginal increase in tensile, flexural, compressive and impact strength of 30% and 40% volume fractions of fibres.

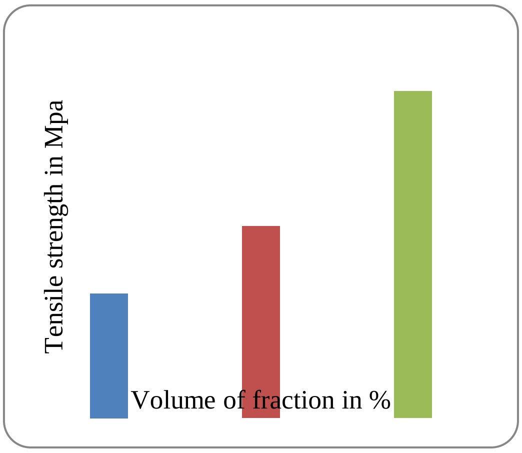

Fig.12. Tensile strength for groundnut and broom

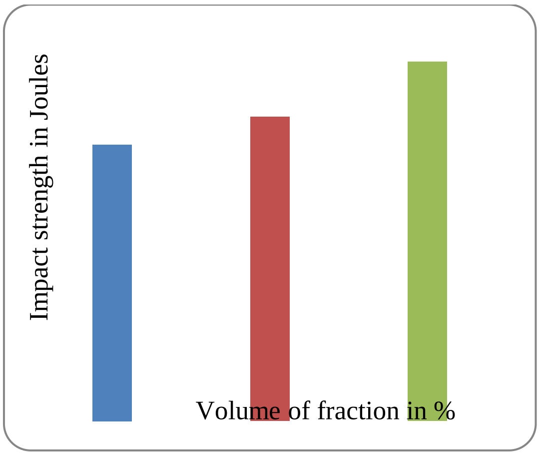

Fig.13. Impact strength for groundnut and broom

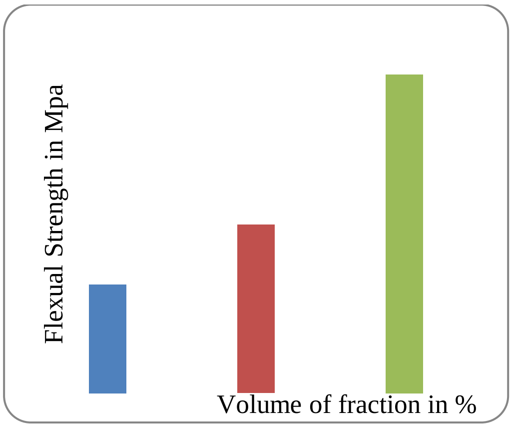

Fig.14. Flexural strength for groundnut and broom

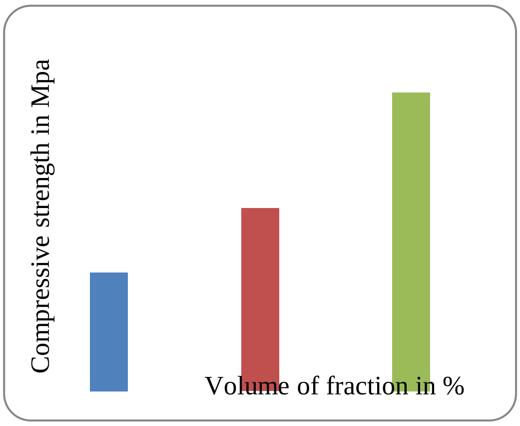

Fig. 15. Compressive strength for groundnut and broom

Conclusion

The hybrid natural fibre composites were fabricated and characterized successfully. The variation of compressive, impact, tensile and flexural properties of the groundnut and broom fiber reinforced epoxy polymer hybrid composites for 30%, 40%, and 50% fibers content were studied as a function of alkali treatment. It is reported that composites having 40% treated fiber content exhibited higher values for the fore mentioned properties than a broom and groundnut fiber polymer composites with 30% and 50% fibre contents. Thermo gravimetric analysis was performed to compare the thermal characteristics of conventionally cured and microwave cured composites. Microwave cured samples exhibited higher thermal stability indicating a better extent of cure.

The feasibility of drilling the composite by conventionally used twist drills has been established. There are good chances of optimal drilling (with low thrust force values) at feed rates up to 0.35mm/rev and within this range, solid carbide has proved to be the better tool material. Anyhow the high cost of solid carbide comparison to HSS is a limiting factor for the adoption of the former. Feed rate has proved to be a most influential parameter on the thrust force, than spindle speed. This work has explored and reasoned the difference in thrust force characteristics of composite materials with non-fibrous filler types and has established that this can account to low delamination.

In the present work, it was found that optimum values and significant improvements were at 40% treated fiber reinforced composites. The morphology of a fractured surface observed by SEM suggests that the networking of structure restricts the pull out of fiber, which is responsible for higher mechanical properties for 40 % fiber content. The decrease in strength at 50% fiber content is due to insufficient wetting of fiber with the matrix.

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