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Mechanical Characteristics for Different Composite Materials Based on Commercial Epoxy Resins and Different Fillers

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Abstract: In this research, different compositions of composite materials based on epoxy resin and four different fillers were prepared and all mechanical characteristics were investigated to reach a composite material having high resistance to impact by high kinetics energy projectiles which is required in the production of bulletproof jackets and also in cassette shields of explosive reactive armors to protect tanks. This composite material is usually applied as layers with other polymeric fibers such as carbon fibers and Kevlar (polyamide) sheets. The used epoxy consists of Epon as linear epoxy and tertiary amine as hardener. The used fillers are carbon black, magnesium carbonate, wood flour and sand. The pure thermoset epoxy (without filler) which gives the highest different mechanical properties is based on 10:5 by weight (linear Epon/Hardener). The composition which gave the highest resistance to impact by high kinetics energy projectiles was epoxy resin containing 15% by weight wood flour where the resistance to impact was increased by 32% when compared with the pure epoxy.

Key words: Composite, production, shields, composite, magnesium

INTRODUCTION

Problem definition and objectives: The bullet proof jacket and the cassette shields of explosive reactive armors are formed from different layers containing polymeric composite material of low density but with high resistance to penetration of high kinetic energy projectiles. Composites based on epoxies are very rigid and can resist bullet penetration specially when made with other layers of carbon fibers or Kevlar. In this research different composites based on epoxy resins were prepared and all mechanical properties were determined including resistance to high kinetic energy by falling steal ball to reach the optimum composition which may be used in the production of the bulletproof jackets and explosive reactive armors cassettes.

Literature review: Epoxy resins are polymeric thermo setting materials which are formed by main cross-linking using the reaction of "epoxide" group (Ellies, 1993). Generally, the simplest molecule of epoxy resin is a ring that containing two carbon atoms and one oxygen atom and it is known as "alpha epoxy ring" (Patil, 2010). They are described to be three-dimensional thermosetting polymeric networks in which the main chains are all combined through a network or matrix this makes the chain stronger they are formed chemically through a reaction between monomers to form the final psolymer (Patel, 2015; Flick, 2012). Epoxy resins are cured with what is so called "curing agents" that change its state from low viscous liquid to a stronger resins also another additives are added to the resin to change in its characteristics called "modifiers" both are used to command the resin to act in a certain way (Unnikrishnan and Thomas, 2006). Epoxy resins are used in a wide range in different applications due to their low viscosity, high insulation at elevated temperatures and their great resistance to thermal and chemical conditions (Borodulin, 2012). Epoxy resins used in adhesives, coatings, corrosion protectors, electric wires covering, optical fibers wrapping (Unnikrishnan and Thomas, 2006; Alibeiki *et al*., 2012).

MATERIALS AND METHODS

Approach to the problem: Four different samples were prepared with different ratios of Epon and hardener (10:4, 10:5, 10:6 and 10:7) and five mechanical tests were applied on the samples to select the best ratio of Epon to hardener. Four different fillers (carbon black, magnesium carbonate, wood flour and sand) were added to study the effect of adding different fillers on the mechanical properties. Mechanical tests are: tensile test, compression test, bending test, impact test by falling ball with weight of 1.4 kg and Hardness test using shore D device. The samples were prepared in moulds, petri dishes and test tubes to get the final shapes with the required dimensions and the petroleum jelly was used as a separating medium (Fig. 1 and 2).

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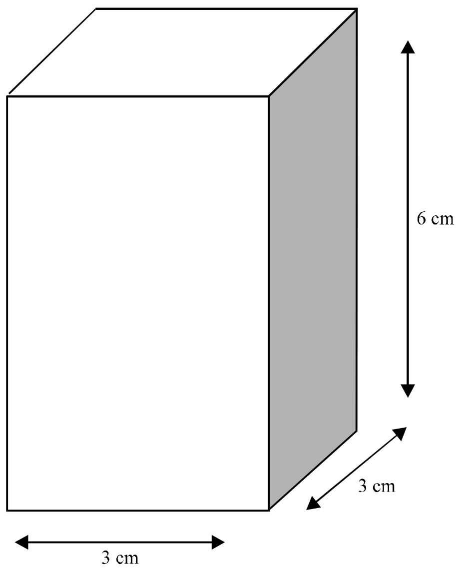

Fig. 1: Specimen dimensions for the compression test

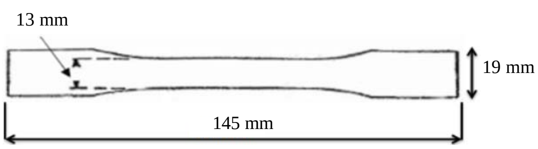

Fig. 2: Specimen dimensions used in the tensile test

RESULTS AND DISCUSSION

Selection of the best ratio between Epon and Hardener

Hardness test: Surface hardness was measured to check the complete curing of pure epoxy prepared samples by using shore D apparatus. The resultant values given are the average of at least three readings. The prepared samples were measured every 24 h until same readings are obtained. The time required for complete curing and the values of surface hardness are show in (Table 1).

Table 1: Results of hardness test

Samples	Curing time (days)	Average values
10:4	3	84.0
10:5	3	85.5
10:6	3	85.0
10:7	5	74.5

As it shown from the data above the sample with ratio 10:5 (Epon to hardener) showed the best performance as the curing time was observed to be three days and the average value was recorded to give the highest value 85.5.

It is clear from Fig. 3a that the best sample that resisted the stretching loading force to break it down was that with the ratio of 10:5. The tensile strength is the strength applied when the sample experiences stretching or elongation until fracture so having the highest value of the load applied on it, sample 10:5 (Epon/hardener) is concluded to have the highest resistance to tensile load.

Figure 3 the maximum force needed to begin the compression without any change in its dimensions was that with the ratio 10:5 (Epon/Hardener). Figure 3c shows that the best sample that resisted the loading force in the middle of the beam to bend it until breaking it down was with the ratio of 10:5. The data (Fig. 3d) represents the maximum energy released from the free fall that is required to hit the sample in order to break it down using a metal ball with weight of 1.4 kg. The sample with ratio (10:5) showed the best performance among all the other samples.

Effect of carbon black filler in the sample on the mechanical test results: It is clear from Fig. 4a that the best sample that resisted the stretching loading force to break it down was the pure sample without adding any percentage of filler. The sample with 2.5% filler showed the lowest resistance to the applied force. Decreasing the percentage of the filler showed a higher value of resistance than that of the 2.5%.

The maximum force needed to begin the deformation to decrease the length of the sample which represents the ability of samples to withstand the compression without any change in its dimensions was the pure sample without adding any percentage of filler (Fig. 4b). The sample with 2.5% filler showed the lowest resistance to the applied force. Decreasing the percentage of the filler to 0.25% showed a higher value of resistance than that of the 2.5%.

Figure 4c shows that the best sample that resisted the loading force in the middle of the beam to bend it until breaking it down was the sample with 1% filler in its content. The sample with 2.5% filler showed the lowest resistance to the applied force.

The data recorded many readings for different samples that representing the energy released from the free fall that is required to hit the sample in order to break it down using a metal ball with weight of 1.4 kg (Fig. 5a). It is clear that the sample with 1% filler has the highest energy of the material and thus it was observed to show the best performance of the test among all the other samples.

Figure 5b shows the hardness shore D test of many samples with different percentages of the filler. The pure sample showed a relatively low performance that kept improving by increasing the percentage of the filler until reaching the 0.5% sample and then the performance starts to decrease again until the 2.5% sample which shows the lowest performance among all samples. As it has been shown in the graphical representation, the maximum hardness of the material is found to be when adding 0.5% of the filler into the sample as it was observed to show the best performance of the test among all the other samples.

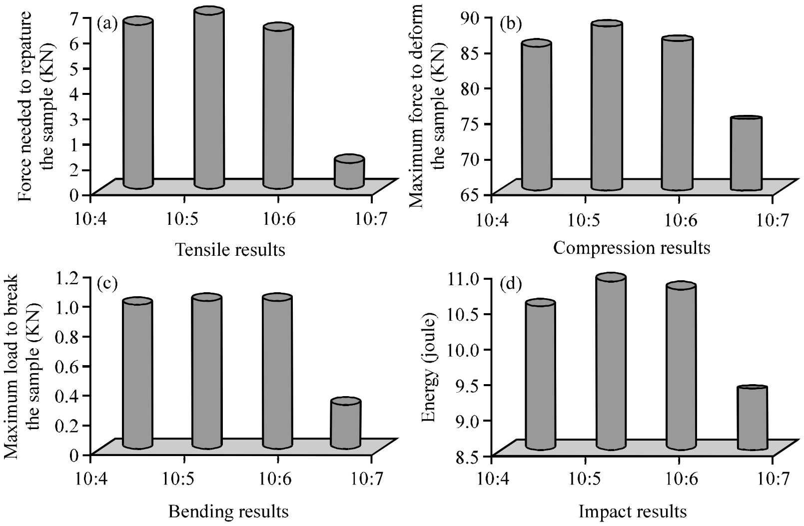

Fig. 3: a-d) Mechanical tests results of pure samples with different ratios

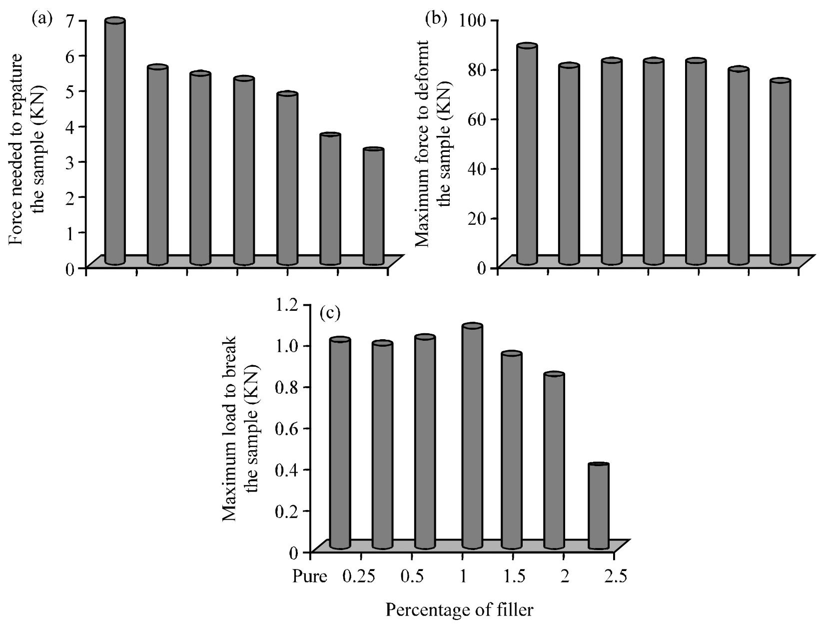

Fig. 4: Mechanical tests results of different percentage of carbon black: a) Tensile results; b) Compression results and c) Bending results

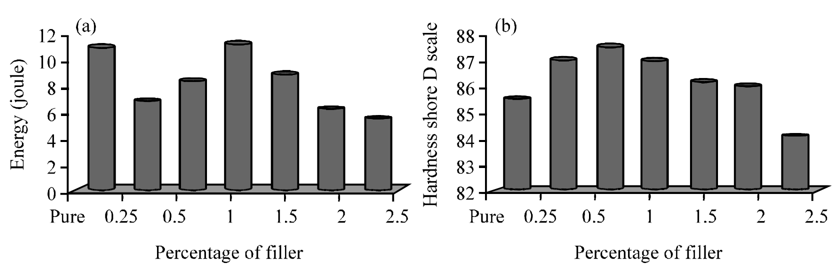

Fig. 5: Impact and hardness tests results of different percentage of carbon black: a) Impact results and b) Hardness results

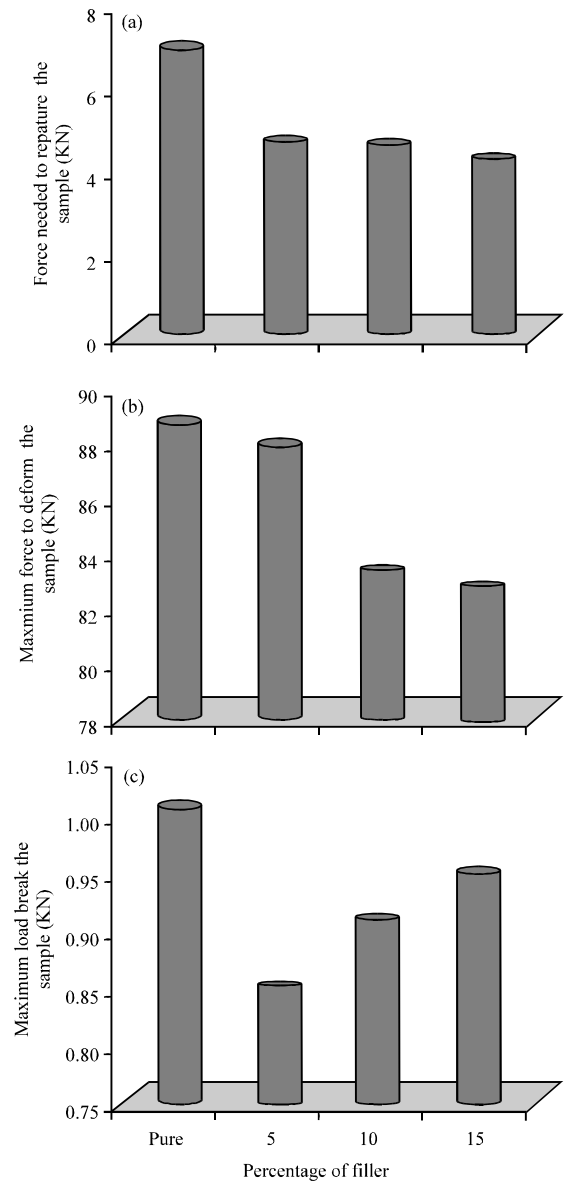

Fig. 6: Mechanical tests results of different percentage of magnesium carbonate: a) Tensile results; b) Compression results and c) Bending results

Effect of magnesium carbonate filler in the sample on the mechanical test results: It is clear from Fig. 6a that the best sample that resisted the stretching loading force to break it down was the pure sample without adding any percentage of filler. The sample with 15% filler showed the lowest resistance to the applied force. Decreasing the percentage of the filler showed a higher value of resistance than that of the 15%. Figure 6b the maximum force needed to begin the deformation to decrease the length of the sample which represents the ability of

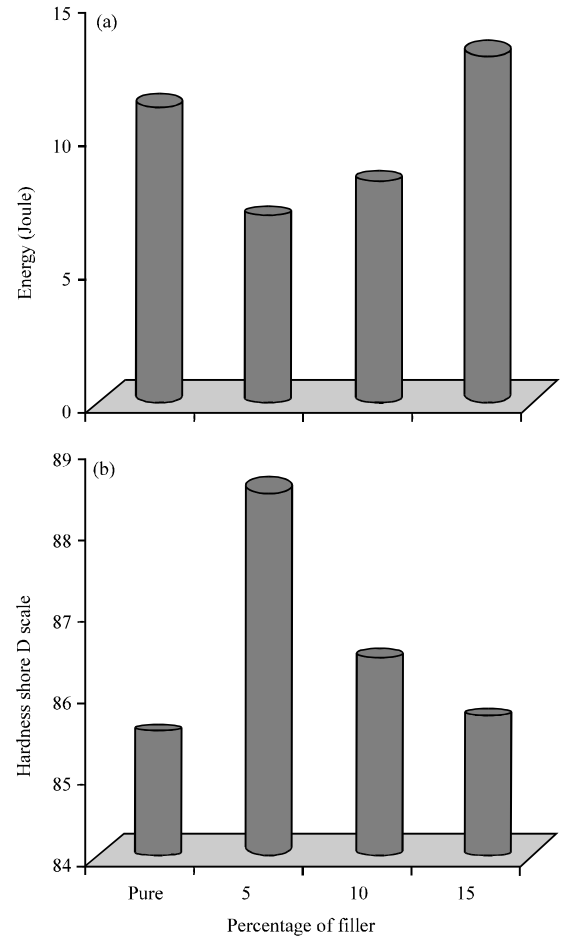

Fig. 7: Impact and hardness tests results of different percentage of magnesium carbonate: a) Impact results and b) Hardness results

samples to withstand the compression without any change in its dimensions was the pure sample without adding any percentage of filler.

The sample with 15% filler showed the lowest resistance to the applied force. As it has been shown in the figure, increasing the filler percentage decreases the deforming force.

Figure 6c shows that the best sample that resisted the loading force in the middle of the beam to bend it until breaking it down was the pure sample without adding any percentage of filler. The sample with 5% filler showed the lowest resistance to the applied force.

Figure 7a represents the maximum energy released from the free fall that is required to hit the sample in order to break it down using a metal ball with weight of 1.4 kg. It is clear that the sample with 15% filler showed the highest performance and thus it was observed to show the best performance of the test among all the other samples.

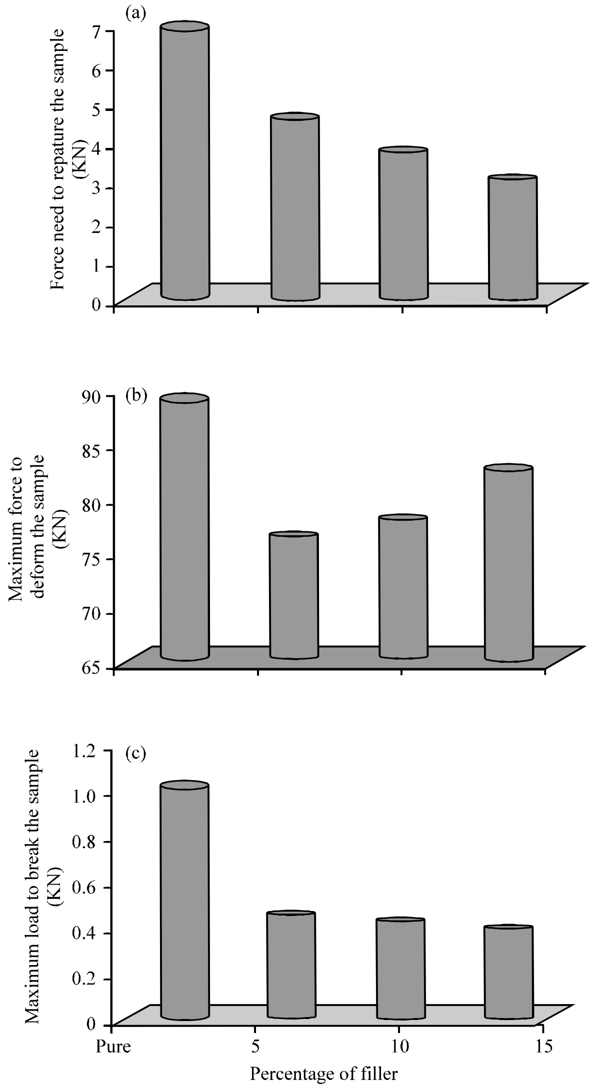

Fig. 8: Mechanical tests results of different percentage of wood flour: a) Tensile results; b) Compression results and c) Bending results

Figure 7b and c shows the hardness shore D test of many samples with different percentages of the filler. The pure sample showed the lowest performance that kept improving by increasing the percentage of the filler until reaching the 5% sample and then the performance starts to decrease again at the 10% sample and the 15% sample. As it has been shown in the graphical representation, the maximum hardness of the material is found to be when adding 5% of the filler into the sample as it was observed to show the best performance of the test among all the other samples.

Effect of wood flour filler in the sample on the mechanical test results: Figure 8a mechanical tests results of different

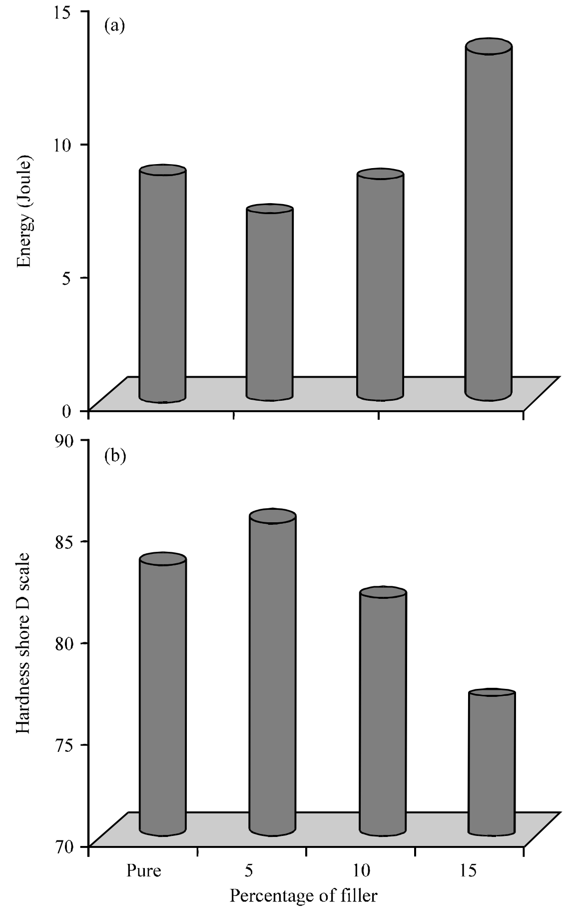

Fig. 9: Impact and hardness tests results of different percentage of wood flour: a) Impact results and b) Hardness results

percentage of wood flour. It is clear from Fig. 8b that the best sample that resisted the stretching loading force to break it down was the pure sample without adding any percentage of filler. The samples with 5, 10 and 15% filler showed quite similar behavior during testing. As it has been shown in the graphical representation, the pure sample with no filler in its structure was observed to show the best performance of the test among all the other samples.

The maximum force needed to begin the deformation to decrease the length of the sample which represents the ability of samples to withstand the compression without any change in its dimensions was the pure sample without adding any percentage of filler (Fig. 8b). The sample with 15% filler showed the lowest resistance to the applied force. As it has been shown in the figure, increasing the filler percentage decreases the deforming force. Figure 9a shows that the best sample that resisted the loading force in the middle of the beam to bend it until breaking it down was the pure sample without adding any percentage of filler. The sample with 15% filler showed the

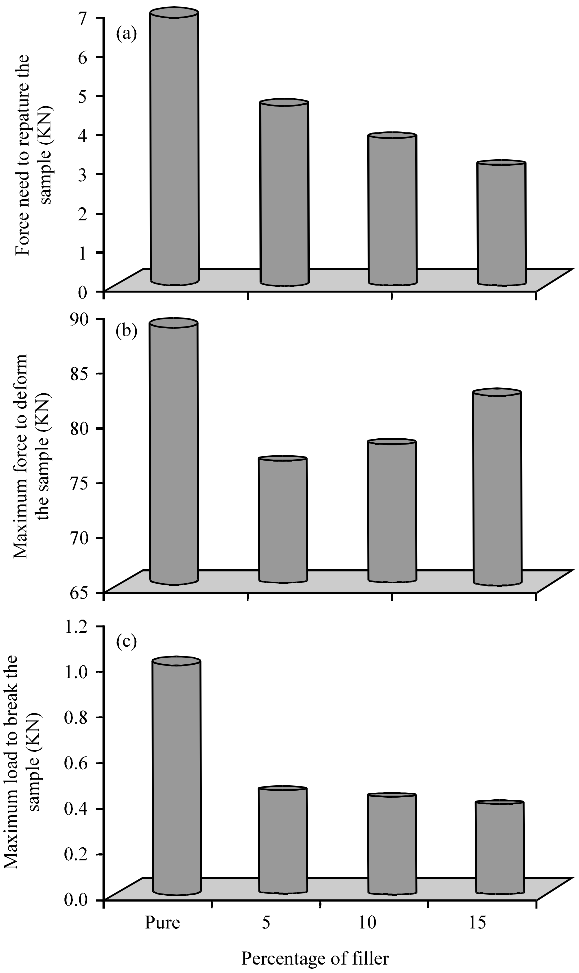

Fig. 10: Mechanical tests results of different percentage of sand: a) Tensile results; b) Compression results and c) Bending results

lowest resistance to the applied force. Figure 9 represents the maximum energy released from the free fall that is required to hit the sample in order to break it down using a metal ball with weight of 1.4 kg. It is clear that the sample with 15% filler showed the highest performance and thus it was observed to show the best performance of the test among all the other samples. Figure 10 shows the hardness shore D test of many samples with different percentages of the filler. The 5% sample showed the highest performance that kept decreasing by increasing the percentage of the filler until reaching the 15% sample.

Effect of sand filler in the sample on the mechanical test results: It is clear from Fig. 10 that the best sample that resisted the stretching loading force to break it down was

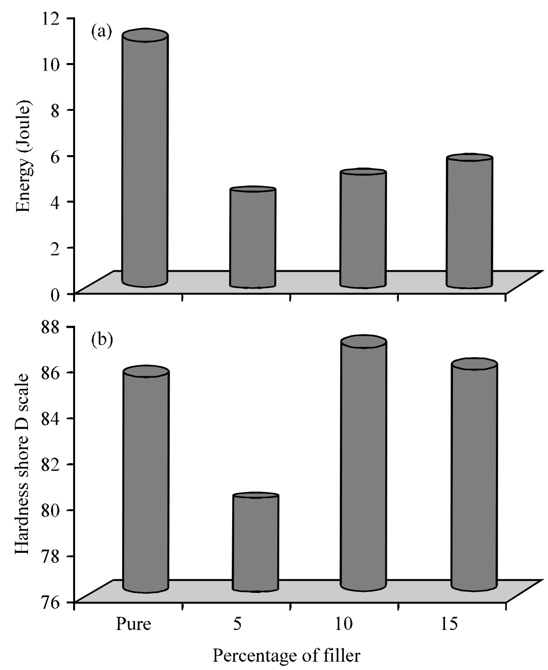

Fig. 11: Impact and hardness tests results of different percentage of sand: a) Impact results and b) Hardness results

the pure sample without adding any percentage of filler. The sample with 15% filler showed the lowest resistance to the applied force.

The maximum force needed to begin the deformation to decrease the length of the sample which represents the ability of samples to withstand the compression without any change in its dimensions was the pure sample without adding any percentage of filler. The sample with 5% filler Fig. 10b showed the lowest resistance to the applied force. As it has been shown in the figure, increasing the filler percentage increases the deforming force.

Figure 10c shows that the best sample that resisted the loading force in the middle of the beam to bend it until breaking it down was the pure sample without adding any percentage of filler. The sample with 15% filler showed the lowest resistance to the applied force. Figure 11 represents the maximum energy released from the free fall that is required to hit the sample in order to break it down using a metal ball with weight of 1.4 kg. It is clear that the pure sample without adding any filler showed the highest performance and thus it was observed to show the best performance of the test among all the other samples.

Figure 11a shows the hardness shore D test of many samples with different percentages of the filler. The pure sample showed a relatively high performance that decreased by increasing the percentage of the filler until reaching the 5% sample and then the performance started to improve again at the 10% sample showing the highest performance. The 15% sample showed a slightly lower performance than that of the 10% sample but still relatively high. As it has been shown in the graphical representation, the maximum hardness of the material is found to be when adding 10% of the filler into the sample as it was observed to show the best performance of the test among all the other samples.

CONCLUSION

It was observed that the stated aim was fulfilled through this study as composite epoxy with different fillers showed high resistance against the applied kinetic energy projectiles through the impact test. There were many introduced samples with different ratios of hardener and epoxy, the sample with the highest performance was observed to be the 10:05 sample. After performing the impact test with high kinetics energy on many samples of epoxy with different fillers, it was concluded that wood flour filler showed the best performance when added with a percentage of 15% to the epoxy resin and the performance was improved by percentage of 32% compared to the pure sample. Other mechanical tests were performed on the samples and it was proved that the mechanical characteristics of the samples show a slight change that does not affect the performance. On an industrial range, this was taken in considerations as it was proved to be a cheaper method than using a pure epoxy and will show an advanced mechanical performance as well.

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