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Research Article

Investigation of Mechanical and Thermo-Mechanical properties of Cement-by-Pass Dust Filled Short Glass Fiber Reinforced Polyester Composites

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Abstract:
The present work is carried out for the investigation of mechanical and thermo-mechanical properties of cement-by-pass (CBPD) dust as a filler material in the short fiber reinforced polyester resin composites in various engineering applications. It is observed that with the addition of CBPD drastic changes has been observed in mechanical and thermo-mechanical properties of the present composites. The hardness, tensile Modulus, flexural modulus and impact strength of the composites increases with increase in the CBPD as a filler contents. On the other side with addition of filler contents there is decrease in tensile and flexural strength. At the end, there is improved in the visco-elastice and damping property of present composites with the addition of cement-by pass dust filler contents.

Keywords: Composite; Cement-by pass dust; Glass fiber; Polyester; Dynamic Mechanical Analysis

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1. Introduction

The main challenges in the present scenario of the world is to the utilization of cement by-pass dust, which is a by-product of cement manufacturing as partial replacement of Portland cement (PC). The environment protection agencies are trying to find the ways to minimize the dual problems of disposal and health hazards of these by-pass products. Cement by-pass dust is a fine powdery material similar to Portland cement in appearance. It is generated during the calcining process in the kiln. As the raw materials are heated in the kiln, dust particles are produced and then carried out with the exhaust gases at the upper end of kiln. These gases are then cooled and accompanying dust particles are captured by efficient dust collection system [1]. For many years, by-products such as fly-ash, silica fume and slag were considered as waste materials. These by-products have been successfully used in the construction industry as a portland cements substitute [2]. However, with the increase of industries the different types of by-products are being generated by various industries, which could have being a promising future for partial replacement of portland cement. During composite fabrication, the physical and mechanical characteristics can be modified by adding a solid filler phase to the matrix body. The particles in these composite are larger than in dispersion reinforced composites. With the addition of particulate fillers, the performance of polymer and their composites in structure and industrial application has been improved, which shows a great promise.

The fillers play a major role in determining the properties and behaviour of particulate reinforced composite materials. The particles are used to increase the modulus and decrease the ductility of the matrix. So by the addition of both the fiber and particles in the matrix could provide a synergism in the way of improved properties and performance. However, some recent reports and research publications presented that with the addition of filler particles into the fiber reinforced composites, interactive effects may be achieved in the form of higher modulus and reduced material cost, yet accompanied with decreased strength and impact toughness [3, 4]. Such multi-component composites are termed as hybrid composites which consist of the matrix phase reinforced with fiber and filled with particulate matters.

The mechanical performance of composites is of more interest to the component designer. The mechanical properties of polymer composites are depending on the properties of the constituent materials (type, quantity, fiber distribution and orientation, void contents). A few numbers of researchers has carried out their studies on the use of cement by-pass dust as industrial wastes in fabrication of polymer composites. The effect of cement by-pass dust on the compressive strength of cement paste was studied and the corrosion behavior of embedded reinforcement and observed that up to 5 wt.-% of cement by –pass dust has less effect on cement paste strength and on reinforcement [5]. Patnaik et al. [6] reported the effect of fly ash, alumina and silicon carbide filler on the erosive wear behaviour and mechanical properties of the glass polyester composites which shows that the addition of these fillers the mechanical properties and erosion wear behaviour of the composites improved significantly. Also Biswas and Satapathy [7] reported the effect of red mud filled bamboo-epoxy and glass-epoxy composites on the erosive wear behaviour and mechanical properties of the composites. Similarly, Satapathy et al. [8] fabricated the cenosphere-filled polypropylene (PP) composites and studies their structural/morphological characteristics and fracture mechanical behaviour.

Dynamic mechanical analysis (DMA) is important technique which is used to study the effect of temperature, stress and phase compositions of fiber composites on the mechanical properties of the composite materials. When considering the energy dissipation processes in cyclic loading applications the knowledge of dynamic mechanical properties of the polymer composites is important. Qiao et al. [9] conducted the dynamic mechanical analysis to study the effect of the fly ash volume fraction on the composites mechanical properties. It was found that the storage and loss moduli of the composite increases with increase in the volume fraction of fly ash. The storage and loss moduli of the composites relative to those of pure polyurea initially increase significantly with temperature and then slightly decrease or stay flat, attaining peak values around the glass transition region. The glass transition temperature shifted toward higher temperatures as the fly ash volume fraction increased. Kumar et al. [10] analyzed the thermo-mechanical properties of short carbon fiber reinforced vinyl ester matrix composite to access the energy absorption/viscous recoverable energy dissipation and reinforcement efficiency of the composites as a function of fibre content in the temperature range of 0-140C. Liang [11] investigated the dynamic mechanical properties of inorganic glass beads fillers polymer composites in the temperature range of -150^{0}C to 100^{0}C and found that the storage modulus increased roughly nonlinearly with an increase of the glass bead weight fraction.

Hence, from the above literature review the present work is carried out to investigate the physical, mechanical and thermo-mechanical properties of polyester based cement by-pass dust filled short glass fiber reinforced hybrid composite which leads to maximum utilization of cement by-pass dust as an industrial waste and minimizing the CBPD disposal problem for the industries.

2. Materials & methods

2.1 Materials

Short E-glass fibers (Elastic modulus = 72.5 GPa; Density = 2.59 gm/cm^3) of 6 mm length are used to prepare the composites. The unsaturated isophthalic polyester resin (Elastic modulus = 3.25 GPa; Density = 1.35 gm/cm3) manufactured by Ciba Geigy and locally supplied by Northern Polymers Ltd. New Delhi, India.

2.2 Fabrication of composites

The composite fabricated by keeping the fiber percentage fixed (50 wt.-%) in polyester resign and varying CBPD filler loading in three different percentage (0 wt.-%, 10 wt.-% and 20 wt.-%) respectively. The fabrication was carried by adopting manual stir casting technique. An accelerator cobalt-nephthalate of 2 wt.-% and hardner methyl-ethyl-ketone-peroxide (MEKP) of 2 wt.-% was mixed with polyester resin while fabrication. The mixture is poured into various moulds conforming to the requirements of various testing conditions and characterization standards. The castings were put under load for about 24 h for proper curing at room temperature. Thereafter, specimens of suitable dimension were cut using diamond cutter for the testing physical, mechanical and thermo-mechanical properties respectively.

3. Physical and mechanical characterization of the composites

The fabricated composites are tested for physical, mechanical and thermo-mechanical properties as per the ASTM standards.

The theoretical density of composite materials in terms of weight fraction can easily be obtained as for the following equations given by Agarwal and Broutman [12] in Eq. (1),

$$\rho_{ct} = \frac{1}{\frac{w_f}{\rho_f} + \frac{w_m}{\rho_m} + \frac{w_p}{\rho_p}} \quad (1)$$

Where, *w* and • represents the weight fraction and density, respectively. The suffix *f*, *m*, *p* and *ct* stand for the fiber, matrix, particulate filler and the composite theoretical density respectively. The actual densities (•$_{ce}$) of the composite were determined experimentally by simple water immersion technique and the void fraction (V_v) presence in the composites was calculated using Eq. (**2)** is as below,

$$V_v = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \quad (2)$$

The hardness measurement was performed using a micro-hardness tester equipped with a square based pyramidal (angle 136° between opposite faces) diamond indenter by applying a load of 10 N. The tensile test was performed on flat specimens (length of the test section 200 mm) as par ASTM D3039-76 standards on the universal testing machine Instron 1195. Similarly, the flexural test was performed on the specimen (span length of 100 mm; crosshead speed of 5 mm/min). The impact strength was evaluated using low velocity pendulum impact testing machine following ASTM D 256 on a specimen 60 ×10 × 4 mm^3 and the depth under the V-notch (45º) is 2 mm.

3.1 Thermo-mechanical analysis of the composites

The dynamic mechanical analysis (DMA) was conducted in oxygen atmosphere at a fixed frequency of 1 Hz, heating rate of 5°C/min, a temperature range of 25-250°C and a strain of 1% on rectangular samples with dimension of 25×4×1 mm^3 using Q800 DMA instrument in bending mode.

4. Results and discussion

4.1 Effect of filler content on void fraction of the composite

The density is a material property which is of prime importance in several weight sensitive applications. Thus, due to the low densities of the polymer composites they replace conventional metal and materials in such type of applications. It is seen from Table 1 that the theoretical calculated density values are not in agreement with the experimental determined density values. Therefore, the voids and pores present in the composites can be calculated on the basis of difference between theoretical and experimental calculates density values. In the present work the density of the composites increased with the addition of cement by-pass dust particulate as filler materials in the composite. The density of the short glass fiber reinforced polyester composite without filler is 1.30 gm/cm^3 and void fraction of 8.4%. However, on addition of cement by-pass dust (10 wt.-% and 20 wt.-%) the density of the resulting hybrid composite increases to 1.58 gm/cm^3 with a void fraction of 20% and 1.66 gm/cm^3 with a void fraction of 23% respectively. It means that with the increase in the filler contents the voids fraction increases. This is due to the apparently greater density of fillers than that of the polyester matrix. Another reason for this is the irregular shape of the fillers and presence of empty spaces near sharp edges of the filler particles and less efficient dispersion of particulate fillers in the composites.

The important conclusion is that these composites are very light materials that can be useful in applications that require low weight.

Table 1 Theoretical and experimental densities of the composites

Sample no.	Filler Content (wt.-%)	Theoretical density (gm/cm^3)	Experimental density (gm/cm^3)	Void fraction (%)
1	0	1.30	1.19	8.4
2	10	1.58	1.25	20
3	20	1.66	1.27	23

4.2 Effect of filler content on hardness of the composites

The variation in hardness values with addition of cement by-pass dust filler in short glass fiber-polyester composites is shown in Figure 1. It is observed form the figure that CBPD filled composites shows higher value of hardness as compare to the unfilled short glass fiber-polyester composite. This increase in hardness value with the addition of CBPD filler may be due to the increase in weight percentage of filler contents, which leads to the increase in ductility of materials and offers resistance to penetration [13]. With increase in filler loading in matrix materials decreases the inter particle distance, thus the polymeric matrix phase and the solid filler phase would be pressed together and touch each other more tightly and interface between them can transfer pressure more effectively which results in resistance to penetration [14].

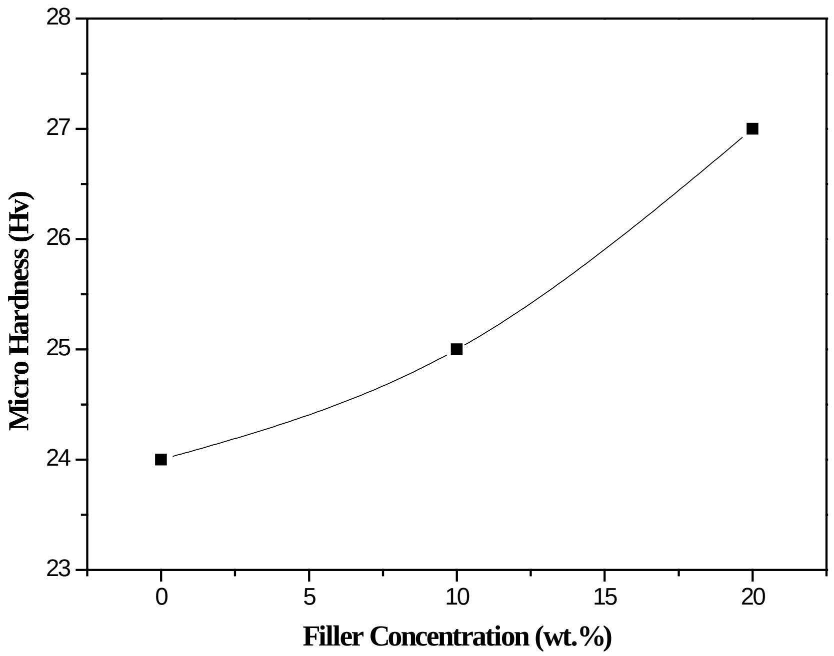

Figure 1 Variation of micro hardness with CBPD filler percentage

4.3 Effect of filler content on tensile strength and modulus of the composites

It is seen form the Figure 2 that tensile strength of the composite decreases with increase in cement by-pass dust contents. The tensile strength of the composite without CBPD filler is 24.96 MPa whereas for 10 wt.-% CBPD it is 16.07 MPa and for 20 wt.-% CBPD it is 11.83 MPa respectively. Therefore the unfilled short glass fiber-polyester composite has higher tensile strength as compared to the CBPD filled short glass fiber-polyester composites. The decrease in tensile strength may occur due to the agglomeration of filler particles or physical contact between adjacent agglomerates [15]. The agglomerate is a domain that can act like a foreign body in composites. Since there was a higher amount of agglomerates in higher filler loading composites, these agglomerates act as obstacles to chains movement and initiate failure under stress. Agglomerates will become stress concentrator and building up stresses in composites quicker than usual and caused earlier rupture, if compared to unfilled samples. However, a different explanation was given by Ismail & Chia [16] who claimed that poor tensile strength may be attributed to the geometry of fillers. Strength of the composites with irregularly shaped fillers decreased due to the inability of the fillers to support stresses transferred from the polymer matrices [17].

Whereas the, tensile modulus of present composites increases reasonably with increase in the CBPD contents which is shown in Figure 3. This increase may attributed to low strain rate of the composite during tensile test. It is seen from previous reports [18, 19] that normally the glass fibers in the composite restrain the deformation of the matrix polymer reducing the tensile strain. So even if the strength decreases withfiller addition the tensile modulus of the hybrid composites is expected to increase.

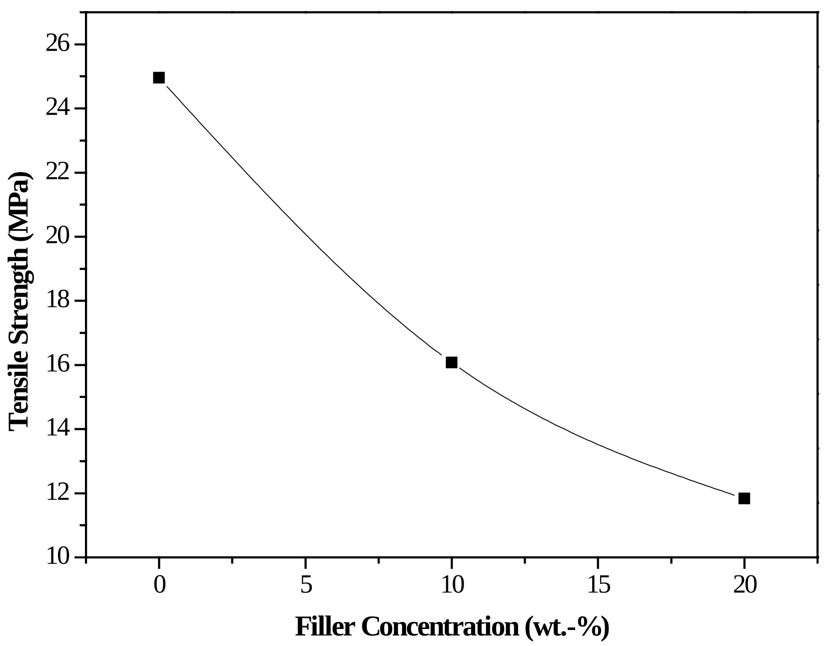

Figure 2 Variation of tensile strength with CBPD filler percentage

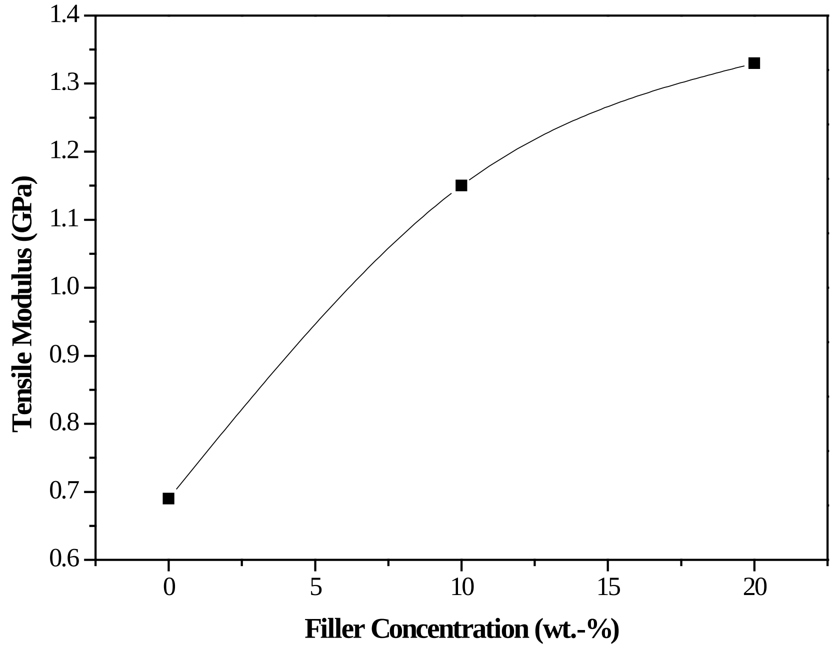

Figure 3 Variation of tensile Modulus with CBPD filler percentage

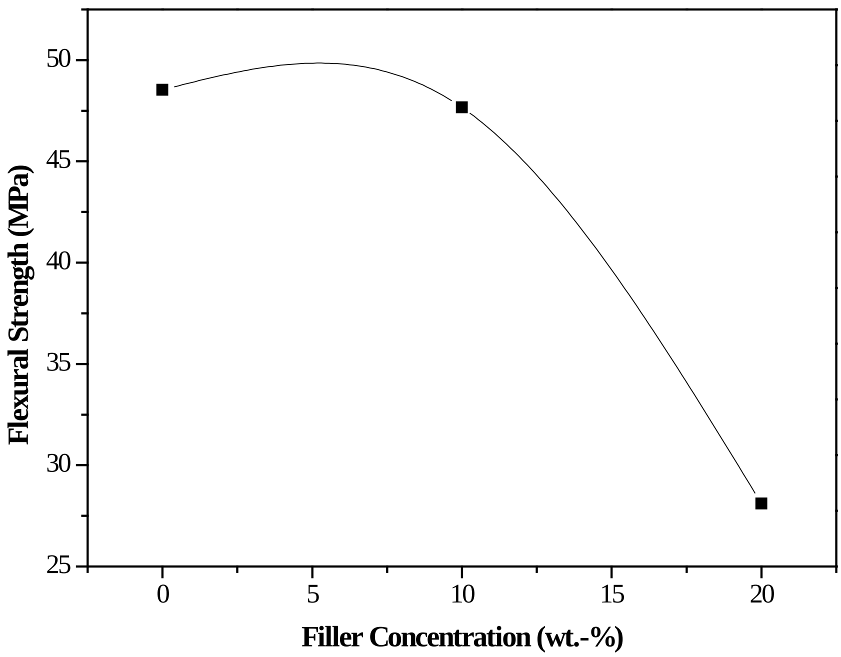

Figure 4 Variation of flexural strength with CBPD filler percentage

4.4 Effect of filler content on flexural strength and modulus of the composites

It is observed from Figure 4 that with the addition of 10 wt.-% and 20 wt.-% of CBPD filler contents, the flexural strength decreases. The decrease in flexural strength of filled composites may be due to the poor interfacial adhesion and incomplete matrix fusion and the voids presets in the composites. The voids within the matrix indicated boundary areas where complete fusion was not attained. Therefore the flexure strength decreases of the present composite decreases with increase the filler contents. However, it is observed from the Figure 5 that the composites filled with cement by pass dust (CBPD), the flexural modulus improves with the addition of 10 wt.-% of CBPD content but on further increase up to 20 wt.-% of CBPD contents, the modulus values are found to be decreasing. The increase and decrease in flexural modulus may be the level of reinforcement in the composites. These include the volume fraction of particulate filled, the surface area of the filler relative to particle size, particle shape, the level of adhesion between the filler and polymer [20], as well as the thickness and nature of inter-phase between the two phases.

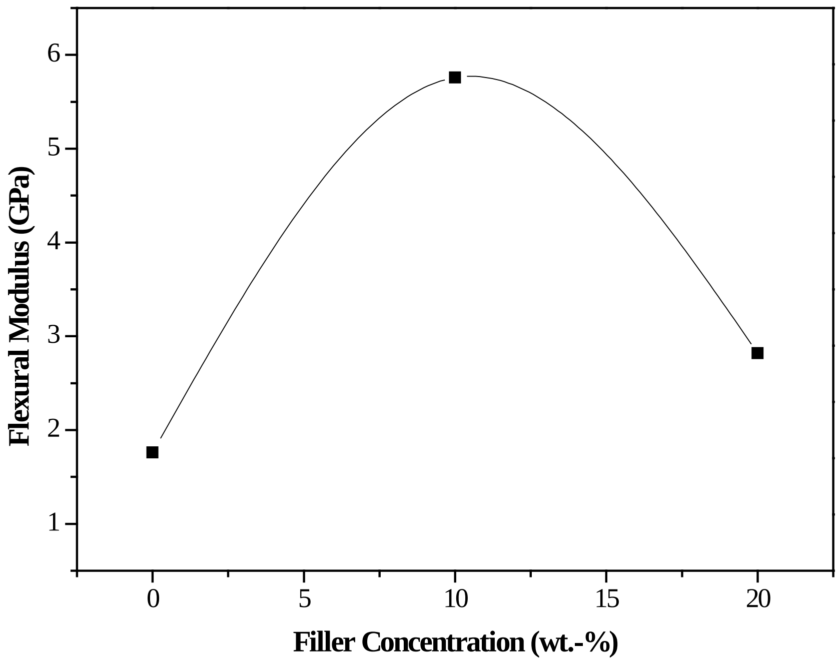

Figure 5 Variation of flexural modulus with CBPD filler percentage

4.5 Effect of filler content on impact strength of the composites

Impact strength is another important mechanical property that is difficult to predict in a filled polymer composite. Impact resistance is the ability of a material to resist breaking under a shock loading or the ability to resist the fracture under stress applied at high velocity. The impact performance of fiber reinforced composites depends upon many factors including the nature of constituents, fiber/matrix interface, the construction and geometry of the composite and test conditions. The impact failure of the composite occurs due to factors like matrix fracture, fiber/matrix debonding and fiber pullout. Fiber pull out is found to be an important energy dissipation mechanism in fiber reinforced composite [21]. Figure 6 presents the measured impact energy values of the CBPD filled composites under this investigation. It is seen from the figure that the impact energies of the short glass-polyester composites increased gradually with the increase in the CBPD contents from 0 wt.-% to 20 wt.-%. In case of unfilled glass polyester composite impact energy is 2.284 J, as the addition of CBPD contents increases from 10 wt.-% to 20 wt.-% the impact energy increases from 3.885 J to 4.99 J respectively. This shows that with increase in the filler contents the impact strength of the composite increases simultaneously.

A polymer having good impact resistance should absorb most of the impact energy and propagate a crack very slowly. Therefore, with the increase in the filler contents in the composites the toughness of the composite increases and composite becomes toughened. There are several mechanisms for toughing of polymers. For the inorganic particles toughened polymers, at least three factors are necessary: inherent ductility of the matrix, weak interface supporting the filler/matrix debonding and suitable inter-particle distance [22]. Therefore, there are so many engineering applications of composites materials in which high strain rate and impact load may be expected [23].

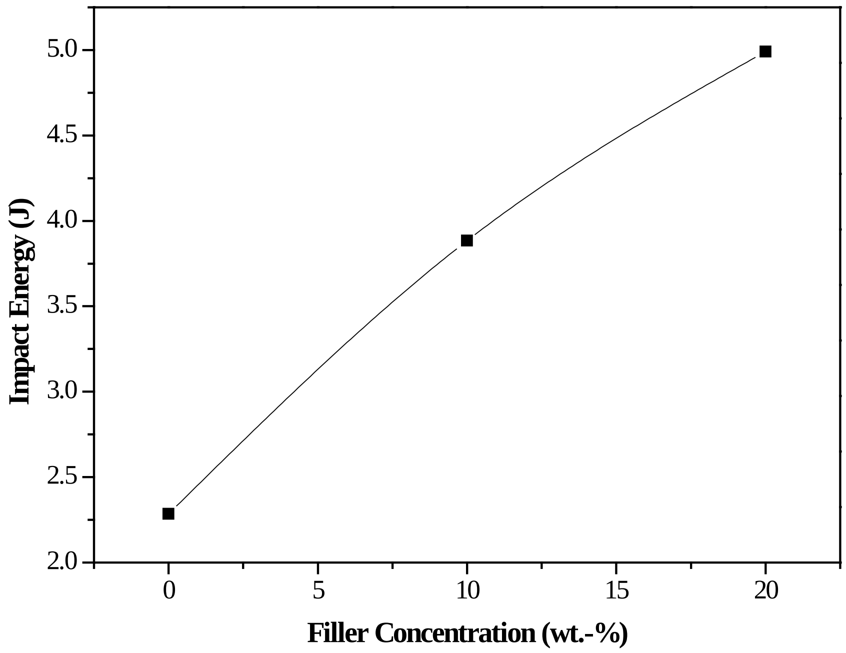

Figure 6 Variation of impact strength with CBPD filler percentage

4.6 Effect of filler contents on dynamic mechanical analysis of the composites

The storage modulus is a measure of the maximum energy stored in the material during one cycle of oscillation. This provides valuable insight into the stiffness of the fiber, representing the elastic nature of the materials [24]. In general, there are three physical states of polymer materials: glassy region, glass transition region, and rubbery region. In the glassy region the movement of chain segment is mostly "frozen" due to tight packing, so the material is prone to store energy; this results a high storage modulus [25].

The variation of storage modulus with temperature as shown in Figure 7, shows that the magnitude of storage modulus increases dramatically with the incorporation of 10 wt.-% of CBPD in the virgin composite leading to a maximum, which however, gets subsequently decreased with further increase in CBPD (20 wt.-%) content. At room temperature (25ºC) the increase in storage modulus value is about ~50% with the addition of 10 wt.-% CBPD and further addition of CBPD (20 wt.-%) it decreases by ~20% of its value to that of 10 wt.-% of CBPD. As the temperature increases, the components become more mobile and lose their close packing arrangement, leading to decrease of storage modulus in the glass transition region 30-80°C. The temperature dependent decay of the storage modulus for the composites with 10 wt.-% and 20 wt.-% CBPD remain almost same in the in the glass temperature range and becomes as a result, in the rubbery region there is no significant change in storage modulus; this can be ascribed to a highly entangled state of the polyester much steeper in both the composition in between 50-80^{0}C.

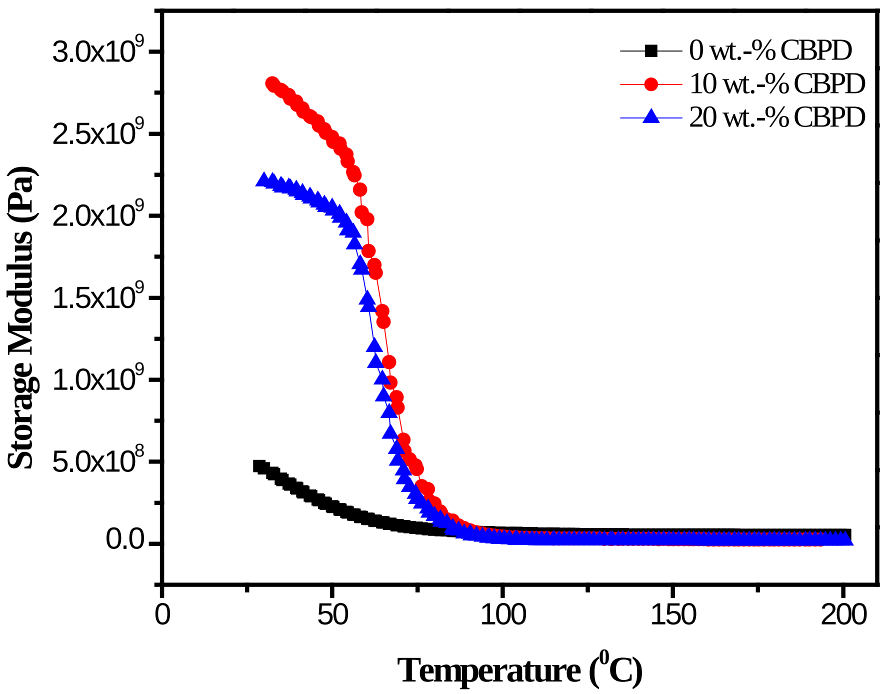

Figure 7 Variation of the storage modulus (E') as a function of temperature

The variation of loss modulus with temperature as shown in Figure 8, in relation to energy lost to friction as heat and internal motions reflecting viscous behavior [26], shows that the magnitude of loss modulus also increased with the incorporation of 10 wt.-% of CBPD in the virgin composite leading to a maximum, which however, gets subsequently decreased with further increase in CBPD (20 wt.-%) content. The loss modulus peaks is higher for 10 wt.-% CBPD than those with 20 wt.-% CBPD filled composites because of the hindrance of the molecular motion [25]. This qualitatively indicates the enhancement in the energy dissipation ability of the composite with 10 wt.-% CBPD. The ratio of loss modulus to storage modulus is referred to as internal damping or the loss tangent (tan •), as indicated by the dynamic behaviour of the composites. Generally, the major contributing causes of composites damping are: the nature of the matrix and filler, the nature of the interface, frictional damping due to slippage in the unbound region between the filler and the matrix interface, delamination and energy dissipation in the area of matrix cracks [25].

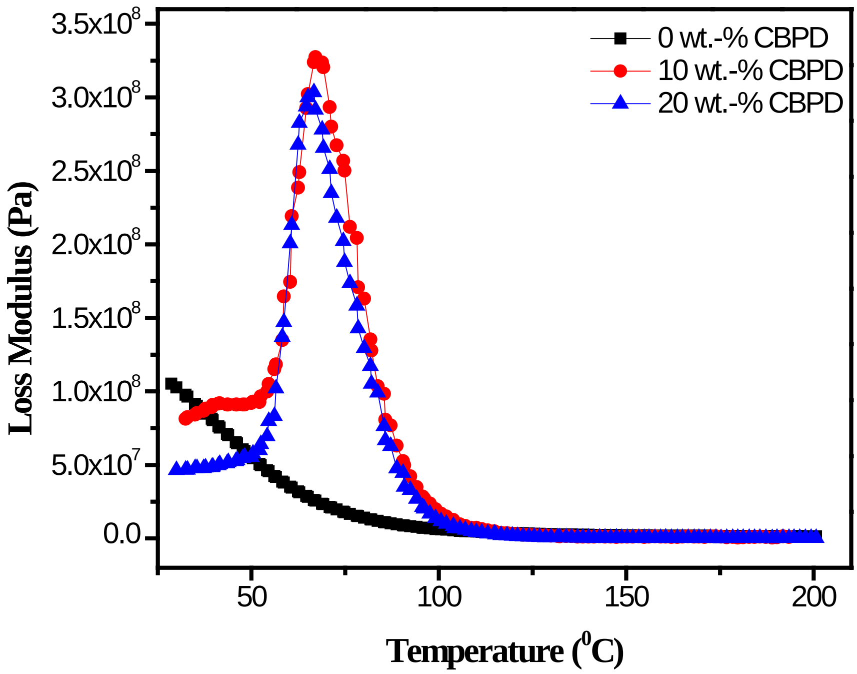

Figure 8 Variation of the loss modulus (E") as a function of temperature

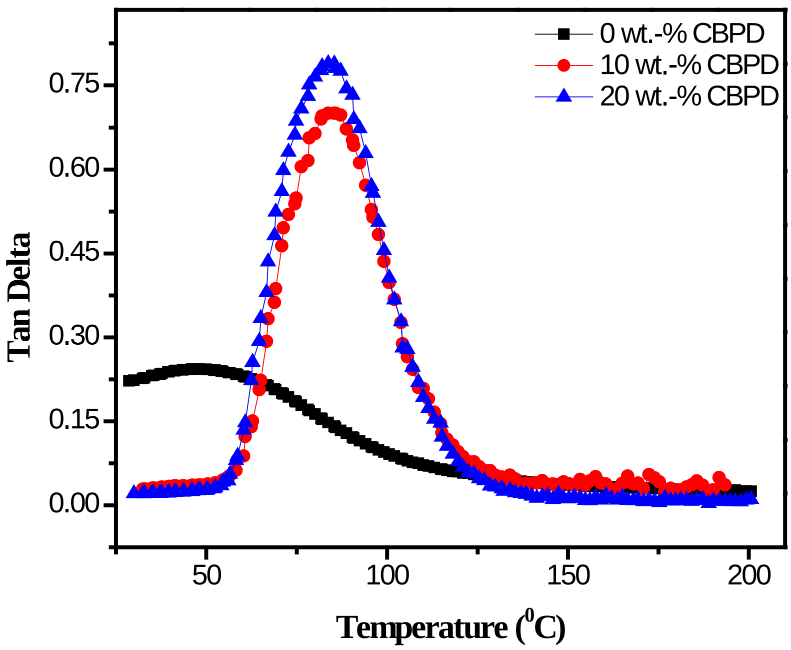

Figure 9 Variation of the damping parameter (tan •) as a function of temperature

The damping peaks usually occur in the glass transition region, and are associated with the movement of side groups or low-molecular-weight units and molecular chain with in the matrix. Therefore, the higher the damping peak, the greater the degree of molecular mobility [27].The glass fibre reinforced and CBPD filled polyester composites are used in the present study. With 10-20 wt.-% CBPD loading the glass transition temperature, Tg, determined from the peak position of tan •, increased from ~50 ^{o}C to ~80 ^{o}C. The interaction between polymer matrix and the fillers are affected by the temperature. At the lower temperature, molecular chains are fixed in a small space, holding the glass fibre and CBPD filler. But at the higher temperature, molecular chains can move freely in a large space, and the interaction between matrix and the ingredients becomes weak. There is no difference in T_g (Figure 9) with 10 wt.-% and 20 wt.-% addition of CBPD in the parent composition but the value of tan • increases to 0.82 for 20 wt.-% CBPD loading.

5. Conclusions

Present work investigates the physical, mechanical and viscoelastic behavior properties of polyester based CBPD filled short glass fiber reinforced hybrid composite. Following observations are made from the work:

1) It is found that the tensile strength and flexural strength of all the particulate filled composites decrease with the addition of fillers contents. This is due to the poor bonding of fillers with matrix and irregular shapes of the fillers.

2) The hardness and the impact strength of all the composites increase with increase in the fiber contents in the short glass-polyester composites.

3) Whereas, the tensile modulus and flexural modulus of all the composites increases with increase in the filler contents in the composites.

4) The thermo-mechanical properties of the composites increases with increase in the filler contents i.e. the particulate filled composites show the higher viscoelastic properties as compared to the unfilled composites.

6. References

1. Gupta A, Kumar A, Patnaik A, Biswas S. Effect of filler content and alkalization on mechanical and erosion wear behavior of CBPD filled bamboo fiber composites. ***Journal of Surface Engineered Materials and Advanced Technology.*** 2012, 2(3): 149-157
2. Al-Jabri KS, Taha RA, Al-Hashmi A, Al-Harthy AS. Effect of copper slag and cement by-pass dust addition on mechanical properties of concrete. ***Construction and Building Materials***. 2006, 20(5): 322-331
3. Kuljanin J, Vuckovic M, Comor MI, Bibic N, Djokovic V, Nedeljkovic JM. Influence of CdS-filler on the thermal properties of polystyrene. ***European Polymer Journal.*** 2002, 38(8):1659-1662
4. Weidenfeller B, Hofer M, Schilling F. Thermal conductivity, thermal diffusivity, and specific heat capacity of particle filled polypropylene. ***Composites Part A: Applied Science and Manufacturing.*** 2004, 35 (4): 423-429
5. El-Sayed HA, Gabr NA, Hanafi S, Mohran MA. Re-utilization of by-pass kiln dust in cement manufacture. In: Proceedings of the International Conference on Blended Cement in Construction, Sheffield, UK. 1991
6. Patnaik A, Satapathy A, Mahapatra SS. Study on erosion response of hybrid composites using taguchi experimental design. ***Journal of Engineering Materials Technology***. 2009, 131:1-16
7. Bisawas S, Satapathy A. A comparative study on erosion characteristics of red mud filled bamboo-epoxy and glass- epoxy composites. ***Materials and Design***. 2010, 31, 1752-1767
8. Satapathy BK, Das A, Patnaik A. Ductile-*to*-brittle transition in cenosphere filled polypropylene composites. ***Journal of Materials Science***. 2011, 46(6):1963-1974

9. Qiao J, Amirkhizi AV, Schaaf K, Nasser SN. Dynamic mechanical analysis of fly ash filled polyurea elastomer. ***Journal of engineering materials and technology***. 2011, 133(1), doi:10.1115/1.4002650
10. Kumar S, Satapathy BK, Patnaik A. Thermo-mechanical correlations to erosion performance of short carbon fibre reinforced vinyl ester resin composites. ***Materials and Design***. 2011, 32(4): 2260-2268
11. Liang JZ. Dynamic mechanical properties and characterization of inorganic particulate-filled polymer composites. ***Journal of Thermoplastic Composite Materials***. 2011, 24: 207-220
12. Agarwal BD, Broutman LJ. Analysis and performance of fiber composites. 2nd ed. John Wiley and Sons, Inc. New York 1990
13. Ferrigno TH. Principles of filler selection and use. In: Katz HS, Milewski JV, editors. Handbook of Fillers for Plastics, New York: Van Nostrand Reinhold. 1987, 38
14. Vainio MH, Heino M, Seppala JV. Reinforcement of biodegradable poly (ester-urethane) with fillers. ***Polymer***. 1998, 39: 865-872
15. Zhou B, Ji X, Sheng Y, Wang L, Jiang Z. Mechanical and thermal properties of poly (ether ether ketone) reinforced with $CaCO_3$. ***Eur. Polym J***. 2004, 40: 2357-2363
16. Ismail H, Chia HH. The effects of multifunctional additive and vulcanization systems on silica filled Epoxidized Natural Rubber compounds. ***Euro. Poly. J***. 1998, 34(12): 1857-1863
17. Ishak ZAM, Bakar AA. An Investigation on the potential of rice husk ash as fillers for epoxidized natural rubber (ENR). ***Euro. Poly. J***. 1995, 31(3): 259-269
18. Fu SY and Lauke B. Characterization of tensile behaviour of hybrid short glass fibre calcite particle ABS composites. ***Composite Part A***. 1998, 29A: 575-583
19. Ismail H, Chia HH (1998) The effects of multifunctional additive and epoxidation in silica filled natural rubber compounds. Poly. Test, 17: 199-210
20. Thomason JL, Vlug MA, Schipper G, Krikor HGLT. Influence of fibre length and concentration on the properties of glassfibre reinforced polypropylene: Part 3. Strength and strain at failure. ***Composites A***. 1996, 27: 1075-84
21. Arjula S, Harsha AP. Study of erosion efficiency of polymers and polymer composites. ***Polymer Testing***. 2006, 25: 188-196
22. Porter SJ, DeArmitt CL, Robinson R, Kirby JP, Bott DC. The surface characterization of polyacrylonitrile-phantom plastics. ***High performance polymers***. 1989 1(1): 85-94
23. Zhang S, Cao XY, Ma YM, Ke YC, Zhang JK, Wang FS. The effects of particle size and content on the thermal conductivity and mechanical properties of Al_2O_3/high density polyethylene (HDPE) composites. ***eXPRESS Polymer Letters***. 2011, 5(7): 581-590
24. Jacob M, Francis B, Thomas S, Varughese KT. Dynamical mechanical analysis of sisal/oil palm hybrid fiber-reinforced natural rubber composites. ***Polymer Composites***. 2006, 27: 671-680
25. Wu G, Gu J, Zhao X. Preparation and dynamic mechanical properties of polyurethane modified epoxy composites filled with functionalized fly ash particulates. ***Journal of Applied Polymer Science***. 2007, 105: 1118-1126
26. Jiang H, Kamdem DP. Thermal and dynamic mechanical behavior of poly (vinyl chloride)/wood polymer composites. ***Journal of Applied Polymer Science***. 2008, 107: 951-957
27. Kuzak SG, Shanmugam A. Dynamic mechanical analysis of fiber-reinforced phenolics. ***Journal of Applied Polymer Science***. 1999, 73: 649-658