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Thermal Characterization of CBPD Filled and Kevlar Fiber Reinforced Homogenous and Graded Composite Material

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Abstract—This research monograph reported the thermal behavior of Kevlar fiber reinforced/cement by pass dust (CBPD) filled vinyl ester resin based homogeneous and graded composite materials. The designed composites characterized for their thermal behavior via Thermo-Gravimetric Analysis (TGA) method. The thermal behavior of the composites could easily be understood by dividing the TGA curve in three major temperature stages. The stage-1 has the part ranging from room temperature to 300°C, stage-2 ranging from 300-400°C and stage-3 has the part ranging from 400-500°C. The TGA shows that major weight loss occurs in stage-2 and with increase in the CBPD content thermal stability of both the homogeneous and graded composite increases.
Index Terms— Graded Composite Material, CBPD, TGA, Kevlar fibre, Centrifugation casting, Vinyl ester, Mechanical stirring.

1 Introduction

One can envisage the evolution in the field of technological depends on the advancement in materials. One does not have to be an expert to realize the most advanced in automotive, electrical and electronic, aerospace and machine building industries, sport and leisure industry, civil engineering, etc. [1], [2], [3] is of no use if adequate materials are not available to bear the service loads and conditions. Composite materials in this regard represent nothing but a giant step in the ever-constant endeavor of optimization in materials. More advancement in the field of material has taken place with the development of “Functionally graded composites”. Functionally graded materials (FGMs) are unique in properties as the properties of FGM vary in particular directions to serve the desired purpose. A key feature of fibre/particulate reinforced polymer graded composites that make them so promising as engineering materials is the opportunity to tailor the material properties through the control of fibre/filler content and matrix combinations and the selection of processing techniques. Several methods were used to obtain the graded polymer composites in the materials. Moudling under a centrifugal force is one of the effective and efficient methods for the fabrication of graded materials [4], [5], [6]. Fiber/fillers made of Kevlar are being used these days to noticeably improve the thermal and wear resistance of composites, even up to the great orders of magnitude [7]. Several researchers all over the globe worked on functionally graded polymer composite materials by centrifugal technique and determine the mechanical and wear properties, but only few papers were reported on the thermo- mechanical properties of graded composites. The Thermo-mechanical properties of polymers graded are generally carried out with dynamic thermogravimetry. Normally the sample starts losing weight at a very slow rate up to a particular temperature and thereafter, the rate of loss becomes large over a narrow range of temperature. After this temperature, the loss in weight levels off. TGA curves are characteristic for a given polymer because of a unique sequence of physical-chemical reactions, which occur over definite temperature ranges and at the rates that are functions of the polymer structure. The change in weight is a result of the rupture and/or formation of various physical and chemical bonds at elevated temperatures that lead to the evolution of volatile products in the formation of heavier reaction products. Thermal studies of cellulose fibres and their pyrolitic behavior are reported extensively in the literature [8], [9]. Kokta and Valde [10] studied the effect of grafting of various polyacrylates on to cellulose and its influence on the temperature and heat of degradation using TGA and DSC. The determination of filler content and its distribution analysis was carried out by Fuad et al. [11] using thermo-gravimetric analysis. They observed good agreement and consistency between the actual filler content and filler content obtained by TG analysis. Gangil et.al [12] carried out Dynamic mechanical analysis to investigate behavior of Kevlar fibre reinforced vinyl ester FGMs and homogenous composites and found that damping capacity of the graded composite remains higher than the homogenous composites, and this improves with fiber loading. The same author [13] studied the thermal behaviors of Kevlar/CBPD filled vinyl ester homogenous and functionally graded composites in order to investigate the overall flexibility and interaction of the constituents and find out that Graded composites have superior thermal properties then homogenous and unfilled CBPD composites.

Against this background, the present research work has been undertaken, with an objective to explore the potential of Kevlar fiber and industrial waste cement by pass dust (CBPD) as a filler material in polymer composites and to investigate the thermal characterization of different graded/ homogenous composition by weight in the composites. To serve this purpose, vinyl-ester resin matrix with chopped Kevlar fibre and CBPD as filler material is chosen.

2 Materials and Methods

The composition and designation of the homogeneous and their FGMs composites prepared for this study are listed in Tables 1. Composites are prepared by taking vinyl-ester resin (locally supplied), chopped fibre (Kevlar and carbon) and/or filler (CBPD), cobalt-naphthenate (accelerator, 1.5 wt.-%) and methyl-ethyl-ketone-peroxide (hardener/catalyst, 1 wt. %). The obtained mixture is mixed by simple mechanical stirring technique to disperse cylindrical specimens (Φ 12 mm, length 120 mm). Four ternary formulation for both homogeneous/FGMs are prepared having Kevlar fibre fixed (10 wt. %) while the CBPD filler composition is 0-12 wt.-% in a steps of 4 wt.-%. For homogeneous composites hand layout technique is used while for graded composites vertical centrifugation casting arrangement is used. In centrifugal casting the specimens were rotated at 1000 rpm for 30 minutes, rotation axis perpendicular to the cylinder axis. In last, the specimens are kept for curing in open air at room temperature for ~ 48 h and then the hardened FGM samples are extracted from the container. At the end, a gradient in the filler content is obtained along the radius of the cylinder from centre to periphery.

Table 1
Details of composite designation and composition.

Composition (wt.-%)	Vinyl ester Resin	CBPD	Kevlar
HCBPD-0	90	0	10
GCBPD-0	90	0	10
HKCBPD-1	86	4	10
GKCBPD-1	86	4	10
HKCBPD-2	82	8	10
GKCBPD-2	82	8	10
HKCBPD-3	78	12	10
GKCBPD-3	78	12	10

3 Thermo-Gravimetric Analysis (TGA)

Thermo-Gravimetric Analysis (TGA) is a thermal analytic technique commonly used to determine thermal stability, ash content etc. associated with composite materials. It computes loss of sample weight with-respect-to temperature. The thermo gravimetric analysis of the fabricated friction composite was carried on TA-60WS model supplied by Shimadzu scientific instruments. The thermo-gravimetric analysis was carried out on approximately 15±0.1mg of fabricated composite material. Samples placed in platinum crucibles were heated from 30-500°C at a heating rate of 10°C min^{-1} in oxygen atmosphere, at a flow rate of 40 ml/min.

4 Result and Discussion

The TGA curves of both homogeneous and graded of CBPD filled and Kevlar fibre (10 wt.-% fixed) reinforced vinyl ester composites are shown in Figure 1. As observed from Figure 1, weight loss occurred in three stages for both homogeneous and graded composites. During the first stage change in temperature from 30-300°C, the weight loss of the composites is around 14-20%. As weight loss in this region can be associated with the evaporation of moisture, degradation of resin due to the liberation of gases, due to the evaporation of the organic constituents of the resin and removal of hydrogen from the Kevlar fibre. In this region 8 wt.-% GKCBPD shows better thermal stability followed by 12 wt.-% HKCBPD as compared to the other composites. The TGA curve for CBPD filled reinforced composites confirms that the fast phase of decomposition is the second stage taking place from 300-400°C. The weight loss in this stage is mainly due to the degradation of the vinyl ester resin by oxidation into volatile elements such as volatilization of accelerator, evaporation of styrene [14] and loss of hydrogen bonding in the Kevlar fibre and weight loss 60-70% for both homogeneous and graded composites as shown in Table 2.

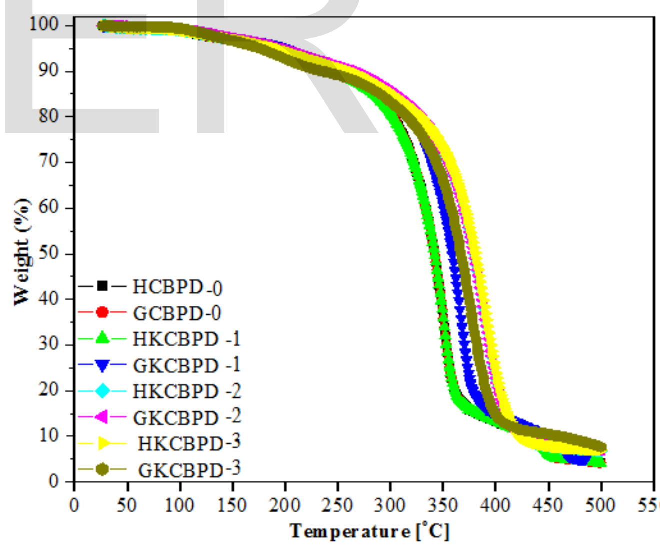

Fig. 1. TG-analysis of CBPD filled homogenous and graded composites.

During a TGA run in a nitrogen environment, the pure vinyl-ester resin under-went firstly the natural evaporation of solvent and styrene at temperatures below around 80°C and then the heat-induced-evaporation of styrene within temperatures of 200°C. However, vinyl-ester kept stable at temperatures within 200-300°C, the decomposition initiated at temperatures higher than 300 °C and then decomposed completely at 450°C. The weight loss in the third stage (400-500°C) is around 7-16 %. The ash contents of the composites increase with increase in CBPD contents which imparts thermal stability to the composite [15]. This data indicates that the increased CBPD content composites are more thermally more stable than that of lower content of CBPD. On the one hand, the degradation of CBPD is activated at higher temperature. Table 2 highlights the relative comparison among the investigated composites to assess material stability across various temperature zones (30-300°C; 300-400°C; 400-500°C) so as to understand damage assessment under elevated thermal environment.

TABLE 1
TG-ANALYSIS OF CBPD FILLED HOMOGENOUS AND GRADED COMPOSITES.

Composite	Weight Loss (%) with respect to temperature (°C)		
	30-300	300-400	400-500
HCBPD-0	19.15	67.48	9.21
GCBPD-0	19.14	67.48	9.21
HKCBPD-1	19.14	67.49	9.21
GKCBPD-1	14.76	70.22	10.31
HKCBPD-2	14.87	62.34	15.87
GKCBPD-2	14.69	62.47	15.90
HKCBPD-3	14.67	61.42	16.88
GKCBPD-3	16.71	68.49	7.11

CONCLUSION

In the presented research work, CBPD filled and Kevlar fiber reinforced homogeneous and graded composite materials are designed and fabricated. The fabricated composites are then characterized for their thermal stability behavior via thermogravimetric analysis. The following conclusions are drawn from the study:

1. The decomposition of the friction composites was due to decomposition of organic constituents.
2. During 300-400˚C, all composites show faster degradation rate.
3. At higher temperature range 400-500˚C, all the composites show gradual degradation; with 12 wt.-% of CBPD filled composites show highest thermal stability.
4. Overall, inclusion of CBPD content increases the thermal stability of both the homogeneous and graded composite.

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