Fibre Fraction Effects on Thermal Degradation Behaviour of GFRP, CFRP and Hybrid Composites

A. VANAJA AND R.M.V.G.K. RAO*

FRP Pilot Plant Unit

National Aerospace Laboratories

Kodihalli, Bangalore, 560 017, India

ABSTRACT: The effects of fibre fraction on thermal degradation of composites containing glass, carbon and glass/carbon hybrid reinforcements in a bifunctional epoxy resin system were studied. Thermogravimetric technique was used to monitor the weight loss with the temperature. The degradation patterns so obtained were correlated with the fibre fraction of the composites.

KEY WORDS: GFRP, CFRP, hybrid composites, fibre fraction, thermal degradation, thermogravimetric analysis (TGA).

INTRODUCTION

GLASS AND CARBON fibre reinforced epoxy composites are widely used in a number of aerospace and non-aerospace applications. Selection of reinforcements and matrix systems, as well as the fibre fraction is crucial in structural designing of the composite product for specific applications. On the other hand, thermal stability and hot wet property retention are the matrix dominated deciding factors that govern the long term performance capabilities of the composites.

Glass fibres are better known for their toughness, medium modulus, strength and stability, but are unsuitable for use in fatigue resistant composites, while carbon fibres are characterized by high modulus, brittleness, low density and superior fatigue properties. However, carbon fibres are thermally less stable and have lower toughness when compared to

*Author to whom correspondence should be addressed. E-mail: karger@ivw.uni-kl.de

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glass fibres [1]. Hence, to tailor the properties for balanced performance requirements, fibre hybridization has recently become an attractive approach [2,3]. Hybrid fibre reinforced composite materials can be made in two ways.

1. By mixing the fibres (co-mingling) in a common matrix
2. By laminating alternate layers of each type of reinforcement

The thermal stability of a given composite is further governed by the matrix functionality and cure temperature. Also, for a given fiber/resin system, the thermal degradation behaviour depends on the fibre fraction (in a way on the matrix content) since at higher temperatures of exposure it is the matrix which practically degrades.

The objective of this work therefore, is to study the effect, of fibre fraction on the thermal behaviour of composites containing glass, carbon and glass/carbon hybrid reinforcement in a bifunctional epoxy resin system. The Thermogravimetric Analysis technique (TGA) has been chosen and adopted to monitor the behaviour as it best represents the composite's weight loss (which is mainly due to matrix loss) with temperature.

In the present study, Glass Fibre Reinforced Plastic composites (GFRP), Carbon Fibre Reinforced Plastic composites (CFRP) and their hybrid composites of different fibre fractions were subjected to thermal degradation in a TGA furnace under nitrogen atmosphere to avoid any oxidation effects and respective thermograms were recorded. As the thermograms so obtained showed distinctly different characteristics mainly in relation to the final losses beyond 400°C, a correlation emerged between the fibre fractions and their thermograms, clearly reflecting characteristic degradation trends. The fibre fractions were also measured by the conventional techniques namely, the resin burnout test for GFRP and acid digestion method for CFRP. An empirical relationship based on mixture rule has been employed to calculate the fibre fraction of a given composite from the thermogravimetric data. Through the studies presented, it is hoped that the fibre fractions of composites, especially those of CFRP, can be determined in a simple way using TGA technique avoiding the cumbersome chemical methods presently used for composites.

EXPERIMENTAL DETAILS

Materials

Epoxy resin system chosen is LY5052/HY5052 (Ciba Speciality Chemicals Ltd.). The reinforcements were unidirectional (UD) carbon tape (Anchor Reinforcements, USA), bidirectional (BID) carbon fabric (HEXCEL) and BID glass fabric (CS Interglass, UK).

Specimen Preparation

Neat resin casting: Epoxy resin and hardener were mixed in stoichiometric ratio and the mixture was degassed before curing. The degassed mixture was cast between stainless steel moulds covered with Teflon sheets eliminating the use of releasing agents and thereby avoiding possible contamination of the resin. The system was allowed to cure at room temperature and was post cured in a step-wise manner (50°C/0.5 h, 70°C/1 h, and 85°C/2 h), ensuring that the glass transition temperature always led the post cure temperature.

Preparation of Composite Laminates (GFRP, CFRP and Hybrid)

CFRP laminates with UD carbon tape as reinforcement, GFRP laminates with BID glass as reinforcement and hybrid laminates with BID carbon/BID glass reinforcements were fabricated using room temperature vacuum bag moulding technique (RTVBM). These laminates were cured at room temperature for 24 h, followed by a step post cure process as mentioned earlier.

The global weight fraction of the cured composites were determined by using gross weights of the constituents (fibre and resin) taken during fabrication. The actual (local) weight fractions of the composites were determined by acid digestion method (ASTM D3171-76) for CFRP laminates and by resin burn out test (ASTM D 2584-68) for GFRP laminates. Table 1 shows the details of different test laminates fabricated.

TGA Technique

The composites were cut into small test specimens and placed in the TGA pan. Dynamic TGA thermograms were recorded using TGA 2950 of TA

Table 1. Details of laminates fabricated.

Laminate Code	Description
UDCFRP 1	Composite with epoxy resin reinforced with UD Carbon tape
UDCFRP 2	Composite with epoxy resin reinforced with UD Carbon tape
UDCFRP 3	Composite with epoxy resin reinforced with UD Carbon tape
UDCFRP 4	Composite with epoxy resin reinforced with UD Carbon tape
BIDGFRP 1	Composite with epoxy resin reinforced with BID Glass
BIDGFRP 2	Composite with epoxy resin reinforced with BID Glass
HYBICG 1	Composite with epoxy resin reinforced with BID Carbon and BID Glass
HYBICG 2	Composite with epoxy resin reinforced with BID Carbon and BID Glass
HYBICG 3	Composite with epoxy resin reinforced with BID Carbon and BID Glass
HYBICG 4	Composite with epoxy resin reinforced with BID Carbon and BID Glass

W_f values were chosen in the range of 0.45–0.60.

Instruments, USA. All experiments were conducted from 50°C to 600°C at a heating rate of 20°C per minute under inert atmosphere. Figures 1–4 represent the thermograms of composite constituents, CFRP, GFRP and hybrid composites respectively.

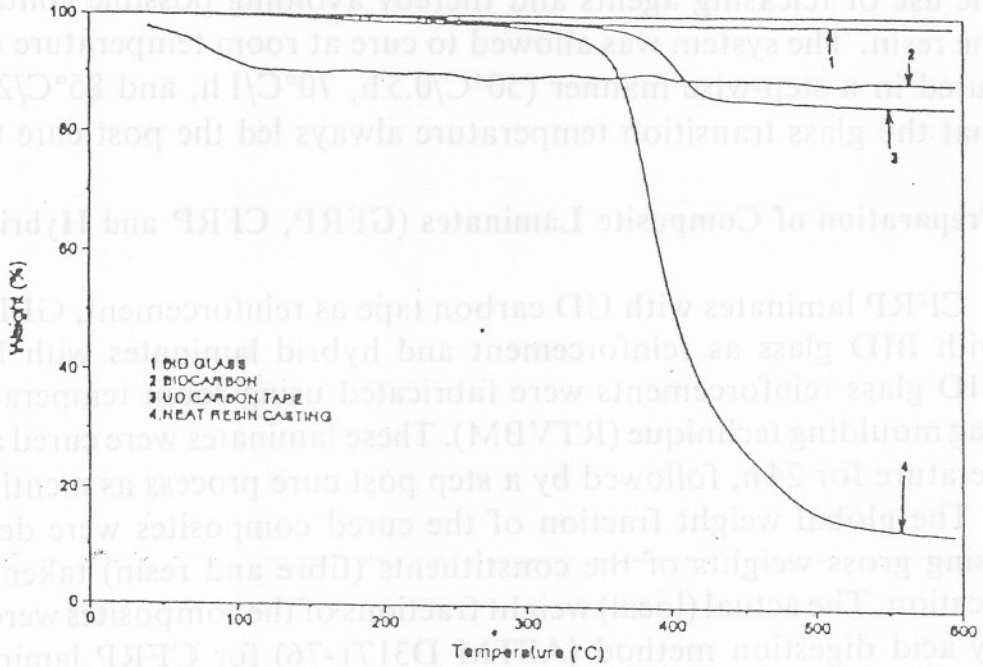

Figure 1. Thermograms of constituent materials of the composites.

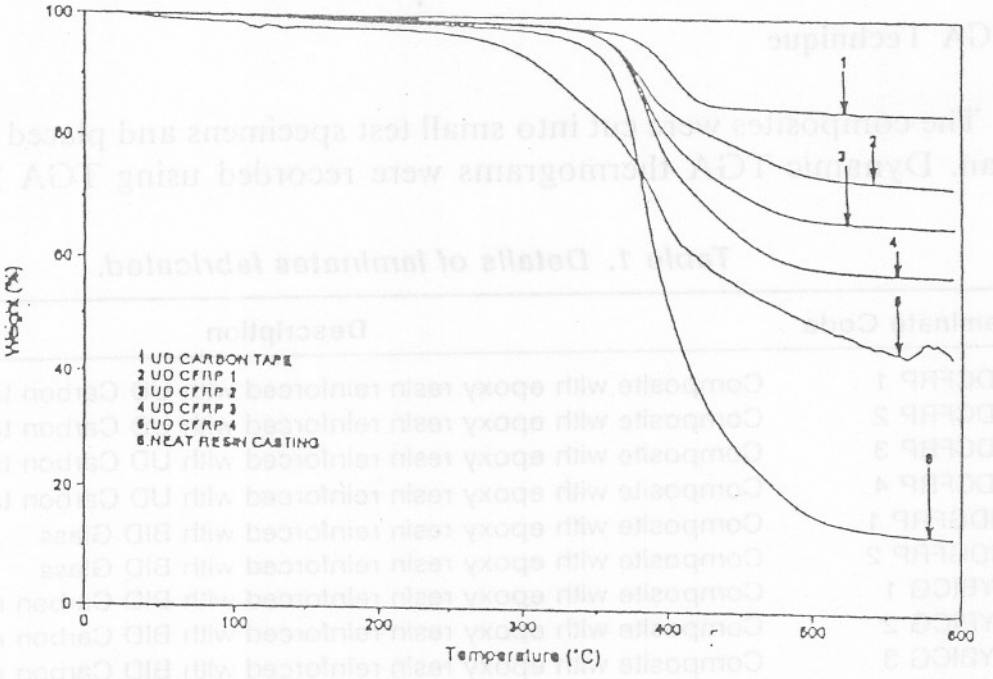

Figure 2. Degradation curves of CFRP composites in comparison with UD carbon tape and neat resin casting.

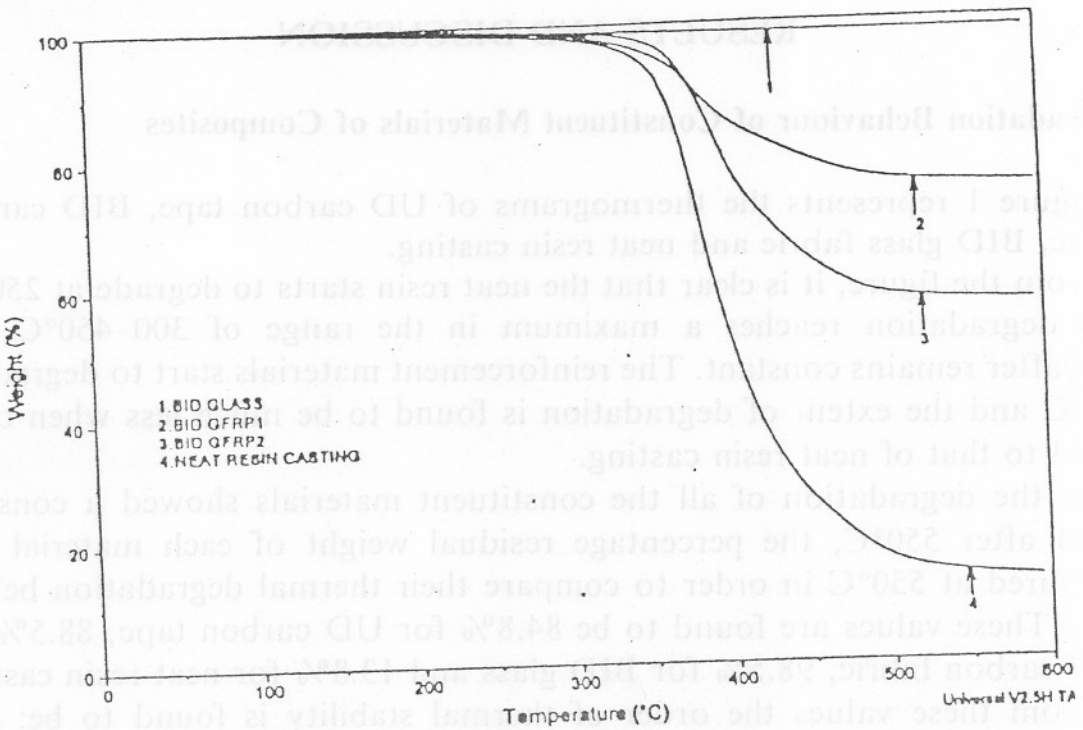

Figure 3. Degradation curves of GFRP composites in comparison with BID glass and neat resin casting.

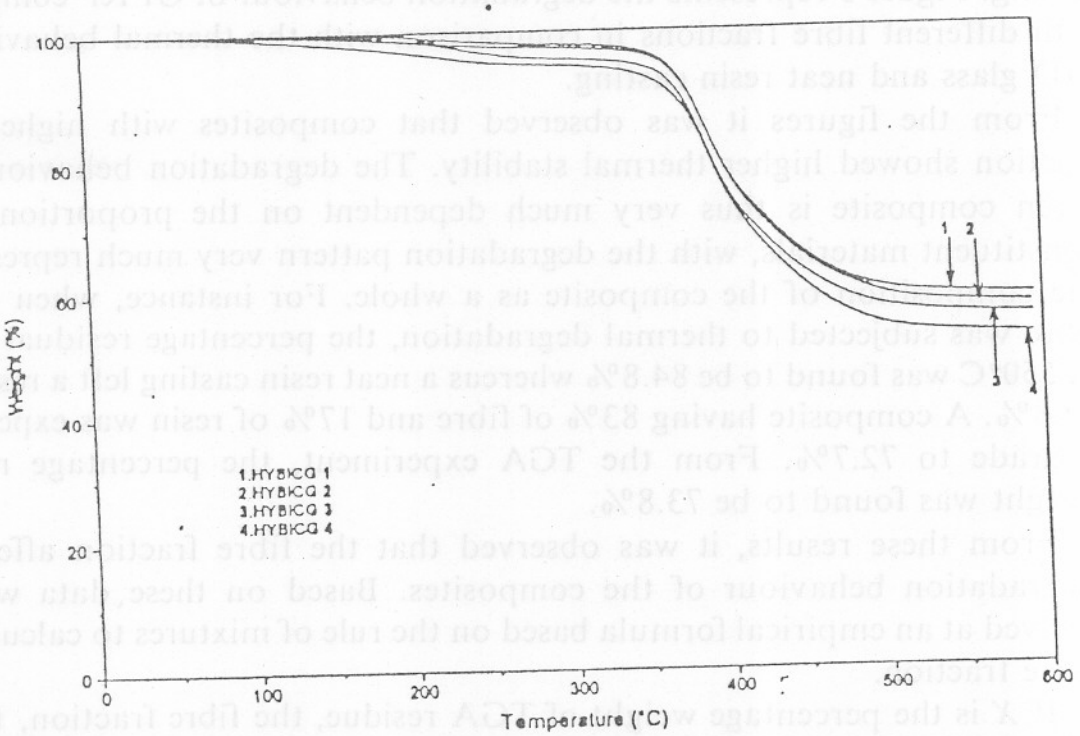

Figure 4. Thermal degradation behaviour of hybrid laminates.

RESULTS AND DISCUSSION

Degradation Behaviour of Constituent Materials of Composites

Figure 1 represents the thermograms of UD carbon tape, BID carbon fabric, BID glass fabric and neat resin casting.

From the figure, it is clear that the neat resin starts to degrade at 250°C. The degradation reaches a maximum in the range of 300–450°C and thereafter remains constant. The reinforcement materials start to degrade at 300°C and the extent of degradation is found to be much less when compared to that of neat resin casting.

As the degradation of all the constituent materials showed a constant trend after 550°C, the percentage residual weight of each material was measured at 550°C in order to compare their thermal degradation behaviour. These values are found to be 84.8% for UD carbon tape, 88.5% for BID carbon fabric, 98.5% for BID glass and 13.8% for neat resin casting.

From these values the order of thermal stability is found to be: BID glass > BID carbon > UD carbon ≫ neat resin.

Degradation Behaviour of CFRP and GFRP Composites

Figure 2 shows the degradation curves of UD-CFRP composites with different fibre fractions in comparison with UD carbon tape and neat resin casting. Figure 3 represents the degradation behaviour of GFRP composites with different fibre fractions in comparison with the thermal behaviour of BID glass and neat resin casting.

From the figures it was observed that composites with higher fibre fraction showed higher thermal stability. The degradation behaviour of a given composite is thus very much dependent on the proportion of its constituent materials, with the degradation pattern very much representing the composition of the composite as a whole. For instance, when carbon fibre was subjected to thermal degradation, the percentage residual weight at 550°C was found to be 84.8% whereas a neat resin casting left a residue of 13.8%. A composite having 83% of fibre and 17% of resin was expected to degrade to 72.7%. From the TGA experiment, the percentage residual weight was found to be 73.8%.

From these results, it was observed that the fibre fraction affects the degradation behaviour of the composites. Based on these data we have arrived at an empirical formula based on the rule of mixtures to calculate the fibre fraction.

If X is the percentage weight of TGA residue, the fibre fraction, W_f, can be calculated by using the equation:

Table 2. Percentage degradation calculated vs. experimental values for GFRP and CFRP laminates.

Laminate Code	Weight Fraction by Conventional Methods	Weight Fraction by TGA
UDCFRP 1	83	84.5
UDCFRP 2	76	75
UDCFRP 3	64	63
UDCFRP 4	43	44
BIDGFRP 1	73	72.5
BIDGFRP 2	50	50.6

$$X = a(W_f) + b(1 - W_f) \tag{1}$$

where, W_f is the weight fraction of the fibre, a is the percentage residual weight when 100% fibre is degraded and b is the percentage residual weight when 100% neat resin is degraded.

The fibre fraction values calculated using this formula were tabulated and compared with those obtained by conventional methods. Table 2 presents the comparison of W_f values obtained by TGA technique with conventional methods. Further, from the thermograms of Figure 1, it is evident that 100% of UD carbon degrades to 84.8%. Therefore, the percentage of degraded material will be 15.2%, for UD carbon tape, 11.5% for BID carbon fabric, 1.5% for BID glass fabric, and 86.2% for neat resin casting. Hence, the unit degradations contributed by these materials will be 0.152, 0.115, 0.015 and 0.862 respectively.

The percentage degradation for a given composite can be calculated using the following equation:

$$D = d_f(W_{fc}) + d_r(1 - W_{fc}) \tag{2}$$

where D is the percentage degradation, d_f is the unit degradation of fibre, d_r is the unit degradation of Resin and W_{fc} is the weight fraction of the fibre determined by conventional method. D can also be calculated from the following equation.

$$D = (100 - X) \tag{3}$$

where X is the percentage residual weight of the composite obtained at 550°C from TGA data.

Table 3 presents the comparison of values obtained by using Equations (2) and (3). They were found to be in good agreement.

Table 3. Comparison of W_f values obtained by conventional methods with those obtained by TGA data.

Laminate Code	Calculated % Degradation Using Equation (2)	Experimentally Obtained % Degradation
UDCFRP 1	72.7	73.8
UDCFRP 2	67.7	67.1
UDCFRP 3	59.2	58.6
UDCFRP 4	44.3	45.2
BIDGFRP 1	75.6	75.2
BIDGFRP 2	56.1	56.7

Degradation Behaviour of Hybrid Laminates

To prove the efficacy of TGA technique, hybrid composites were also analysed according to their composition. Figure 5 represents the lay up sequence of hybrid laminates. Table 4 presents the percentage composition of hybrid laminates prepared. These laminates with varying glass/carbon and resin ratios showed typical degradation behaviour related to their composition. For example, HYBICG1 composed of 41.84% glass, 12.06% carbon and 46.1% resin is expected to degrade to 58.2% using Equation (2). Experimentally it was found to be 57.6%. Table 5 presents the percentage degradation calculated using Equation (2) versus experimental values. From the table, it is clear that they are in good agreement.

CONCLUSION

The effects of fibre fraction on the thermal behaviour of different types of composites based on a DGEBA matrix system were studied. From the

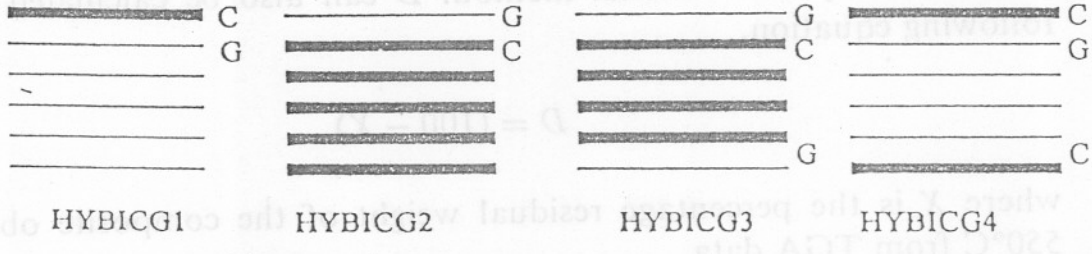

Figure 5. Lay-up sequences of hybrid laminates.

Table 4. Details of composition of hybrid laminates.

Laminate Code	Weight Fraction of Individual Constituents of the Hybrid Composites (Global)		
	% Glass	% Carbon	% Resin
HYBICG 1	41.84	12.06	46.1
HYBICG 2	7.99	49.57	42.5
HYBICG 3	18.8	33.40	47.8
HYBICG 4	16.68	36.82	46.5

Table 5. Percentage degradation calculated vs. experimental values for hybrid laminates.

Laminate Code	Calculated % Degradation Using Equation (2)	Experimental Obtained % Degradation
HYBICG 1	58.2	57.6
HYBICG 2	57.5	56.2
HYBICG 3	54.6	52.9
HYBICG 4	57.4	58.6

results it was observed that the thermal behaviour was dependent on individual constituents of the composites. An empirical relationship proposed based on rule of mixtures was used to calculate the fibre fraction by TGA technique. The values obtained were compared with those by conventional methods. They were found to be in good agreement. The efficacy of TGA technique was verified using hybrid composites also. The degradation behaviour of hybrid laminates was correlated with the weight fraction of the components as calculated using the mixture rule derived.

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