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Tensile Property of Ultra High Molecular - Weight Polyethylene (UHMWPE) Fibre and Its Composite Laminate

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The present paper reports the uni-axial tensile property results obtained during an experimental investigation conducted by testing Dyneema HB80 filament and its laminated composite under quasi-static conditions. The tensile strength of the filament of Dyneema HB80 has been found 2.96 GPa with an average elongation of 4.15%, both of which give much higher as compared to its laminated composite. The effect of curing temperature (one of the most significant processing parameters) on the ultimate tensile strength (UTS) of laminated composite was studied and the results obtained showed that at higher the curing temperature, lower is the UTS. The SEM analysis of the fractured samples showed that higher curing temperature results in higher degree of damage to the fibre laminate and hence, lower UTS.

***Keywords*:** UHMWPE, Dyneema HB80, Composite Material, Filament/fibre.

1. Introduction

Ultra High Molecular Weight Polyethylene (UHMWPE) is a crystalline polymer with a wide range of structural applications from aerospace to defence industry. The UHMWPE based composites exhibit excellent mechanical properties, adequate elongation and fatigue response, apart from high rigidity, high strength and good energy absorption capabilities [1-3]. Due to these attractive properties, the UHMWPE materials find many important protective gears such as bulletproof armour, ballistic protective helmets and bulletproof vest etc [4,5].

Many investigations were conducted earlier on these materials which include time, temperature and creep response investigation of UHMWPE fibers [6,7]. Peijs et al. [8] extended this work to laminates by fabricating laminates from UHMWPE fibres and also reporting their mechanical properties with the aim of clarifying the potential of such composites for structural applications. An initial numerical study on the ballistic performance of UHMWPE fibre laminates was reported by Grujicic et al. [9]. The mechanical properties of single fibres used in fibrous composite have their own bearing on the overall properties of composites. Keeping in view of above, a comprehensive experimental study is taken up to evaluate various deformation and tensile properties under quasi-static loading condition of UHMWPE based Dyneema HB80 grade fibre and laminated composites. The very first set of experimental findings have been reported and discussed in the present paper.

2. Experimental Details

In this section, the description of material system and experimental details for tensile testing of fibre, lamina strip and composite has been discussed.

2.1. Material Descriptions

Dyneema-HB80 is made of ultrahigh-molecular-weight polyethylene fibres (UHMWPE) oriented in the polymer matrix in the form of flat sheets. It is made of several layers of ultra high molecular weight polyethylene (UHMWPE) filament/fibre, as shown in Fig. 1. The Dyneema

filament/fibre are bonded together by small amount of polyurethane (PUR) matrix material. Dyneema laminated composites are developed by pressing number of sheets together at elevated temperature and on application of adequate level of pressure. The DSC plot of Polyurethane matrix is shown in Fig. 2.

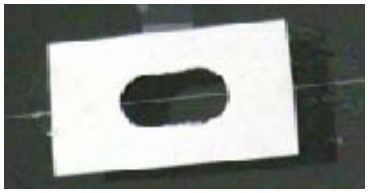

Fig. 1. Dyneema filament

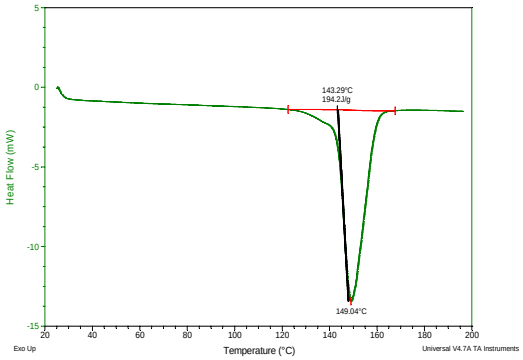

Fig. 2. DSC curves of Polyurethane (PUR) resin

The DSC curve indicates melting/softening temperature (149.04 ^{o}C approximately) of the matrix and hence it gives an idea about the processing window for hot pressed compression moulding conditions.

2.2. Tensile Testing

One of the most important test that provides basis for all the mechanical properties is the uni-axial, quasi static tensile test. This experimental investigation of Dyneema HB80 fibre/filament and laminated composite allows the determination of (i) ultimate tensile strength (UTS), (ii) Young modulus and (iii) elongation. Additionally, tensile toughness too can be determined.

The single fiber testing was carried out using the Favimat instrument (Textechno, Germany). The Favimat measures the fineness of fibers utilizing the vibroscopic technique. Fiber strength and elongation were measured at constant loading rate of extension of the measuring head, gauge length 20 mm and a constant head speed of 2 mm/minutes using samples of 20 filaments of Dyneema HB80. The breaking force and elongation as well as the tenacity-to-elongation were measured for each fiber. The load cell used for the tensile testing was 1200 cN and a pre tension of 0.5 cN/ tex was applied to the fiber.

The tensile testing of Dyneema composite laminate was carried out by computerized Universal Testing Machine.. The test specimens of Dyneema HB80 composite laminates employed for testing are shown in Fig. 3. Special tabs with riveted arrangement in the test specimens of Dyneema HB80 were used to have adequate and proper gripping.

Fig. 3. Dyneema HB80 composite specimen with tab for tensile test

3. Result and Discussion

3.1. Fibre Tensile Testing

Figure 4 shows the load elongation plot of the 20 number of test samples tested at same conditions.

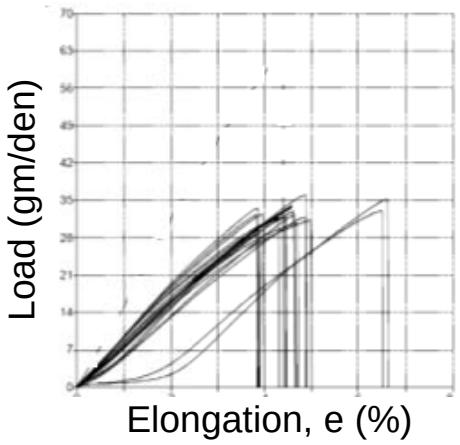

Fig. 4. Load and elongation curves of Dyneema HB80

Microscopic examination of post test specimens using a Zeiss Optical Microscope at a magnification of 20X has been shown in Fig. 5. The figure shows that there are multiple and gradual breakage of the fibre during the tensile test corresponding to different displacement values. From the test result, the tensile strength of the fiber was found 2.96 GPa and the maximum elongation was 4.15 %.

3.2. Composite Tensile Testing

Dyneema HB80 composite tests were carried out for 15 sets of specimens processes using different pressure, curing temperature and curing time as shown in Table 1 and 2. Each set (whose details are given in Table 2) consisting of 3 specimens and average value of UTS are listed.

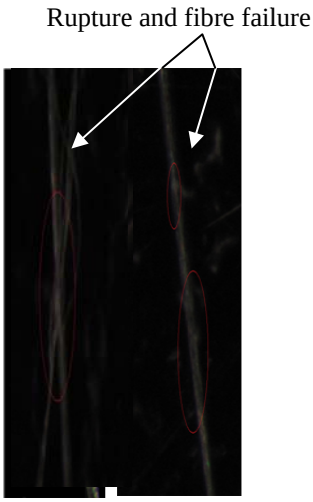

Fig. 5. Microscopic examination of tested specimen

One of the test specimens after the tensile failure is shown in Fig. 6. The experimental results show that when the applied pressure is 9.8 MPa, curing temperature 125°C and curing time was 15

minutes the maximum ultimate tensile strength was achieved (Test Set No. 1). In the case of Test Set No. 10, where, the applied pressure, curing temperature and curing time were 13.73 MPa, 135°C and 10 minutes respectively, the minimum ultimate tensile strength has been achieved. From the above results, it is clear that the temperature effect is more significant than the pressure. Higher temperature beyond a critical value results in fibre softening and matrix/resin melting and hence, poor ultimate tensile strength.

Table 1: Range of various process variables

S. No.	Process Parameters	Range
1.	Pressure (P) (MPa)	9.8-17.65
2.	Temperature (T) (^{o}C)	125-135
3.	Time (t) (Minute)	10-20

Table 2: Variables and experimental results

Test No.	Level of process variables			UTS
	P	T	t	
1	9.80	125	15	67.07
2	17.65	125	15	65.67
3	9.80	135	15	65.68
4	17.65	135	15	59.49
5	9.80	130	10	60.95
6	17.65	130	10	60.24
7	9.80	130	20	59.61
8	17.65	130	20	54.80
9.	13.73	125	10	60.67
10	13.73	135	10	40.74
11	13.73	125	20	53.12
12	13.73	135	20	65.72
13	13.73	130	15	49.42
14	13.73	130	15	49.31
15	13.73	130	15	49.52

Fig. 6. Fractured specimen after tensile testing

Scanning electron microscopy (SEM) of tensile fractured surface is carried out to study the nature of fractured surface morphology and associated failure mechanism. Figures 7 and 8 show SEM morphologies of the tested specimens corresponding to the lowest (one of the 3 specimens of Test Set No. 10 of Table 2) and highest (one of the 3 specimens of Test Set No. 1 of Table 2) UTS. These results can be explained in terms of the extent of delamination of filament and the fibers.

Even if the pressure was minimum (in case of Test Set No. 1 of Table 2), curing temperature was sufficient enough to melt the resin between inter layers of specimen and all the fibers were heated up to the curing temperature and resulted in highest UTS.

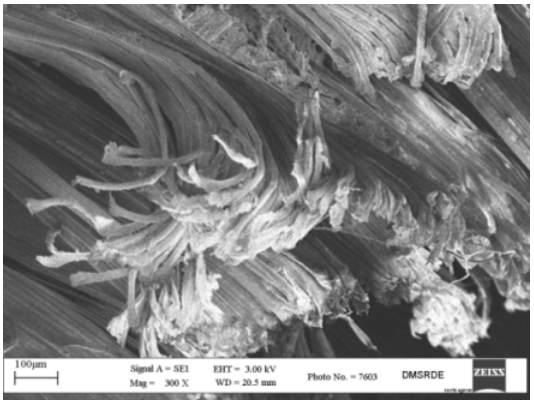

Fig. 7. Morphology of the tensile-fractured sample of the composites for lowest ultimate tensile strength case (test no. 10) at different regions

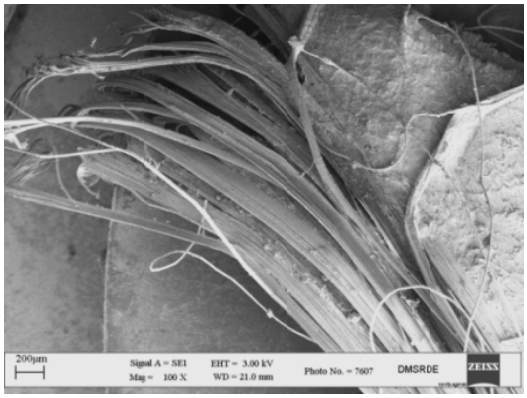

Fig. 8: Morphology of the tensile-fractured sample of the composites for maximum ultimate tensile strength case (test1) at different regions

4. Conclusions

This research work concludes the following:

1. The ultimate tensile strength of filament of Dyneema HB80 fibre (2.90 GPa) is comparatively very high (> 40 times) as compared to the composite laminates (40 - 70 MPa).

2. The ultimate tensile strength of Dyneema composite has been found to be dependent on applied pressure and curing temperature.

3. The microstructure analysis of composite reveals that if the applied pressure and curing temperature is maintained at an appropriate time the voids between two filaments are vanished and the ultimate tensile stress is further increased.

References

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