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Transverse strength of a hybrid carbon/polyethylene composite

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Preface.

This project has been preformed at the Eindhoven University of Technology, departement of Mechanical Engineering. The project was done in a framework of obtaining a degree in Mechanical Engineering.

I would like to thank my coach, Ton Peijs for his support and guidance during this work. Furthermore I would like to thank everyone who helped me gettig started at the lab.

Transverse strength of a hybrid carbon/polyethylene composite

D.Brokken

Introduction.

Use of carbon reinforced composites has grown considerably in automotive and aircraft manufacturing due to its high strength and modulus and good fatigue resistance. It is however a very brittle composite. Peys *et al*[1] showed that hybridisation with high performance polyethylene composite reduces the brittleness, improving the damage tolerance. Chamis *et al*[2] and Bathia[3] already showed that hybridisation offers a means of reducing impact-vulnerability, still keeping other mechanical properties high. Uni-directional composites are extremely anisotropic, having low strength and modulus in directions other than the fiber-direction. Practical use of these materials demands the use of stacked-plies. Failure initiation in these plies in transverse direction will start at much lower loads than in fiber-direction weakening the matrix and lowering the effective strength. Consequently, knowledge of the transverse properties of these composites is of interest. Kalnin[4] investigated unidirectional glass-graphite composites, finding a linear decline of most transverse properties upon progressive hybridisation. Kretsis[5] mentioned 5 different types of hybrid composites, two of which will be distinguished here : Intraply (where tows of different fibers are mixed) and interply or laminated (where alternate layers are stacked in one composite). The first type can be considered as a series model of the two parent composites. Consequently, strength will be dominated by its weakest link. This could be described by a weakest link' model (WLM) with the HE-(High elongation) end LE(Low elongation) composites acting in series. The second type of hybrid behaves more like two composites in parallel, leading to a Constant Strain Model (CSM), following Manders and Bader[6] and Chou and Kelly[7].

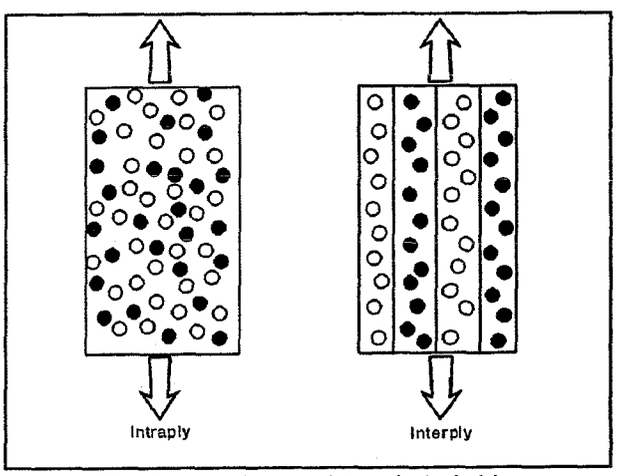

Fig. 1 , Itraply and interply hybrids.

Catastrophic failure in the LE-phase is expected at :

$$\sigma_{hybrid} = \sigma_{HE\,max}\, V_{HE}$$

If there is enough HE-phase present strength will be dominated by the HE-fibers after failure of the LE-phase :

$$\sigma_{hybrid} = \sigma_{LE\,max}\, V_{LE} + \epsilon_{LE\,max}\, E_{HE}\, V_{HE}$$

Thus the CSM leads to an ultimate composite strength formed by two lines in a strength vs. hybrid composition graph. The rule of mixtures could also be used to predict the strength of interply hybrids. Figure 2 gives the predictions for inter- and intraply composites according to the WLM,ROM and CSM, using the following values : σ_{LEmax} = 10 MPa, ε_{LEmax} = 0.3 %, E_{HE} = 6 GPa, σ_{HEmax} = 70 MPa. In this study only the strength of intraply hybrids will be investigated.

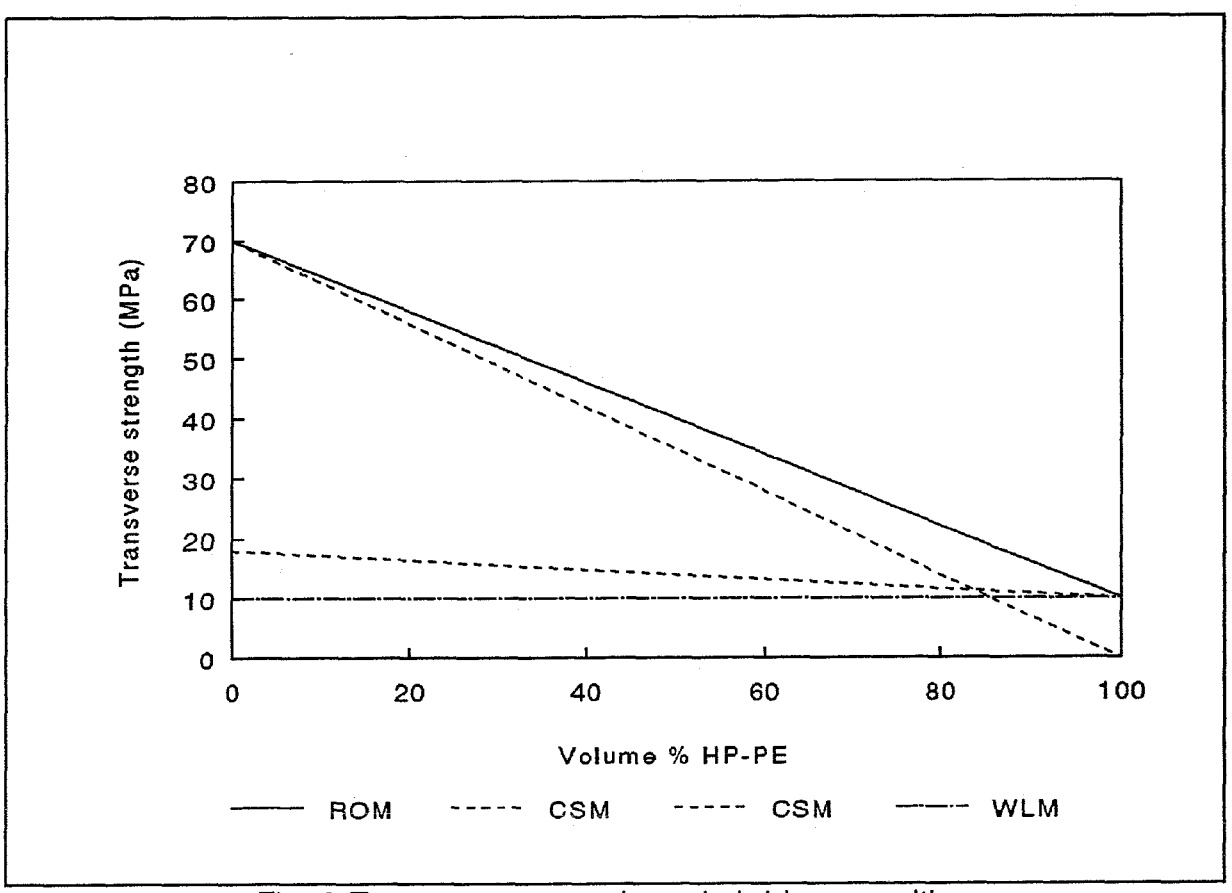

Fig. 2 Transverse strength vs. hybrid composition

Materials.

Uni-directional test-specimens were fabricated using an epoxy resin from Ciba-Geigy (Araldite LY-556 / HY 917 /DY070) reinforced with carbon-fibers from AKZO (Tenax HTA 5131) and HPPE-fibers from DSM (Dyneema).

Table 1, The available fibers and their properties.

Sort of fiber	Density (g/cm^3)	Mass/Length	$A_{fiber}(mm^2)$
Carbon	1.78	200 Tex	0.1124
Carbon	1.78	800 Tex	0.4494
HP-PE	0.97	3×1760 dTex	0.5443
HP-PE	0.97	1760 dTex	0.1814
HP-PE	0.97	3×440 dTex	0.1361
HP-PE	0.97	440 dTex	0.0453

Fabrication.

The fibers were wound on a frame after passing through a bath of pre-heated epoxy and several guiders. A cycle counter registrated the number of fibers wound on the frame so the number of fibers in the composite was exactly known. The fibers were wound parallel over a width of 161 mm, being the width of the mould, until the correct number of fibers was reached to obtain a fiber-volumefraction of 50 %. Afterwards the frame was placed in a vacuumoven for 15 minutes at 70°C and 400 mm Hg to reduce voids. The frame was then placed in the mould in which it was cured at 80°C for 2 hours under pressure. Pressure was increased slowly the first 15 minutes up to 10 kN, which was then maintained for 1.75 hours. The thickness of the composite was adjusted by placing copper plates between the halfs of the mould. Further curing was done for 20 hours in an oven at 80°C. From the resulting plates (161×200×1.5 mm) specimens were cut using a diamond saw. After

cutting the specimens were grinded and polished to minimize the flaws on the edge. The specimen-range had to cover the region from 100% carbon fibers up to 100 % HPPe-fibers. The number of points in this range was chosen 6, which resulted in one specimen every 20%. Since there was only a limited number of fiber types available, some matching was necessary to get the correct 'pairs'. The available fibers and their characteristics are given in table 1. Combining these fibers leads to a set of combinations, where the number of fibers needed is calculated from the cross-section of the mould : 161×1.5=241.5 mm^2. Using 50% of fibervolume this results in fibre cross-section of 120.75 mm^2. The different compositions are presented in table 2.

Table 2, The compositions of the used specimens.

%Carbon	Carbonfiber	HP-Pe fiber	$A_{fibers}(mm^2)$	Number of fibers needed
100	800 Tex	none	0.4494	269
76.75	800 Tex	3×440 dTex	0.5855	206
62.3	2×200 Tex	3×440 dTex	0.3608	334
38.3	200 Tex	1760 dTex	0.2938	411
17.1	200 Tex	3×1760 dTex	0.6567	183
0	none	3×1760 dTex	0.5443	221

Testing.

Two types of testing were performed : 3-point bending and tensile experiments. The bending experiments were performed according to ASTM standard 790M, the tensile tests according to ASTM D 3039. This resulted in bending specimens of 51×12.5 mm and tensile specimens of 160×25 mm. Both tests were performed on a Frank type 81565 tensile machine. Bending tests were performed with a support span of 25 mm which resulted in an L/d of 16.

Tensile experiments were done with a gage length of 80 mm, leaving 40 mm on each side for contact with the grips. Instead of using the more conventional tabs, grinding paper was used between grip and specimen. The test speed was 0.01 min^{-1} for tensile as well as bending tests. This resulted in a crosshead speed of 0.8 mm/min for tensile and 0.716 mm/min for bending experiments. After testing, the depth and width of the specimen were measured at the point of fracture thus giving a reliable stress-output. During testing al data was monitored by a computer, giving easy access to force/displacement diagrams.

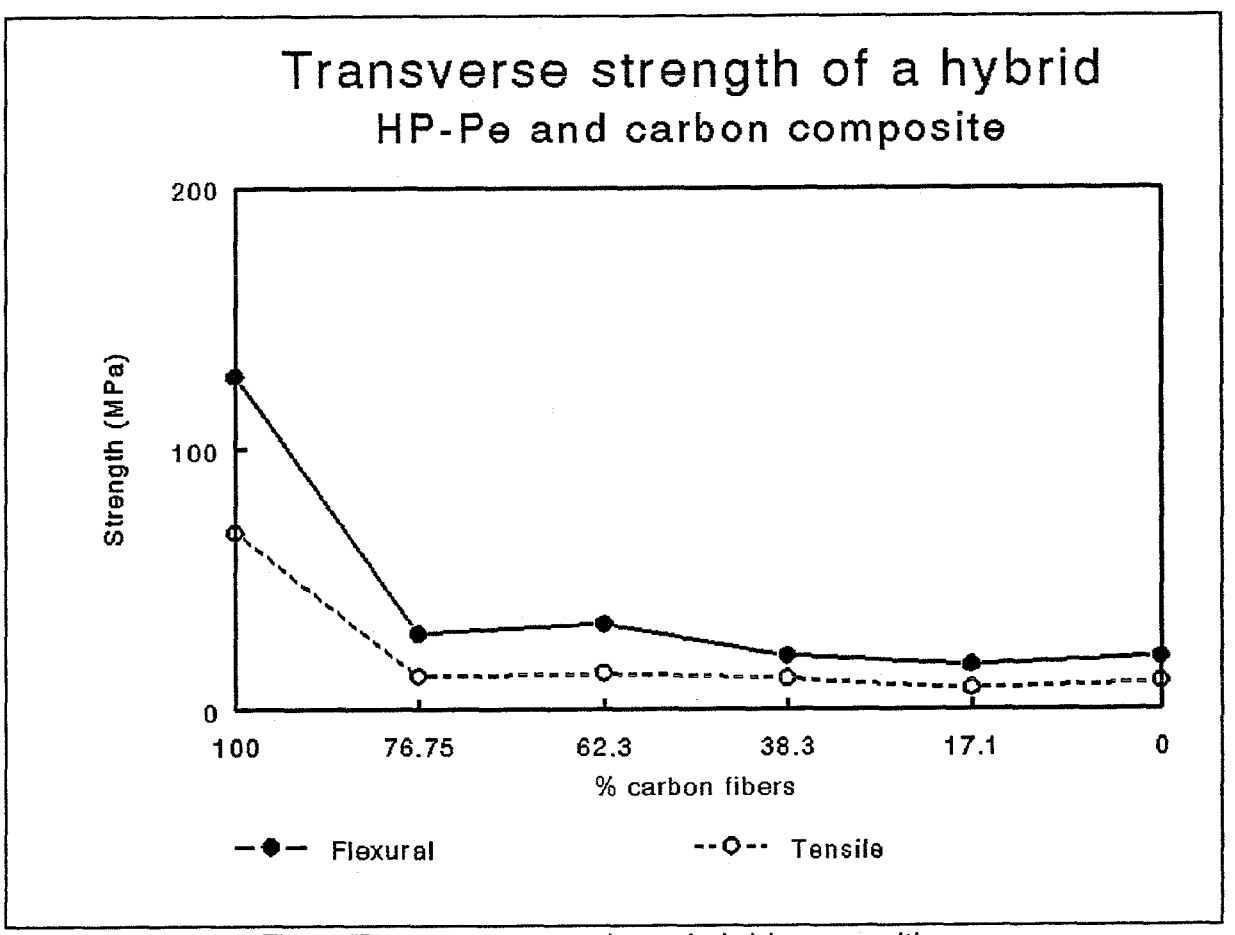

Fig. 3,Tranverse strength vs. hybrid composition.

Results.

The measured average strengths are displayed in table 3.

Table 3 : measured average strengths.

% Carbonfibers	Flexural strength(MPa)	Tensile strength(MPa)
100	128	68
76.75	29	13
62.3	33	14
38.3	21	12
17.1	17	9
0	20	11

Examining these results we see that the strength drops rapidly even if a small amount of HPPE-fibers is added to the carbon composite (Fig. 3). Adding more HPPE does not significantly influence the strength further. We can also see that the flexural strength behaves similar to the tensile strength however at a higher overall strength. Overall quality of the plates seems to be good, the measured strengths of the plain composites being normal to high. Errors in the calculated strength due to measurement and rounding errors have an upper bound of 7 % for flexural testing and 5 % for tensile testing.

Conclusions

The transverse strength of a hybrid carbon/HPPE composite is strongly dominated by the poor transverse properties of the HPPE-composite. Tensile strength is determined by the weakest link, which is in this case formed by the HPPE-composite. The flexural strength is higher because of the stress-concentration in a smaller area i.e. , size effects, resulting in less 'weakest links' being tested. It should be noted that the flexural strengths were measured with an L/d of only 16, not totally

excluding shear effects. In fig. 4 a comparison of the measured tensile strengths to a WLM (Weakest Link Model) is made, showing that transverse loading of this intraply hybrid composite is in fact a worst case scenario. Practical use of this carbon/HPPE in epoxy hybrid demands the use of stacked-plies or multi-directional laminates because of the poor transverse properties of the uni-directional composite. Further investigation on this subject is needed to discover the real potential of these interply hybrids.

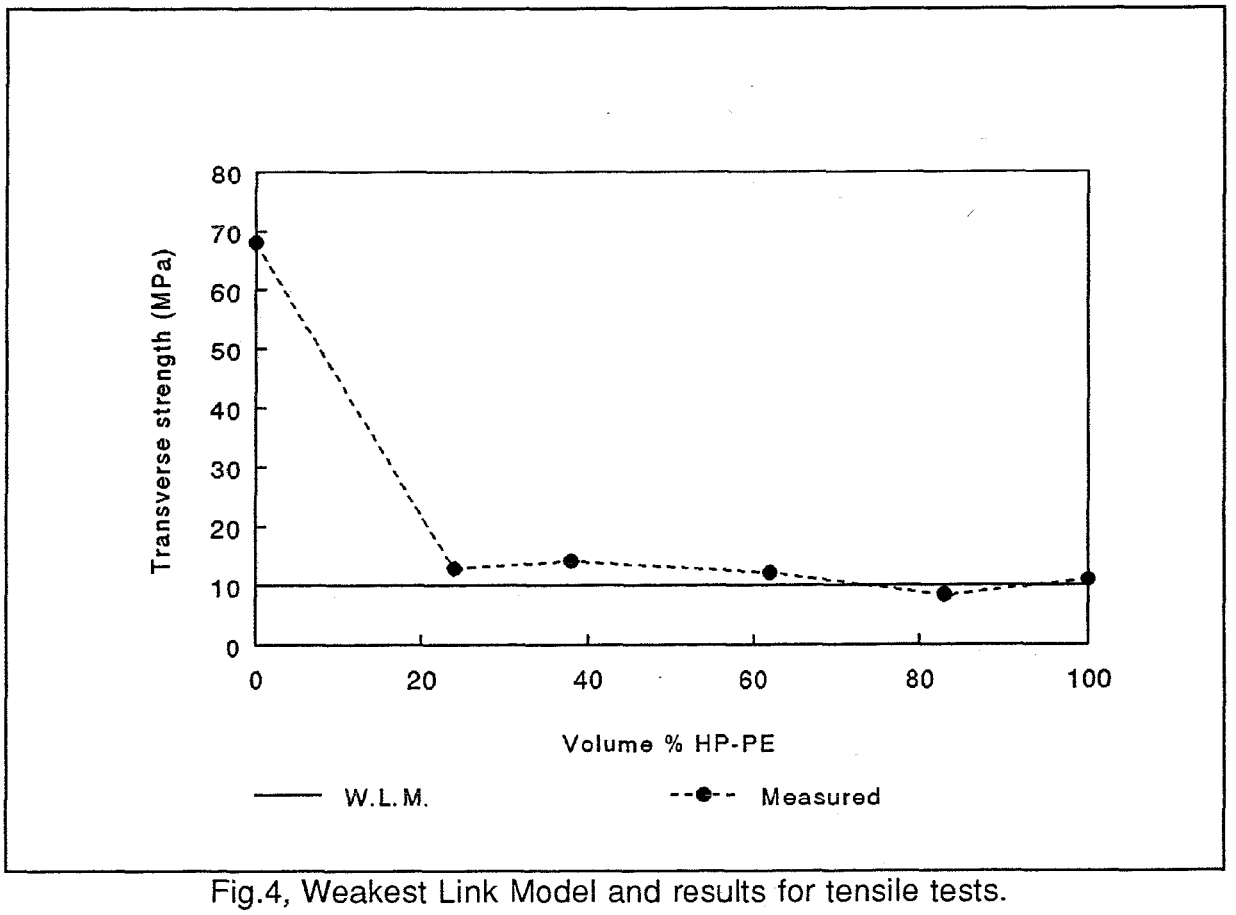

Fig.4, Weakest Link Model and results for tensile tests.

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