Optimum percentage of fly ash reinforcement in vinyl ester composites

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Abstract: The previous work of another group of researchers found that the modulus of tension, flexural and compression increased with increasing percentage by volume of fly ash. They also documented that the viscosity of the composite increased exponentially with increasing percentage by volume of the filler. The viscosity increased sharply when the percentage by volume of reinforcer is between 35 to 50%. They failed to mention the highest percentage by weight of fly ash that could be added to the resin to get highest mechanical properties while still ensuring that the composite could be cast into moulds with ease. This project attempts to find out the optimum percentage by weight of slg in vinyl ester resin as far as yield strength, tensile strength, Young's modulus and Poisson's ratio of the composite are taken into account. The research found that 33% by weight of filler is a favourable and convenient percentage by weight of slg to use because up to this percentage by weight of reinforcement, the mechanical properties like modulus of tension are increasing with the increase in percentage by weight of filler, while at the same time the viscosity is not high enough to prevent ease of casting the composite into moulds.

Keywords: vinyl ester, slg, composite, yield strength, tensile strength, Young's modulus and Poisson's ratio.

Introduction

A research centre in the University of Southern Queensland (USQ) manufactures a lot of composite structures for civil engineering applications for local governments and industries at a very competitive cost. A lot of research has been done in the centre in finding the most suitable combination of resin and reinforcer; up to date, cenospheres (ceramic hollow spheres or slg) reinforced vinyl ester composite is found to be the most suitable material for their current applications, e.g. bridges. The sample is simply made by casting the mixture of the resin, initiator and the slg into the moulds**.** The most common thermosets used as composite matrices are unsaturated polyesters, epoxies and vinyl esters. Unsaturated polyesters dominate the market, whereas epoxies are preferred in high-performance applications. Unsaturated polyester offers an attractive combination of low price, reasonably good properties, and simple processing. However, basic unsaturated polyester formulations have drawbacks in terms of poor temperature and ultra-violet tolerance. Additives may significantly reduce these disadvantages to suit most applications. Where mechanical properties and temperature tolerance of unsaturated polyesters no longer suffice, epoxies are often used due to their significant superiority in these respects. These improved properties come at a higher price and epoxies are most commonly used in areas where cost tolerance is the highest (Astrom, 1997). Epoxy vinyl ester range of resins (vinyl ester resins) was developed in the 1960s (Pritchard, 1999). Vinyl esters (VE), as they are usually called, are closely related chemically to both unsaturated polyesters and epoxies and in most respects represent a compromise between the two. They were developed in an attempt to combine the fast and simple crosslinking of unsaturated polyesters with the mechanical and thermal properties of epoxies (Astrom, 1997). The pure vinyl ester resin is brittle and one approach to increase its performance and minimize the costs of the resin is to reinforce it with fillers. As the structural products are cast to shape, the best option to reinforce the vinyl ester resin is to mix it with ceramic microsphere derived from fly-ash.

The Samples and Tensile Tests

The vinyl ester resin used is Hetron 922 PAW. The vinyl ester is dissolved in 50% by weight of styrene. The resin hardener is MEKP (methyl ethyl ketone peroxide) and the resin to hardener ratio used in the previous study is 98% resin and 2 % hardener by volume (Davey, et al., 2005). The same the resin to hardener ratio has been used in this study. The reinforcer is slg (ceramic hollow spheres) particulates and its percentage by weight was from 30 % to 35 % in the cured vinyl ester composite, VE/SLG because previous study showed that the yield and tensile strengths of composites with 25% or less by weight of fly ash were lower than those at 30% by weight of filler and they are therefore not considered here (Davey, et al., 2005). As the raw materials of the composites are liquid resin and ceramic hollow spheres, the tensile test specimens were cast to shape. The resin is first mixed with the accelerator, (MEKP). After that slg is added to the mixture and they are then mixed to give the uncured composite, which was then poured into the moulds of polyvinylchloride (PVC) for curing in ambient conditions (Ku, 2003).

If the percentage by weight of slg in the mixture was equal to or higher than 40%, the composite would be too viscous and unsuitable for casting. This was in line with the work of another USQ researcher who found that the viscosity with a filler volume of 40% was 4350 cP or 4.35 N-sm^{-2} which was more than double the viscosity, 1750 cP or 1.75 N-sm^{-2}, of a composite with a filler volume of 30% (Davey, et al., 2005; Calister, 2003).

A Material Testing Systems (MTS) 810 was used for the tests. The capacity of the testing machine was 100 kN. The rate of extension, 1 mm per minute, was in accordance with an Australian Standard (Australian Standard 1145.2, 2001). A sample in test was shown in Figure 1. A total of five samples were tested for each fly ash percentage under consideration. The results of tensile tests were used in evaluating whether 33% by weight of fly ash was the best percentage of reinforcement.

Results and discussions

Yield Strength

It is the yield strength at which a definite amount of plastic strain has occurred. Figure 2 shows the force-extension curve of the composite material studied and how a 0.2% offset line was drawn parallel to the most approximated linear portion of the curve and the intersection of the offset line with the curve (John, 1990). When the intersection was projected to the y-axis, the load found was 1312 N which is the 0.2 % offset yield load. For example, the yield strength of sample 4 cured under ambient conditions $\frac{0.2\%\ \ offset\ \ load}{Original\ \ cross - \sec tional\ \ area}$ = $\frac{1312}{14.46x4.32}$ = 21.00(MPa, mega Pascals).

Tensile strength

This tensile strength can be calculated by dividing the maximum load with the original cross sectional area of the specimen as follows area in mm^2. For example, the tensile strength of sample 4 cured under ambient conditions $\frac{1407}{14.46x4.32}$ = 22.52 (MPa).

The tensile strength is most sought after result of a tensile test. It is easy to determine and has become a familiar property and is useful for the purposes of specifications and quality control of a product.

Young's modulus

The Young's modulus (E) or modulus of elasticity is to measure the stiffness of the material. The Young's modulus can be calculated by calculating the slope of the initial linear portion of the stress-strain curve. For example, the Young's modulus of sample 4 cured under ambient conditions was calculated using the data provided from Figure 3, in which a portion of the most linear part of the curve was selected; after projecting the top and bottom points of the selected linear portion into the x- and y-axis respectively, the force (530.9 – 143.6) N and the extension (0.20- 0.05) mm were obtained and used in the calculation.

$$E = \frac{\frac{530.9-143.6}{14.46x4.32}}{\frac{(0.20-0.05)}{105^{+}}} = 4340.15 \text{ (MPa)} = 4.340 \text{ (GPa, giga Pascals)}.$$

$^{+}$is grip separation length in mm.

Poisson's ratio

When a tensile stress is imposed on ε_x a composite specimen, an elastic elongation and accompanying strain result in the direction of the applied stress (arbitrarily taken to be the x direction). As a result of this elongation, there will be constrictions in the lateral (y and z) directions perpendicular to the applied stress; from these contractions, the compressive strains ε_y and ε_z may be determined. If the applied stress is uniaxial, and the material is isotropic, then $\varepsilon_y = \varepsilon_z$. A parameter termed Poisson's ratio ν is defined as the ratio of the lateral and axial strains, or

$$\nu = -\frac{\varepsilon_y}{\varepsilon_x} = -\frac{\varepsilon_z}{\varepsilon_x} \tag{1}$$

The negative sign is included in the expression so that ν will always be positive, since ε_y and ε_z will always be in opposite sign (Callister, 2003). Theoretically, the Poisson's ratio for isotropic material is 0.25; furthermore, the maximum value for ν is 0.50 (Callister, 2003). The Poisson's ratio of sample 4 cured under ambient conditions is 0.353

Table 1 summarizes the yield strength, tensile strength, Young's modulus and Poisson's ratio of VE/SLG at different percentages by weight of fly ash. The values of the standard deviations are low and it can be argued that the data are reliable. Figure 4 illustrates the yield and tensile strengths of VE/SLG composites with varying percentages by weight of slg. From the two curves (yield strength and tensile strength in Figure 4), it can be argued that the highest strengths are at 30% by weight of slg.

However, Figure 5 shows that the Young's modulus increases with increasing percentage by weight of fly ash; this implies that 35 % is a better option. Moreover, Figure 6 illustrates that the values of the Poisson's ratio at 30% and 33% by weight of filler are the same; the value at 35% is much higher. This again shows that 35% by weight of reinforcer is a better option for the applications of the composites in centre's projects because of its higher Poisson's ratio. Higher Poisson's ratio means less brittleness and many of the items made by the centre need to have better toughness. Of course, if the Poisson's ratio is too high, e.g. 0.50, the material will be rubbery. Figures 5 and 6 show that the Young's modulus and Poisson's ratio increase with increasing percentage by weight of filler. On the other hand, the yield and tensile strengths go in the opposite direction; this may be due to the fact that by increasing the percentage by weight of fly ash, the composite becomes more brittle and the 0.2 % offset load and maximum load decrease. However, considering higher percentage by weight of slg will reduce cost of the composite, no one will stop increasing the percentage by weight of fly ash. Other mechanical properties like viscosity and modulus of tension, flexure and compression are favourable with the increase in percentage by weight of filler because their values are higher. However, the maximum percentage by weight of fly ash can only be up to 40% (53.3 % by volume) as the viscosity (19,210 cP, centi Poise or 19.21 N-sm^{-2}) of the composite at this volume fraction of filler will be high and the composite cannot be cast properly into the mould (Davey, et al, 2005; Kota, 2006). However, the graphs of yield and tensile strengths in Figure 4 illustrates that at 35% by weight of slg, the yield and tensile strengths of the composite will be outside the 5 percent markers of their respective values at 30% and are unacceptable for the components made in the centre; this is because they were 5 percent less than the maximum values (at 30% by weight of fly ash); even at 34% by weight of fly ash, the yield and tensile strengths of the composite will still be outside the 5 percent markers of their respective values at 30%. This means that maximum percentage by weight of filler should not exceed 33 percent otherwise all advantages obtained by increasing the percentage by weight of fly ash will be compromised by the reduction in yield and tensile strengths. At 33 % by weight of filler, the viscosity, the modulus of tension, flexure and compression of the composite are 7,630 cP or 7.36 N-sm^{-2}, 4.56 GPa, 4.33 GPa and 2.87 GPa respectively (Davey, et al., 2005); the yield strength, tensile strength, Young's modulus and Poisson's ratio of the composite are 20.98 MPa, 21.89 MPa, 4.45 GPa and 0.352 respectively (Kota, 2006). They are all in favourable conditions as compared to their respective values at 30% by weight of filler.

It is worth noting that the tension of modulus (4.56 GPa) at 33% by weight of filler obtained by Davey et al. (2005) is very close to the Young's modulus (4.45 GPa) at the same percentage by weight of reinforcer obtained by Kota (2006). The difference between them is minimal and therefore negligible. The difference between the values obtained by two independent researchers is only 2.5% and the values are obtained by averaging five or more samples and it can be argued that their data are accurate and reliable.

The vinyl ester used in this research is Australian dollar $5.00 per kg and that of fly ash is $0.30. For 1 kg of the composite with 33% by weight of fly ash, the cost for the resin is $ 3.33 and that of the fly ash is $0.20. The total cost is $ 3.53 as compared to $5.00 for unfilled resin. This is a reduction of 30%. On the other hand, the tension of modulus of unfilled resin is 3,300 MPa while that with 33% by weight of fly ash is 4,600 MPa, an increase of 40%.

Conclusion

From the above discussions, it can be found that the optimum percentage by weight of fly ash in vinyl ester resin composite is 33% because at that percentage by weight of filler, the mechanical properties of the composite are the best and its fluidity is also suitable for casting. It can be argued that Davey et al. (2005) decided not to use 37.5% by weight of slg for the composite because at 37.5 % by weight of the filler, the viscosity (13,000cP or 13 N-sm^{-2}) of the composite mix becomes too high for casting; there was no indicator in his research as what is the limit of viscosity at which casting is still favourable. In this project, all mechanical properties measured except yield and tensile strength also favours the percentage by weight of fly ash of up to 40 percent but the yield and tensile strength gives us the limit at which these properties become unacceptable if the percentage by weight of filler is over 33%.

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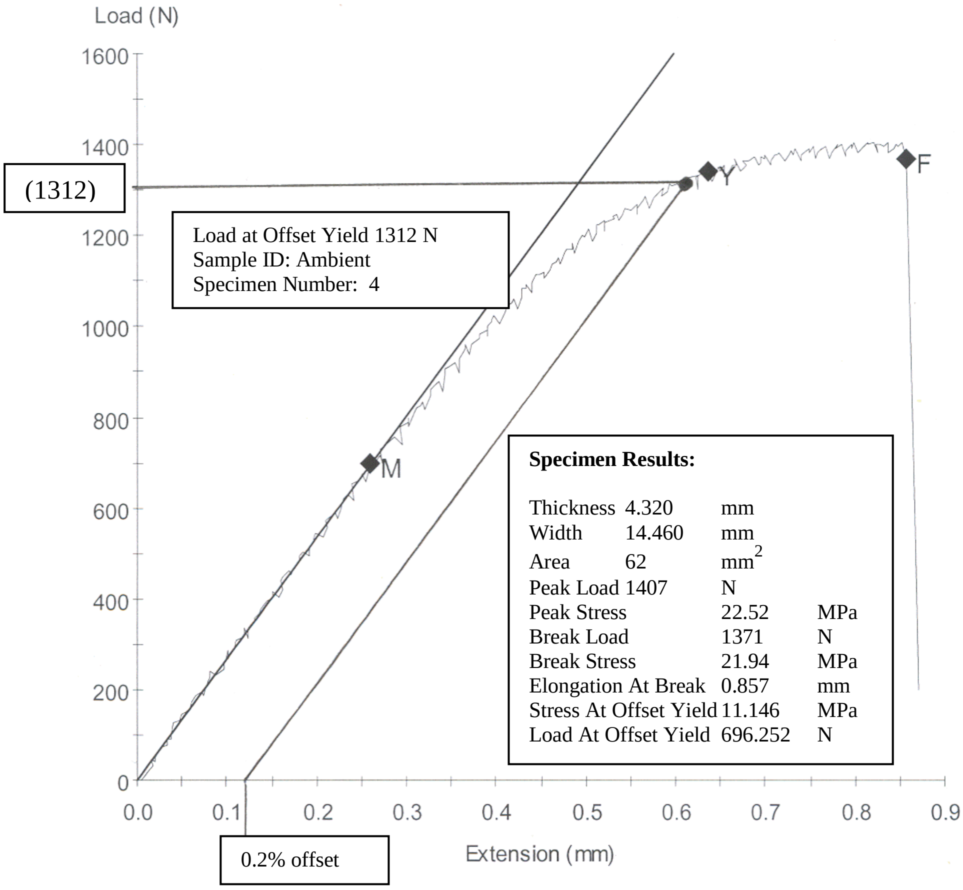
Figure 1: A sample under test



(1312)

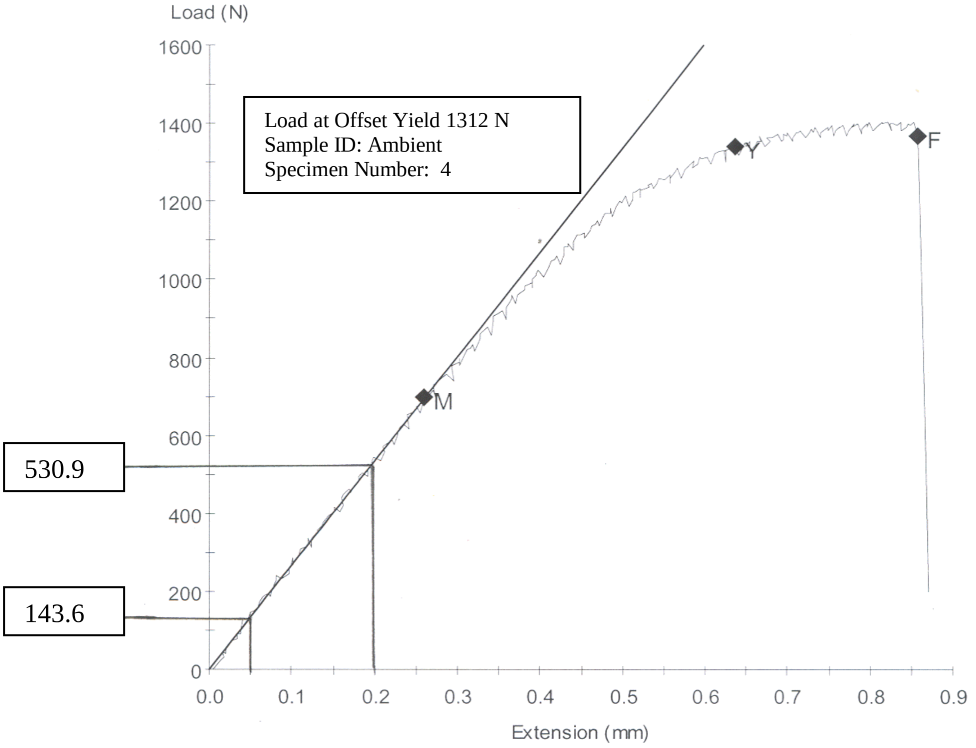
Load at Offset Yield 1312 N
Sample ID: Ambient
Specimen Number: 4

Specimen Results:

Thickness	4.320	mm
Width	14.460	mm
Area	62	mm^2
Peak Load	1407	N
Peak Stress	22.52	MPa
Break Load	1371	N
Break Stress	21.94	MPa
Elongation At Break	0.857	mm
Stress At Offset Yield	11.146	MPa
Load At Offset Yield	696.252	N

0.2% offset

Figure 2: Load against extension of a sample cured under ambient conditions



Load at Offset Yield 1312 N
Sample ID: Ambient
Specimen Number: 4

530.9

143.6

Figure 3: Graph showing how to get data for calculating Young's modulus

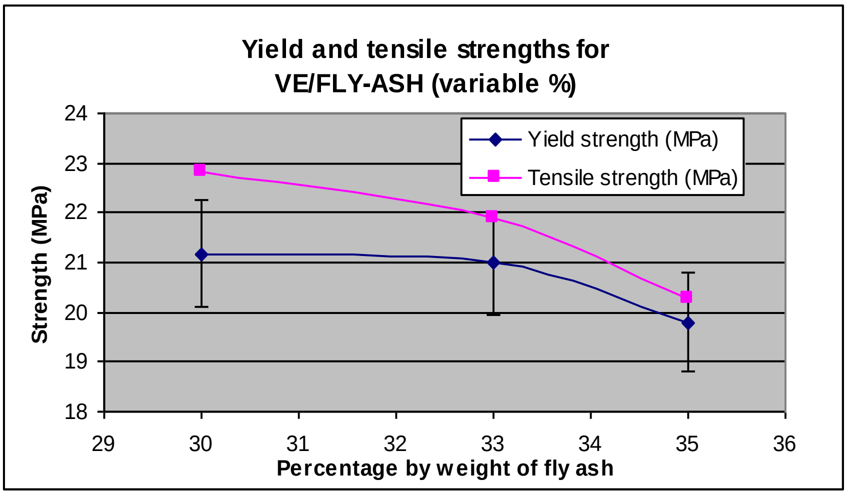


Figure 4: Yield and tensile strengths of VE/FLY-ASH vs percentage by weight of filler

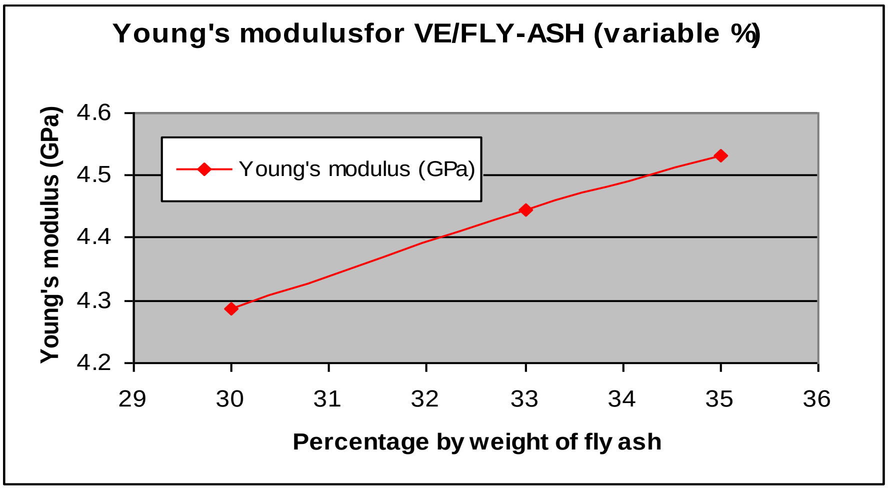


Figure 5: Young's modulus of VE/FLY-ASH vs percentage by weight of filler

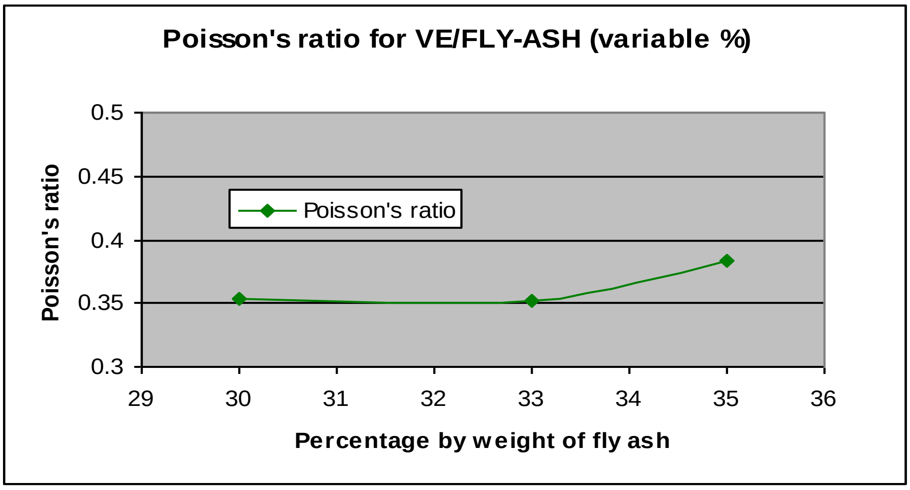


Figure 6: Poisson's ratio of VE/FLY-ASH vs percentage by weight of filler

Table 1: Mechanical prosperities of VE/FLY-ASH with varying percentages by weight of fly ash

Percentage by weight of fly ash / Mechanical properties	30	33	35
Yield strength (MPa)	21.18 (0,184) [##]	20.98 (0.146)	19.8 (0.386)
Tensile strength (MPa)	22.83 (0.47)	21.89 (1.11)	20.28 (0.31)
Young's modulus (GPa, manual)	4.286 (0.089)	4.445 (0.143)	4.532 (0.117)
Poisson's ratio	0.353	0.352	0.383

[##] Standard deviation in bracket