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Identification of Mechanical Strength for Mixture of Thermoset Polyester with Thermoset Vinyl Ester due to Bending Load

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Kata kunci:

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Polyester,
Vinyl ester
b*lends*

ABSTRAK

Pada penelitian ini dilakukan upaya untuk meningkatkan ketangguhan mekanis *Unsaturated Polyester* (UP) dengan menambahkan *Thermoset Vinyl Ester* (VE) dan *Methyl Methacrylate* (MMA). Untuk menunjukkan tingkat ketangguhan material dilakukan pengujian dengan memberikan beban lentur sampai material tersebut putus. Hasil pengujian menunjukkan bahwa campuran 40 % wt VE dan 10% wt MMA pada material UP menghasilkan peningkatan sifat ketangguhan material dari pengujian *bending stress* pada spesimen dengan variasi komposisi *polyester* dan *vinyl ester* dengan *hand lay-up*. Nilai tegangan lentur tertinggi terdapat pada komposisi 60% polyester dan 40% vinyl ester yaitu sebesar 126,88 MPa (meningkat 16 % dari polyester murni).

Keyword:

Toughness,
Polyester,
Vinyl ester
blends.

ABSTRACT

In this study, an attempt was made to increase the mechanical toughness of unsaturated polyester (UP) by adding Thermoset Vinyl Ester (VE) and Methyl Methacrylate (MMA). A test is carried out to show the level of toughness of the mechanical properties of the above material by applying a flexural load until the material breaks. The test results showed that a mixture of 40% wt VE and 10% wt MMA in UP material resulted in an increase in the toughness properties of the material from the bending stress test on specimens with variations in the composition of polyester and vinyl ester with hand lay-up. The highest flexural stress value is found in the composition of 60% polyester and 40% vinyl ester, which is 126.88 MPa (an increase of 16% from pure polyester).

1. INTRODUCTION

Polymer Mixture of polyester and vinyl ester is widely used in engineering fields such as for car bumpers, boat bodies, ultra light aircraft wings, wind turbine blades and others. One of the requirements to meet the application aspects in the engineering field is the ability of the material to withstand bending loads. For this reason, it is necessary to test the flexural stress characteristics of the mixture of the two polymers of unsaturated polyester and unsaturated vinyl ester [2]. The aim is to find out which of the two polymer blends obtains superior flexural resistance properties from each of the polymers with respect to the blend percentage [3]. Therefore, much effort has been devoted to initiating local energy-absorbing mechanisms in the initial fracture point zone of the material to reduce plastic resistance and delay the attainment of brittle strength [4]. This drawback limits the commercial application of unsaturated polyesters. Several things have been done to increase the toughness of polyester by adding fillers, such as water hyacinth fiber [5], threaded pine fiber [6], and rubber [7]. Another approach to strengthening polyester is to reduce stiffness by mixing chemicals that can disrupt the chain structure of unsaturated polyester chains [4] [8]. Studies that have been carried out have increased the use of vinyl materials in the form of couplings to disrupt the cross-linking of the unsaturated polyester chain network due to the similar chain structure between these thermosets [9]. Combining these two polymers has been widely carried out. As previously discussed, the addition of 40% vinyl ester to unsaturated polyester resulted in a 63.6% increase in tensile strength and 85.7% elongation at breakage [2] [8]. [10] [11]. Unsaturated polyester resins that are cured are often very brittle and lack impact resistance. This resin has moderate tensile strength, is economical, and has high chemical and water resistance [2]. This is because thermosets have a macromolecular covalent bond network structure with a high cross-link density and small energy dispersion, which is indicated by plastic deformation in front of the localized crack tip, which causes catastrophic brittle failure [3]. Therefore, much effort has been devoted to initiating local energy absorption mechanisms in the initial fracture point zone of the material to reduce plastic resistance and delay the attainment of brittle strength [4]. These drawbacks limit the commercial application of UP resins. Several things have been done to increase the toughness of this material with fillers, including water hyacinth fiber [5], threaded pine fiber [6], and rubber [7]. Another approach to strengthening UP is to reduce stiffness by mixing with chemicals that disrupt the structure of the interlinked UP chains [4] [8]. Studies that have been carried out have explored the possibility of using the incorporation of vinyl esters into polyesters to increase the tensile strength of these polymers have been carried out [9]. As previously discussed, the addition of 40% vinyl ester to unsaturated polyester resulted in a 63.6% increase in tensile strength and an 85.7% elongation at blend breakage [2] [8] [10] [11]. Although there is a wealth of information on the effect of vinyl esters on increasing the toughness of unsaturated polyesters, there is almost no information on how vinyl ester dispersions modify the crosslinked polyester chain structure, and the fracture surface morphology of the blends is almost non-existent. Therefore, this study aims to characterize the properties of polyester resin reinforced by a vinyl ester polymer material, and the changes in the polymer structure have not yet provided detailed information. Several previous studies have not reported much on this material to study the fracture surface of the material, and this information has not been published. For this reason, several studies will be carried out in this study, including the ability of the material to withstand bending loads [6] [12].

2. MATERIALS AND METHODS

2.1 Material

All materials for preparing the matrix were purchased from Justus Sakti Raya Inc, Indonesia. They consisted of UP resin (YUKALAC BQTN 157-EX type, specific gravity 1.1 g/cm3 at 25 oC and viscosity 4.5-5.0 poise at 25 ^{o}C), VE resin (RIPOXY R-802 EX-1, specific gravity 1.05 g/cm3 at 25 ^{o}C), MMA, and methyl ethyl ketone peroxide (MEKP) as a catalyst [2].

2.2 Preparation Process for making UP/VE blends and Viscosity Measurement

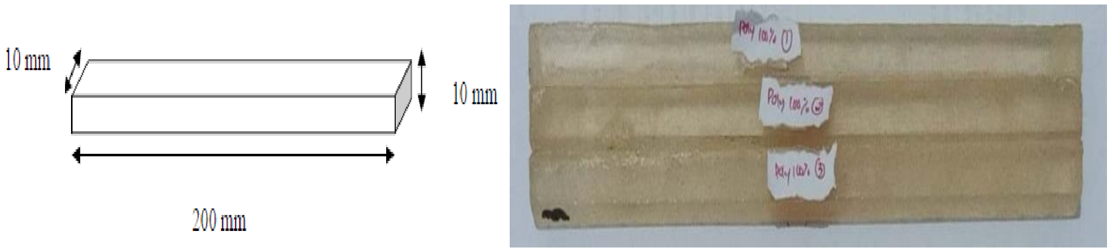
The composition of UP, VE resin, and MMA were mixed in the ratios shown in Table 1. This composition ratio was modified from previous works [2][8]. Each composition of the mixture was homogenized using a magnetic stirrer (Daihan MSH-20D) for 10 min at 400 rpm and about 25 ^{o}C. The viscosity of each mixture was measured five times using a viscometer (NDJ-8S Digital Rotary Viscometer) at 60 rpm at room temperature for 12 seconds. 4% MEKP was added to the then cast onto a silicon-based die for curing at about 25 ^{o}C for 72 hours. polymerimer blends were achieved by adding a vinyl ester (VE) into unsaturated polyester (UP) at 10, 20, 30, and 40 wt.% through a physical-mechanical blending method with styrene crosslinker diluent. Methyl ethyl ketone peroxide (MEKP) is added as catalyst initiator at four wt.% without catalyst-accelerator. Unsaturated polyester, vinyl ester, and MEKP were blended by a mechanical mixer stirring at room temperature for 5 minutes, affording a transparent colorless solution[2].

Table 1. Curing characteristics of UP/VE blends cured at room temperature.

Material No.	**UP Composition (wt %)**	**Vinyl Ester Composition (wt %))**	**MMA Composition (wt %)**	**MEKP Composition (wt %)**
1	100	0	10	4
2	90	10	10	4
3	80	20	10	4
4	70	30	10	4
5	60	40	10	4
6	0	100	10	4

2.3 Morphology Mechanical Characterization of Unsaturated Polyester/Vinyl Ester Blends

The The unsaturated polyester/vinyl ester mixture was subjected to bending moment testing to determine the maximum bending stress with a tool using a universal testing machine Autograph COM-TEN 95T Series 5K [2][15]. In this study, fracture values are measured following the linear elastic fracture mechanics. In this study, a polymer blend was made from an alloy of polyester and vinyl ester. The tests carried out are bending tests or bending tests using a bending test tool. The standard of bending test or bending test used is based on ASTM D 790 [5]



(a) Dimension specimen. (b) Result of specimens of model.

Figure 1. Specimens Testing to Bending Load

Figure 2. Universal testing machine Autograph Machine COM-TEN 95T Series 5K to bending testing

3. RESULTS AND DISCUSSION

3.1 Mechanical properties of unsaturated polyester/vinyl ester blend

The thermoset polymer blends were mixed by stirring mechanical blending method, and room temperature curing of UP/VE blends shows in Table 1. UP was preserved at a curing time of 20 minutes, forming a yellowish transparent solid hard rigid material. Figure 1 shows an example of the resulting cured resin mixture. [4][17]. The curing time increases with the addition of the vinyl ester composition to the mixture 40 up to 270 minute. It suggests that VE needs a catalyst accelerator such as organic salt for the curing process of the resin.

3.2 Mechanical properties of bending moment

Figure 2 shows the tensile strength of UP/VE blends. Table 2 shows the results of Tensile stress of UP/VE blends as the mechanical properties of UP/VE blends. Cured showed high tensile strength, which corresponds to crosslinked chemical structure network [3, 9]. The addition of vinyl ester composition increased the tensile strength of UP/VE blends up to 40 wt.% of VE. At high VE composition, the tensile stress of UP/VE blends decreased due to unreacted bonds and the difficulty of the molecule to be cured [27-31].

Figure 3 shows elongation at the break of UP/VE blends. Cured UP led to high extension at the break. The addition of vinyl ester composition increased the elongation at break of UP/VE even at high VE composition (40 wt.%). The increasing elongation at break is due to the high long-chain chemical structure of the polymer and the more effortless movement of the molecule chain [27][28]. The UP/VE shows high elongation at break, and vinyl ester composition increased the hardness value of UP/VE blends up to 40 wt.% VE composition. At high VE composition, the hardness of UP/VE decreased due to the unreacted molecule [29].

Table 2. The tensile stress of UP/VE blends.

Material UP/VE	**Tensile stress (MPa)**		
100/0	43.50	±	5.98
90/10	44.76	±	5.18
80/20	53.41	±	2.93
70/30	58.55	±	5.41
60/40	73.67	±	8.30
0/100	62.25	±	6.30

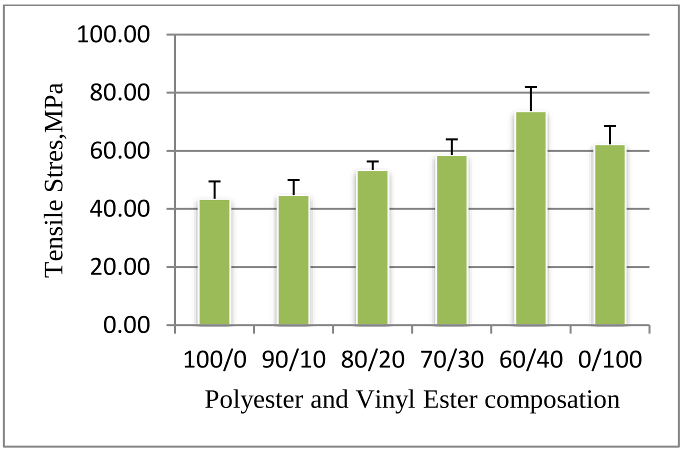


Figure 2. The tensile stress of UP/VE blends

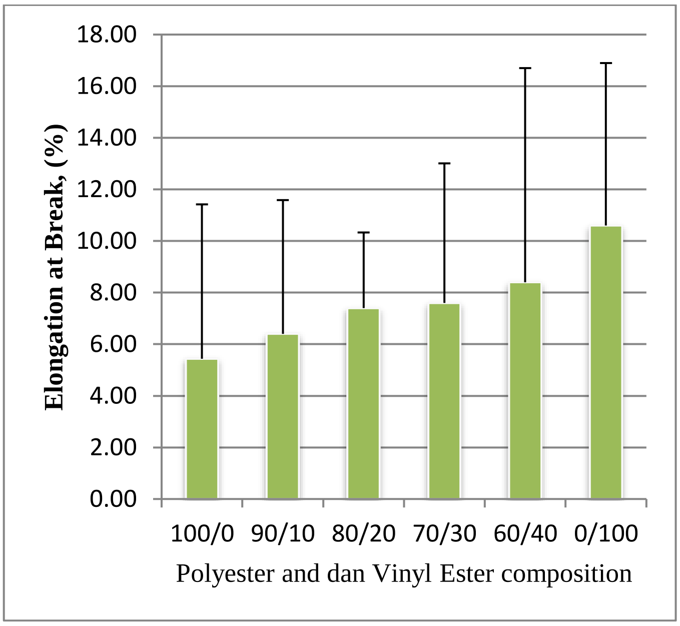


Figure 3. Elongation at break of UP/VE blend

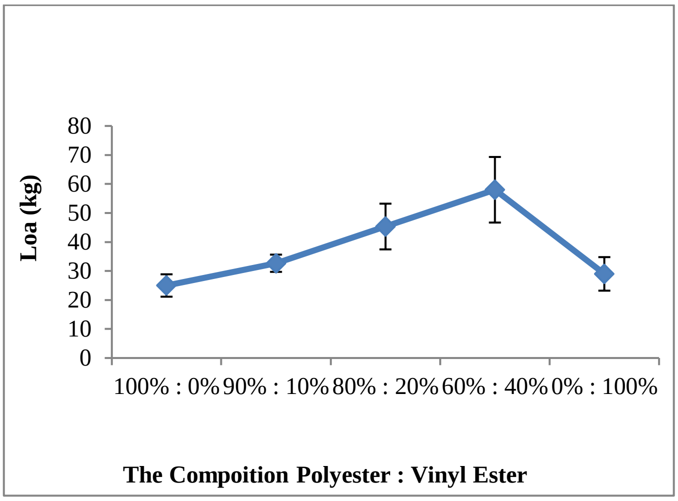


Figure 4. The Bending stress of UP/VE blends

Table 3. Value of Load and Stress on Bending Test

Composation of *Polyester / Vinyl Ester*	**Load (Kg)**	**σ_b (N/mm)**	**Standard Deviations**
100 % //0 %	25	49,71	3,86
90%/: 10%	32,67	63,27	2,97
80% / 20%	45,33	93,79	7,88
60%/ 40%	58.43	126,88	11,30
0% / 100%	29.47	56,50	5,78

The test results showed that the mixture of 40% wt VE and 10% wt MMA to UP material resulted in an increase in the material's toughness properties of bending stress testing on specimens with variations in the composition of polyester and vinyl ester with the hand lay-up method, the highest bending stress value was found at the composition of 60% polyester and 40% vinyl ester, which was 126.88 MPa. [2][34].

5. CONCLUSION

This work reported the successful fabrication of a challenging UP blend and related its tensile stress properties to bending load. The UP mixed with 30% VE and 10% MMA had the highest bending stress (increased by 70.5%) and the higher elongation at the break (a rise of 67.9%) compared to pure UP. The Bending moment strength ruptured at room temperature was characterized according to ASTM D 790 [5], and their fractured surfaces were identified by SEM analysis. The intercalation structure of the UP/VE and MMA blend polymer matrix is observed. The incorporation of MMA up to wt % 10, into the UP resin showed the bending stress σ_b (N/mm) by 16 % higher than the neat UP. The deformation mechanisms of material transferred from a highly brittle fracture without crazing for the neat UP to shear yielding deformation with plausible energy absorption.

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REFERENCES

[1] H. Adam, "Carbon fiber in automotive applications," *Mater. Des.*, vol. 18, no. 4–6, pp. 349–355, 1997, DOI: 10.1016/s0261-3069(97)00076-9.

[2] H. Abral *et al.*, “Improving impact, tensile and thermal properties of thermoset unsaturated polyester via mixing with thermoset vinyl ester and methyl methacrylate,” *Polym. Test.*, vol. 81, p. 106193, 2020, DOI: 10.1016/j.polymertesting.2019.106193.

[3] M. T. Albdiry and B. F. Yousif, “Toughening of brittle polyester with functionalized halloysite

nanocomposites," *Compos. Part B Eng.*, vol. 160, no. October 2018, pp. 94–109, 2019, DOI: 10.1016/j.compositesb.2018.10.032.

[4] M. T. Albdiry, B. F. Yousif, and H. Ku, "Fracture toughness and toughening mechanisms of unsaturated polyester-based clay nanocomposites," *13th Int. Conf. Fract. 2013, ICF 2013*, vol. 5, pp. 3446–3455, 2013.

[5] G. R. Arpitha, M. R. Sanjay, and B. Yogesha, "Review on Comparative Evaluation of Fiber Reinforced Polymer Matrix Composites," *Adv. Eng. Appl. Sci. An Int. J.*, vol. 4, no. 4, pp. 44–47, 2014.

[6] R. Masoodi, R. E. Hajjar, K. M. Pillai, A. Javadi, and R. Sabo, "An experimental study on crack propagation in green composites made from cellulose nanofibers and epoxy," *Int. SAMPE Tech. Conf.*, no. February 2016, 2011.

[7] C. Miao *et al.*, "Superior crack initiation and growth characteristics of cellulose nano papers," *Cellulose*, vol. 27, no. 6, pp. 3181–3195, 2020, DOI: 10.1007/s10570-020-03015-x.

[8] H. Ardhyananta *et al.*, "Mechanical and Thermal Properties of Unsaturated Polyester/Vinyl Ester Blends Cured at Room Temperature," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 202, no. 1, 2017, DOI: 10.1088/1757-899X/202/1/012088.

[9] A. Mahyudin, S. Arief, H. Abral, Emriadi, M. Muldarisnur, and M. P. Artika, "Mechanical properties and biodegradability of areca nut fiber-reinforced polymer blend composites," *Evergreen*, vol. 7, no. 3, pp. 366–372, 2020, DOI: 10.5109/4068618.

[10] M. L. Chan, K. T. Lau, T. T. Wong, M. P. Ho, and D. Hui, "Mechanism of reinforcement in a nanoclay/polymer composite," *Compos. Part B Eng.*, vol. 42, no. 6, pp. 1708–1712, 2011, doi: 10.1016/j.compositesb.2011.03.011.

[11] C. V. Opelt, G. M. Cândido, and M. C. Rezende, "Fractographic study of damage mechanisms in fiber-reinforced polymer composites submitted to uniaxial compression," *Eng. Fail. Anal.*, vol. 92, no. June, pp. 520–527, 2018, DOI: 10.1016/j.engfailanal.2018.06.009.

[12] A. T. Seyhan, M. Tanoğlu, and K. Schulte, "Tensile mechanical behavior and fracture toughness of MWCNT and DWCNT modified vinyl-ester/polyester hybrid nanocomposites produced by 3-roll milling," *Mater. Sci. Eng. A*, vol. 523, no. 1–2, pp. 85–92, 2009, DOI: 10.1016/j.msea.2009.05.035.

[13] Q. Meng and T. Wang, "An improved crack-bridging model for rigid particle-polymer composites," *Eng. Fract. Mech.*, vol. 211, no. January, pp. 291–302, 2019, DOI: 10.1016/j.engfracmech.2019.02.028.

[14] R. Mao *et al.*, "Comparison of fracture properties of cellulose nanopaper, printing paper and buckypaper," *J. Mater. Sci.*, vol. 52, no. 16, pp. 9508–9519, 2017, DOI: 10.1007/s10853-017-1108-4.

[15] Nusyirwan, H. Abral, M. Hakim, and R. Vadia, "The potential of rising husk fiber/native sago starch reinforced biocomposite to automotive component," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 602, no. 1, 2019, DOI: 10.1088/1757-899X/602/1/012085.

[16] a Standard, "Standard Test Methods for Plane-Strain Fracture Toughness and Strain Energy Release Rate of Plastic Materials," *Annu. B. ASTM Stand.*, vol. 99, no. Reapproved, pp. 1–9, 1996, DOI: 10.1520/D5045-99R07E01.2.

[17] S. Magami and J. Guthrie, "Amino resin crosslinked can coatings," *Surf. Coat. Int*, vol. 95, no. 2, pp. 64–73, 2012.

[18] M. Davallo, H. Pasdar, and M. Mohseni, "Mechanical properties of unsaturated polyester resin," *Int. J. ChemTech Res.*, vol. 2, no. 4, pp. 2113–2117, 2010.

[19] Y. Ju *et al.*, "Visualization method for stress-field evolution during rapid crack propagation using 3D printing and photoelastic testing techniques," *Sci. Rep.*, vol. 8, no. 1, pp. 1–10, 2018, DOI: 10.1038/s41598-018-22773-0.

[20] N. Hiremath, S. Young, H. Ghossein, D. Penumadu, U. Vaidya, and M. Theodore, "Low cost textile-grade carbon-fiber epoxy composites for automotive and wind energy applications," *Compos. Part B Eng.*, vol. 198, no. May, p. 108156, 2020, doi: 10.1016/j.compositesb.2020.108156.

[21] C. Feng, S. Kitipornchai, and J. Yang, "Nonlinear bending of polymer nanocomposite beams reinforced with non-uniformly distributed graphene platelets (GPLs)," *Compos. Part B Eng.*, vol. 110, pp. 132–140, 2017, DOI: 10.1016/j.compositesb.2016.11.024.

[22] B. B. Rath and J. J. Vittal, "Mechanical Bending and Modulation of Photoactuation Properties in a One-Dimensional Pb(II) Coordination Polymer," *Chem. Mater.*, vol. 33, no. 12, pp. 4621–4627, 2021, doi: 10.1021/acs.chemmater.1c01124.

[23] M. Mandhakini, S. Devaraju, M. R. Venkatesan, and M. Alagar, "Linseed vinyl ester fatty amide toughened unsaturated polyester- bismaleimide composites," *High Perform. Polym.*, vol. 24, no. 3, pp. 237–244, 2012, DOI: 10.1177/0954008311436263.

[24] S. Table and S. Table, "IR Tables, UCSC Table 1. Characteristic IR Absorption Peaks of Functional Groups * Vibration Alkanes," pp. 1–6.

[25] A. Budiman and S. Sugiman, "Karakteristik Sifat Mekanik Komposit Serat Bambu Resin Polyester Tak Jenuh Dengan Filler Partikel Sekam," *Din. Tek. Mesin*, vol. 6, no. 1, pp. 76–82, 2016, doi: 10.29303/d.v6i1.28.

[26] Z. Yang, H. Peng, W. Wang, and T. Liu, "Crystallization behavior of poly(ε-caprolactone)/layered double hydroxide nanocomposites," *J. Appl. Polym. Sci.*, vol. 116, no. 5, pp. 2658–2667, 2010, DOI: 10.1002/app.

[27] A. A. Betelie, Y. T. Megera, D. T. Redda, and A. Sinclair, "Experimental investigation of fracture toughness for treated sisal epoxy composite," *AIMS Mater. Sci.*, vol. 5, no. 1, pp. 93–104, 2018, DOI:

10.3934/matersci.2018.1.93.

[28] H. N. Dhakal and S. O. Ismail, *Unsaturated polyester resins: Blends, interpenetrating polymer networks, composites, and nanocomposites*. Elsevier Inc., 2019.

[29] Z. Hashin, “Analysis of Properties of Fiber Composites With Anisotropic Constituents.,” *J. Appl. Mech. Trans. ASME*, vol. 46, no. 3, pp. 543–550, 1979, DOI: 10.1115/1.3424603.

[30] M. Santiam, R. Drainage, and W. Cascades, “The Applicability of Linear Elastic Fracture Mechanics to Compressive Damage of the Carbon Fiber Reinforced Plastic Matrix,” 2019.

[31] J. Njuguna, P. Wambua, and K. Pielichowski, *Cellulose Fibers: Bio- and Nano-Polymer Composites*. 2011.

[32] B. Admadi H and I. W. Arnata, “Teknologi Polimer,” pp. 1–46, 2015.

[33] K. Deepak, N. S. Reddy, and T. V. S. Naidu, "Thermosetting Polymer and Nano Clay Based Natural Fiber BioComposites," *Procedia Mater. Sci.*, vol. 10, no. Cnt 2014, pp. 626–631, 2015, DOI: 10.1016/j.mspro.2015.06.095.

[34] K. Liu, S. He, Y. Qian, Q. An, A. Stein, and C. W. Macosko, “Nanoparticles in Glass Fiber-Reinforced Polyester Composites: Comparing Toughening Effects of Modified Graphene Oxide and Core-Shell Rubber,” *Polym. Compos.*, vol. 40, no. S2, pp. E1512–E1524, 2019, DOI: 10.1002/pc.25065.