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Identification of the fracture surface of thermoset polyester due to bending load

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Abstract

In this research, an attempt was made to improve the brittle nature of the Unsaturated Polyester (UP) polymer which cannot undergo plastic deformation to be improved to become more resilient by adding Thermoset Vinyl Ester and Methyl Methacrylate (MMA). To show the change in the toughness of the polyester material, a test is carried out to provide a tensile load and a flexural load until the material breaks This work reports the successful fabrication of polyester blends by mixing vinyl esters with different percentages. The test shows that there is a linear relationship between the shape of the fracture surface due to bending loads and observations through SEM which are directly related to the flexural stress properties with the fracture surface morphology. The mixture of polyester with 40% vinyl ester showed the highest flexural stress of 126.88 MPa while for pure polyester of 49.71 MPa this showed an increase of 255.24% compared to pure polyester. This shows that the addition of vinyl ester to polyester resulted in an increase in the toughness of the polyester, but for 100% vinyl ester the return stress decreased by 56.50 MPa. This indicates that due to the breaking of some of the polyester chain networks causes a decrease in the structural stiffness, which results in an increase in the plastic deformation zone fraction.

Keywords*: toughness; polyester; vinyl ester blends*

1. INTRODUCTION

The development of material technology is currently growing very rapidly, one of which is an attempt to find a strong and lightweight material to replace metal. One type of material that is widely developed and researched today is a polymer. Polymers are lightweight and malleable materials whose strength can still be increased. This material consists of large molecules that are repeatedly arranged from small molecules that are covalently bonded to each other. These molecules are commonly called monomers (1). The properties of polymers that are corrosion resistant, relatively light compared to metals, and have high aesthetic value are one of the reasons polymer materials were developed as an alternative in the industrial world. Polymers have the potential to improve their mechanical and thermal properties (2). The mechanical properties that are generally improved from polymeric materials are strength, stiffness, and ductility. The reason for increasing the mechanical properties of polymeric materials is that polymer materials are generally brittle. Improving the mechanical properties of polymeric materials can be done by mixing several polymers. The mixing of these polymers is known as a polymer blend (3)(4). The purpose of the polymer blend is to obtain the mechanical properties of each polymer that is mixed so that a new polymer alloy material with better mechanical properties is obtained. One of the polymers that are often used in the industrial world is polyester. Polyester is generally used by the industrial world in the manufacture of a product because polyester has flexibility and

ease in the process of forming a structure (5). Polyester has limited mechanical properties compared to some other types of polymers, so other alloys are needed can strengthen and improve their mechanical properties (6). Besides polyester, another type of polymer that is also commonly used is vinyl ester. Vinyl esters have better mechanical properties than other polymers, but are much more expensive than polyester (7). Vinyl ester is a polymer that has high performance and good processability to improve the mechanical properties of an alloying element, so that vinyl esters can be used to improve the mechanical properties of polyester alloys. The improvement of the mechanical properties of the polymer mixture will be related to the percentage of alloy. Information on the value of the flexural strength of polymer blends from polyester and vinyl ester alloys has not been studied extensively (8)(9). For this reason, in this study, it is necessary to study the flexural strength of the above material on the percentage of the mixture.

In this study, a polymer blend was prepared 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 bending test or bending test used is based on ASTM D 790 (10). This research is expected to be a reference for the development and utilization of polyester and vinyl ester in order to increase the use of polymers in the industrial sector. Therefore, this study aims to improve the stiffness properties of polyester by mixing it with vinyl ester so that new mechanical properties are obtained that are better than the properties of pure polyester and pure vinyl ester which are later expected to be used in a wider application sector in the industrial other applications. 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 (11)(12).

2. Material and Methods

2.1 Material

In this study, the mechanical properties of the polyester polymer were strengthened by mixing with vinyl ester polymer to obtain a mixture of two polymer materials that have good mechanical properties from pure polyester polymer (13)(3)(14). There are types of mixed materials.

2.1.1 Polyester

Polyester is a polymer that is commonly used as a matrix to form composite materials when mixed with synthetic fibers or natural fibers to increase the desired good mechanical properties polyester is a polymer that is easy to form and includes inexpensive polymer materials (15). Following are some of the properties of polyester, among others: polyester has good tensile strength, resistance to strain, chemicals, and mildew, excellent abrasion resistance, easy maintenance, and polyester has water repellent properties and dries quickly. The type of polyester used in this research is unsaturated polyester with Yukalac 1560 BL-EX product (2). The mechanical properties of polyester can be seen in Table 1.

Table 1. Mechanical Properties of Polyester (2)

Item	Unit	Value
Tensile strength	MPa	20-100
Tensile modulus	GPa	2,1-4,1
Ultimate strain	%	1-6
Poisson's ratio	-	-
Density	g/cm^3	1,0-1,45
T_g	˚C	100-140
CTE	10^{-6}/˚C	55-100
Cure Shrinkage	%	5-12

2.1.2 Vinyl Ester

The polymer mixed in the polyester polymer is a vinyl ester that has good elastic deformation compared to polyester but has a relatively expensive price from polyester, the vinyl ester is produced by PT. Justus Kimiaraya with the trademark vinyl ester resins.

2.1.3 Methyl Methacrylate (MMA)

Methyl methacrylate or often referred to as MMA is a polymer material that has biocompatible properties. The advantage of adding MMA to an alloy is to produce a material that is non-toxic, relatively low cost, easy to process, compatible, and can be used for processing materials that have great fracture resistance (16)(12). Mixing MMA with thermosetting resins can reduce the viscosity of the polymer blend (13). The addition of MMA here is expected to make the network structure of polyester homogeneous (15)(17).

2.1.4 Catalyst MEKP

The catalyst used is the Mepoxe catalyst produced by PT. Justus Kimiaraya. The function of the catalyst is as a catalyst to accelerate the drying rate of polyester. The use of a catalyst is 4% for polyester alloys (3).

2.2 Process for making polyester and vinyl ester blends

In this research, the manufacture of polymer material mixed with polyester and vinyl ester polymer with the following ratio of polyester to vinyl ester 100%: 0%, 90%: 10%, 80%: 20%, 70%: 30% and 60%: 40% each mixture will be compared with the mechanical properties of all the percentages of the mixture made and will be compared with pure polyester without being mixed with vinyl ester. This section describes the steps for making polymer blends between polyester and vinyl ester. The procedure for making this composite specimen is as follows:

Prepare rice husk, polyester, and MMA.

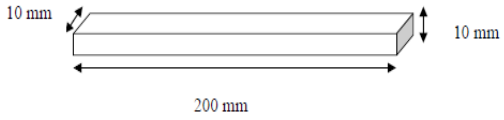
1. Mix 5% vinyl ester and polyester, 95%, and 10% MMA. As a catalyst. Likewise for the percentage of rice husks for the percentage of 10%, 15% and 20%.
2. Dissolve using a hot plate magnetic stirrer with a rotation of 600 rpm, a temperature of 60°C, and a time of 90 minutes.
3. Cool the mixture for 60 minutes.
4. Dissolve again using a hot plate magnetic stirrer for 3 minutes.
5. Insert the crack test specimen into the mold.
6. Dry in the open air (room temperature) for 24 hours.

Table 2. Characteristics of the casting results of a mixture of polyester and vinyl ester materials frozen 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 Methods

The mixed polyester and vinyl ester materials were evaluated using Fourier-transform infrared (FTIR) spectroscopic analysis. In this study, fracture values followed linear elastic fracture mechanics (LEFM). In this study, a polymer blend was prepared 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 bending test or bending test used is based on ASTM D 790 (5).



(a)

(b)

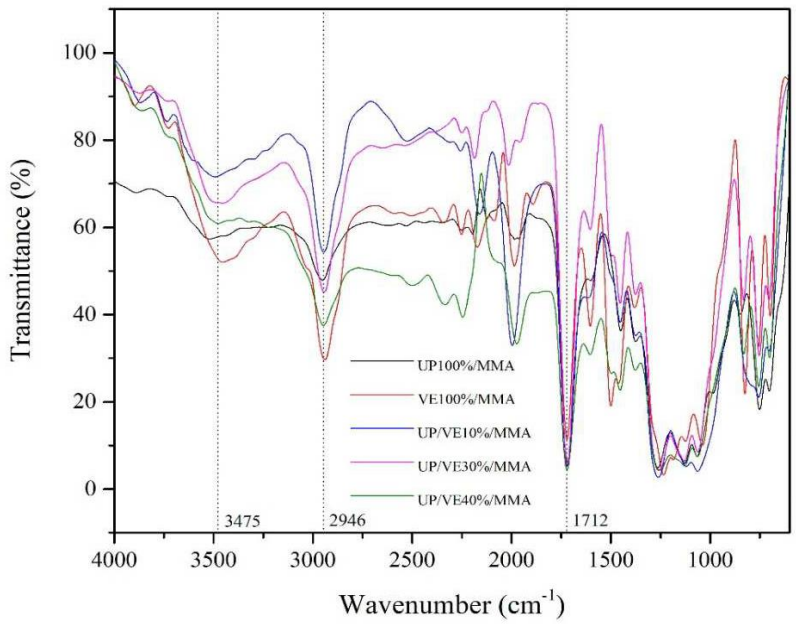
(c)

Figure 2. Sample and universal testing machine. (a) Dimension sample, (b) Sample has frozen moulding, and (c) Universal testing to bending load.

3. RESULT AND DISCUSSION

3.1 Mechanical Properties of Unsaturated Polyester and Vinyl Ester Blend

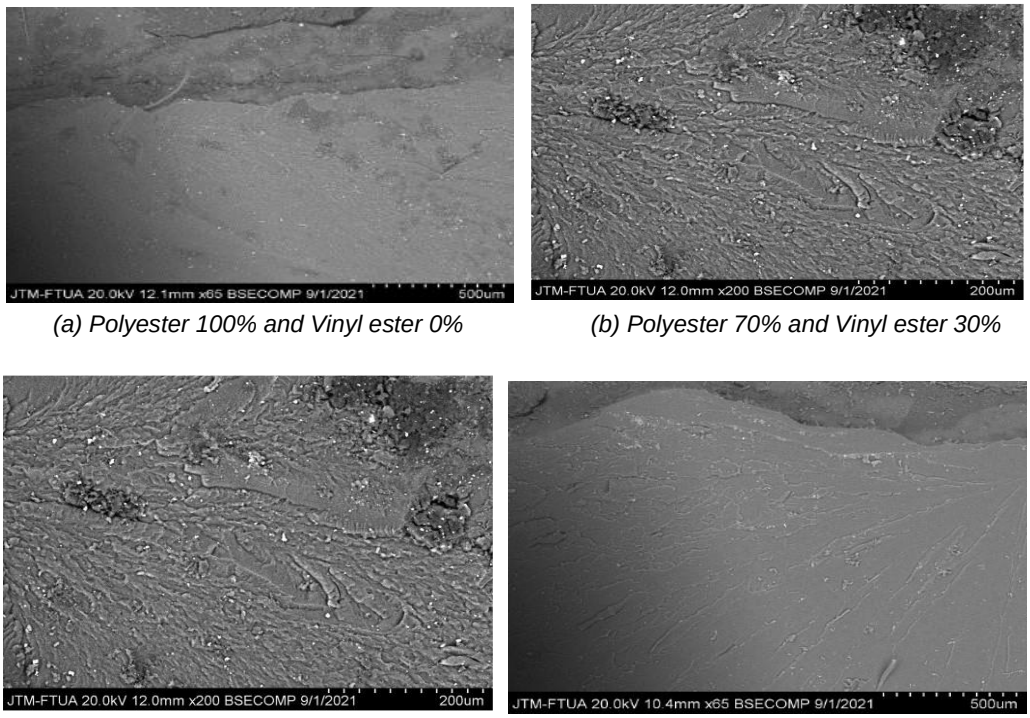
FTIR test results show a mixture of UP/VE polymers to form containing aromatic benzene rings to form UP/VE blends. The thermoset polymer blends were mixed by stirring mechanical blending method, and room temperature curing of UP/VE blends shows Table 1. UP was preserved at a curing time of 20 minutes, forming a yellowish transparent solid hard rigid material. Figure 1 shows an example of the resulting cured resin mixture (18)(19). The curing time increases with the addition of the vinyl ester composition to the mixture at 40 until 270 minutes. VE was cured after 6000 min affording yellowish transparent liquid material. It suggests that VE needs a catalyst accelerator such as organic salt for the curing process of the resin.



Graph 1. FTIR curves for samples polyester mixed with vinyl ester

3.2 Morphological Characterization

The shape of the fracture surface of the test sample that had been damaged by loading was observed using the SEM JIB AXRx83 model with the sample (18)(2)(20). The surface of the sample is stained with a corrosive material, making it easier to show the fracture surface due to loading. Pure polyester Fig. 3(a) and vinyl ester resin Fig. (3b) have a smooth surface which corresponds to this with low toughness. This smooth appearance results from the breakdown of a network of rigid chains connected to the fracture surface perpendicular to the direction of bending stress[20]. The growing crack splits the polymer structure together with the weakest atomic bonds Addition of MMA and vinyl ester to the polyester polymer produces different fracture surfaces depending on the percentage of the mixture and shows a rougher direction Fig. 3(b) Surface roughness increases when polyester mixed with 30% vinyl ester. In Figure. 3(c), the maximum roughness occurs at the fracture surface with a 40% vinyl ester content, this shows the mixture with the highest roughness and is the mixture that shows the highest toughness. Figure 3(d) The higher the vinyl ester content, the roughness decreases and the surface becomes smoother at the vinyl ester content of the nuts. It's 100% or without polyester.



(a) Polyester 100% and Vinyl ester 0% *(b) Polyester 70% and Vinyl ester 30%*

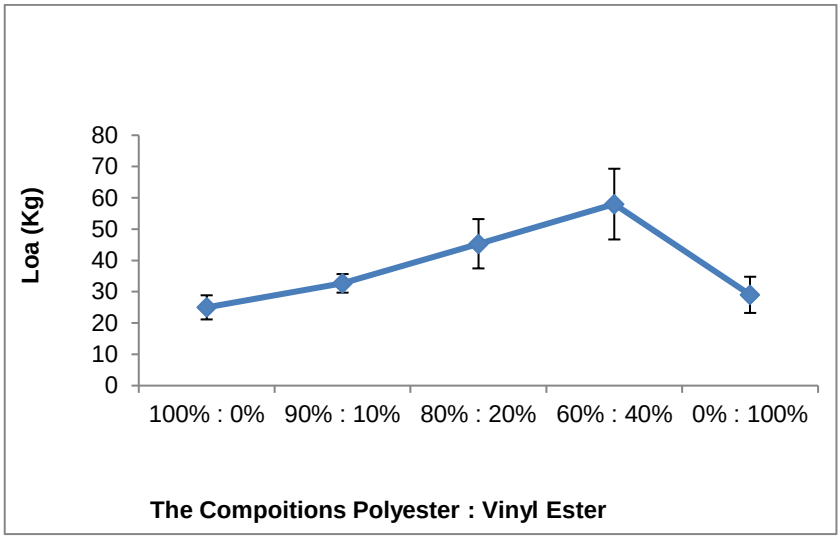
(c) Polyester 60% and Vinyl ester 40% *(d) Polyester 0 5 and Vinyl 100 %*

Figure 3. SEM tensile fracture surface of Polyester and Vinyl ester blend.

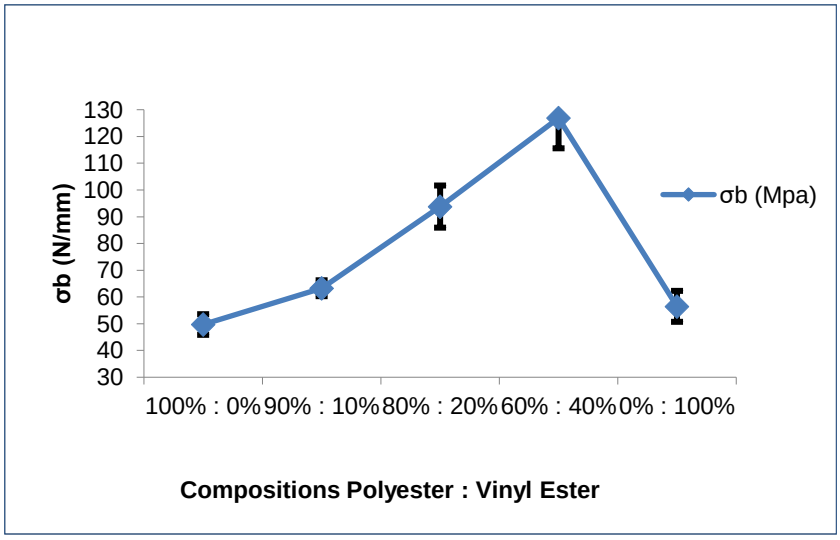
3.3 Mechanical Properties

Graphs 2 and 3 show the bending load curves for each polyester and vinyl ester blend. Pure polyester produces the lowest bending load of 25 Kg with a bending stress of 49.71 Mpa. The content of the vinyl ester mixture in polyester is 40% and 60%, resulting in a bending load of 58.43 Kg and a bending stress of 126.88 MPa. As for the 100% Vinyl ester mixture or pure Vinyl ester mixture without polyester, the bending load is 29.47 Kg and the bending stress is 56.50 MPa and shows a decreased load and stress value. This is in accordance with the results of the SEM test with a smooth surface shape Figure 3(a), while the vinyl ester content of 40% shows a rough fracture shape and this is due to an increase in toughness which indicates plastic deformation, this indicates the material shows an increase in toughness. The test results show that the network structure with many crosslinked chemical structures is disturbed. in the presence of a number of polyester

polymers mixed with vinyl esters (1).For pure vinyl esters, the fracture surface is smooth because there is no mixing of the chemical composition of the mixture.



Graphic 2. Bending Load s of Composition of Polyester and Vinyl ester Blend



Graph 3. The Bending stress of UP/VE blends

Tabel 3. Value of Load and Stress on Bending Test.

Composition *Polyester*: *Vinyl Ester*	Bending Load (Kg)	σ_b (N/mm^2)	Deviation standard
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

Main 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 (1).

4. CONCLUSION

This work reports the successful fabrication of polyester blends by mixing vinyl esters with different percentages. The test shows that there is a linear relationship between the shape of the fracture surface due to bending loads and observations through SEM which are directly related to the flexural stress properties with the fracture surface morphology. The mixture of polyester with 40% vinyl ester showed the highest flexural stress of 126.88 MPa while for pure polyester of 49.71 MPa this showed an increase of 255.24% compared to pure polyester. This shows that the addition of vinyl ester to polyester resulted in an increase in the toughness of the polyester, but for 100% vinyl ester the return stress decreased by 56.50 MPa. This indicates that due to the breaking of some of the polyester chain networks causes a decrease in the structural stiffness, which results in an increase in the plastic deformation zone fraction. The plastic deformation zone displays a smooth surface resulting from the slow fracture growth and tortuous along the lowest stiffness zone in the disturbed crosslinked polymer chain structure. The fracture toughness of the flexural test also showed the same as the tensile test at room temperature characterized according to ASTM D 790(21)(10), and the fracture surface was identified by SEM analysis. The deformation mechanism of polyester material by mixing it with vinyl ester and MMA can increase the plastic deformation of the brittle nature of pure polyester.

REFERENCES

1. 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.
2. 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: http://dx.doi.org/10.1088/1757-899X/602/1/012085.
3. 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: https://doi.org/10.1177/0954008311436263.
4. 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: https://doi.org/10.1016/j.msea.2009.05.035.
5. 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: https://doi.org/10.1002/app.31787.
6. 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: https://doi.org/10.1016/j.engfracmech.2019.02.028.
7. H. N. Dhakal and S. O. Ismail, "Unsaturated polyester resins: Blends, interpenetrating polymer networks, composites, and nanocomposites". Elsevier Inc., 2019. doi: https://doi.org/10.1016/B978-0-12-816129-6.00008-9.
8. M. Santiam, R. Drainage, and W. Cascades, “The Applicability of Linear Elastic Fracture Mechanics to Compressive Damage of the Carbon Fiber Reinforced Plastic Matrix,” *Mechanics of Advanced Materials and Structures*, 2019. doi: https://doi.org/10.1080/15376494.2021.1952663
9. 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: https://doi.org/10.29303/dtm.v6i1.28.
10. 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.
11. D. Frómeta *et al.*, “Identification of fracture toughness parameters to understand the fracture resistance of advanced high strength sheet steels,” *Eng. Fract. Mech.*, vol. 229, no. February, p. 106949, 2020, doi: https://doi.org/10.1016/j.engfracmech.2020.106949.
12. 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: https://doi.org/10.1016/j.compositesb.2018.10.032.
13. J. S. Ullett and R. P. Chartoff, "Toughening of unsaturated polyester and vinyl ester resins with liquid rubbers," *Polym. Eng. Sci.*, vol. 35, no. 13, pp. 1086–1097, 1995, doi: https://doi.org/10.1002/pen.760351304.
14. 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.
15. P. Hari Sankar, Y. V. Mohana Reddy, and K. Hemachandra Reddy, "Polyester/vinylester polymer hybrid blended nanocomposites: Effect of nano on mechanical and thermal properties," *Fibers Polym.*, vol. 16, no. 2, pp. 443–448, 2015, doi: https://doi.org/10.1007/s12221-015-0443-9.
16. 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.
17. 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: https://doi.org/10.1002/pc.25065.
18. 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.
19. S. Magami and J. Guthrie, "Amino resin cross-linked can coatings," *Surf. Coat. Int*, vol. 95, no. 2, pp. 64–73, 2012.
20. S. Jeyanthi and J. Janci Rani, "Improving mechanical properties by KENAF natural long fiber reinforced composite for automotive structures," *J. Appl. Sci. Eng.*, vol. 15, no. 3, pp. 275–280, 2012, doi: https://doi.org/10.6180/jase.2012.15.3.08.
21. N. Adnan, H. Abral, D. H, and E. Staria, "Identification of Mechanical Strength for Mixture of Thermoset Polyester with Thermoset Vinyl Ester due to Bending Load," *JMPM (Jurnal Mater. dan Proses Manufaktur)*, vol. 6, no. 1, pp. 19–25, 2022, doi: https://doi.org/10.18196/jmpm.v6i1.14450.