Effect of Pumice-Based Nanosilica and Sodium Silicate Addition on Impact Strength of GFRP Composite

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Abstract. GFRP composite has become an alternative material for various engineering applications due to its outstanding characteristics. The purpose of this study is to investigate the impact properties of GFRP composites in relation to the addition of sodium silicate (SS) and nano active filler pumice particle (nAFPP). The hand lay-up method, followed by the press mold process was performed to create the composite with the content of 20 wt% glass fiber content (chopped strand mat and woven roving mat) with the addition of 10 wt% fillers (combination of nAFPP and SS) with the unsaturated polyester matrix. An izod impact tester was used to test the mechanical properties of composite specimens and SEM images were taken of their failure surfaces. The result shows that the GFRP composite with 10 wt% of nAFPP (0% of SS) has the highest impact strength among other filled composites, and the lowest is the composite containing the combination of 5 wt% of nFPP and 5 wt% SS. The composite with the highest impact strength also demonstrates good interfacial bonding between the matrix and fibers. The low impact strength of the composite is due to the occurrence of particle agglomeration.

Keywords: Pumice-Based Nanosilica, Sodium Silicate, GFRP Composite

1 Introduction

Composite polymer is a mixture of interactions between two phases, namely the polymer matrix and reinforcement [1]. Composite materials have been widely used both in industry and transportation. In mechanical design applications, a composite is an engineered material that may consist of reinforcing fibers, particles, flakes, and uniforms thereof embedded in a polymer, metal, or ceramic support matrix [2]. Glass fiber reinforced polymer or GFRP composites are the most economical material in terms of cost and have high strength when compared to other polymer matrix composites [3]. Another advantage of composite materials is that they can be designed to strengthen a component according to the type and direction of loading required. Stiffness, fatigue life, resistance to corrosion, thermal insulation, wear strength, electrical conductivity, strength, and toughness are some of the properties that can be improved from the composite material [4].

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In several studies, the use of fiber as reinforcement can affect the characteristics of the GFRP composite [5–8]. Among the several types of fiber, glass fiber is one of the most frequently used types of reinforcement due to considerations of its thermal properties, corrosion resistance, electrical insulation, sound absorption, and relatively cheap when compared to carbon fiber [9]. Other several research has also proven that composites with unsaturated polyester resin reinforced with woven roving mat (WRM) glass fiber show good strength, whereas the composite that reinforced by chopped strand mat (CSM) glass fiber has good flexural strength. The combination of CSM and WRM on GFRP composite is considered to be able to create the best mechanical characteristics [10, 11].

Unsaturated polyester resin (UPR) is the most widely used thermoset resin in commercial applications [12]. Synthetic copolymers called unsaturated polyesters are used in coatings, composites, plastics, and fibers [13]. Polyester resin has many advantages, such as minimal expense, sufficient protection from water and numerous synthetic substances, protection from enduring and maturing, sensible temperature obstruction, great wetting to glass fiber, low shrinkage during restoring, and straight warm development [14]. However, unsaturated polyester has poor fire performance consisting of aromatic rings bonded by relatively long aliphatic chains [15]. In order to achieve improved fire-resistance of polymers, a commonly used method is by admixture of a suitable flame retardant compound with the polymer using additives [15].

The types of fillers commonly used in composites to improve mechanical and physical properties are nanofillers and viscous liquids [12, 13]. Indonesia as a region located in the ring of fire area, which has many active volcanoes, produces a lot of raw materials that can be processed into nanofillers, such as volcanic sand and pumice. [18, 19]. The abundant availability of pumice can be used as an alternative raw material for producing nanosilica particles. There are several steps to change pumice into nanosilica particles, which are preparation, extraction, titration, and purification [20]. Nanosilica particle is a type of filler that is commonly used to enhance the properties of fiber-reinforced composite materials [21]. The use of nanosilica in GFRP composites has been used to maintain mechanical properties, and also plays a role in improving fire-resistance [22].

Sodium silicate is a viscous silicate solution containing 6-18 wt% of Na_2O and 21-34 wt% of SiO_2 [17]. Polysilicates are formed when sodium silicate reacts with aqueous solutions. The addition of sodium silicate filler in the composite can be used as an instrument to improve the mechanical characteristics of composite materials [4].

Studies on the filler addition to improve the mechanical properties of composites have been accomplished. Ermias et al., confirmed that GFRP nanocomposites have low impact strength but have good properties of flexural, tensile and interfacial shear strength. The low-impact strength of GFRP nanocomposites has limited their use, so they were not used for high-impact applications [16]. Nagalingam et al., have conducted research and found comparative data between composites without filler and composites filled with nanopowder with certain compositions, there were no significant differences, they even tended to be similar [23].

Recent research about the combination of nanosilica and sodium silicate was used for reinforcement in road pavement construction [24]. Another study used nanosilica and sodium silicate fillers separately to investigate the composite characteristic [13, 20]. Research on pumice powder filler on composites has also been done, however none previous research that investigate the impact properties of composite with pumice-based filler [25]. In order to enhance the GFRP composite impact properties, a mixture of sodium silicate (SS) and nano-activated filler pumice (nAFPP) was used in this study.

2 Methods

The materials used in this study were supplied from several sources. Singapore Highpolymer Chemical Products Pte Ltd, provided the unsaturated polyester resin 268 BQTN and MEKP (methyl ethyl ketone peroxide), while PT. Makmur Fantawijaya, Indonesia, provided the chopped strand mat (CSM) and woven roving mat (WRM) glass fibers. The pumice was taken from Mount Rinjani, Lombok Island, West Nusa Tenggara, Indonesia.

The sol-gel precipitation process was used to produce the nano-activated filler of pumice particles. Aquades was a washing medium that was used to get rid of impurities. Drying process was performed at 100 °C for 12 hours, then crushed and sieved with 200 mesh size. After the washing process, the thermal activation processes were conducted at 680 °C for 1 hour. Then, the pumice particle of 100 g in weight was dissolved into 1,000 ml of 2.5 M HCl and followed by a stirring process at 300 rpm, at 95 °C, for 2 hours. A washing procedure with distilled water was used during the filtering procedure to obtain silica-rich particles. To create a sodium silicate solution, the 10 percent silica-rich pumice particles were dissolved in 2 M NaOH for two hours at 95 °C. The filtering process followed by the precipitation of sodium silicate was performed to obtain silica gel. Then, the silica gel was washed to eliminate the sodium. To obtain nano filler pumice particles, the drying process was executed for four hours at 80°C [26].

The GFRP composite fabrication process was performed using the hand lay-up method, followed by a press mold process at room temperature. The mixing of UPRs and fillers was performed with a stirring process at 3,000 rpm for 5 minutes [27]. The addition of MEKP was done before pouring it into the mold. The glass fibers, are arranged using the CSM-WRM-CSM sequence. The post-curing process was made at 100°C for 60 minutes [28]. The composition of GFRP composite with the combination of nAFPP and SS fillers are listed in Table 1.

Table 1. Composition of GFRP composite

Composite code	UPR	Glass fiber	Nano filler pumice particle	Sodium silicate
C	80 wt%	20 wt%	0 wt%	0 wt%
C41	70 wt%	20 wt%	10 wt%	0 wt%
C42	70 wt%	20 wt%	7 wt%	3 wt%
C43	70 wt%	20 wt%	5 wt%	5 wt%
C44	70 wt%	20 wt%	3 wt%	7 wt%
C45	70 wt%	20 wt%	0 wt%	10 wt%

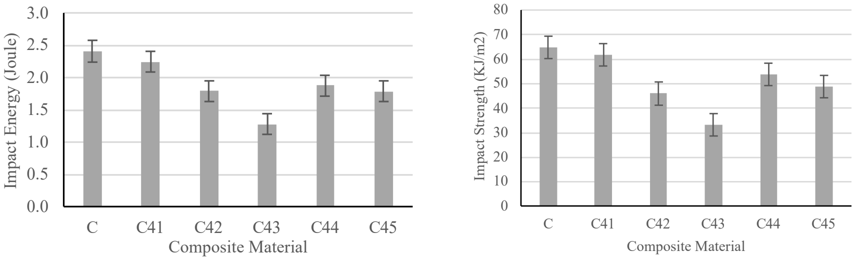
The izod impact test was performed based on the ASTM D5941 standard with 7 repetitions of test for each research variable. The specimen has 64 mm in length, 13 mm in width, and 3,4 mm in thickness. The Impact Izod tester (Toyoseiki, Tokyo, Japan) and Scanning Electron Microscope (Zeiss Evo 10, Germany) were used for impact and scanning electron microscope observation, respectively. Scanning electron microscope (SEM) observations was made on fracture surface of specimens to analyze their failure.

3 Result and Discussion

Fig. 1 shows the impact test result of GFRP composite containing nAFPP and SS fillers. The GFRP composite without filler (C) is also performed to be used as a comparison data reference. The combination of the use of woven roving mat, nanoparticles, and chopped strand mat in the GFRP composite causes a stronger bond between the matrix material and the reinforcing material [21, 22]. According to GFRP composite with fillers addition, the application of 10 %wt of nAFPP gives the highest impact strength of the composite. This result shows that the use of nAFPP is effective to improve the strength of the GFRP composite due to the smaller size of nAFPP can fill the porosity in the contact area between fibers and matrix. The other important benefit of the use of nAFPP is an improvement in fire- resistance [22]. However, the addition of SS (reduction of nAFPP) causes the decrease in impact strength until the lowest strength for 5%wt of nAFPP and 5% of SS. The decrease in impact strength of the GFRP composite is due to agglomeration [29]. Other researchers also proves that the composites with sodium silicate tend to have a decrease in strength due to reduced matrix dispersion as the silica content increases [17].

In the other hand, the addition content of SS for specimens C44 and C45 causes an increase in impact strength. it indicates that the mixing of nAFPP in smaller quantities compared to SS quantities with GFRP composite with UPRs matrix is better to make stronger bonding between the matrix and glass fibers. It is also similar to the GFRP composite of C42. But, the GFRP composite with 10%wt of nAFPP (without SS) has stronger bonding compared to other filled composites. All filled composites have lower impact strength compared to the GFRP without filler (C). But, they have better properties in fire-resistance and other physical properties [22].

Fig. 2 shows SEM observations on the fracture surfaces of the GFRP composites. All fracture surfaces show the fiber pull-out failure on the GFRP composites. For more detail, it can be seen that the increasing content of nAFPP in the matrix system is able to reduce the fiber pull-out significantly and the failure characteristic changes from fiber pull-out to fiber breakage [30]. The agglomeration areas in the composite with nAFPP and SS in the same composition ratio are shown in Fig. 2 (d). The decrease in impact strength that occurs, caused by agglomeration in the composite material [4]. The increased amount of fiber pull-out in various areas found in the composites containing SS without nAFPP may involve more energy dissipation [30]. The addition of SS with a greater ratio than nAFPP to the GFRP composite contributes to the strengthening. Fig. 2 (e) shows the significantly reduced of fiber pull-out area and has a better interfacial bond compared to the composite with a higher ratio of nAFPP and SS in Fig. 2 (c).



(a) (b)

Fig. 1. Izod impact test result of GFRP: (a) Impact energy; (b) Impact strength

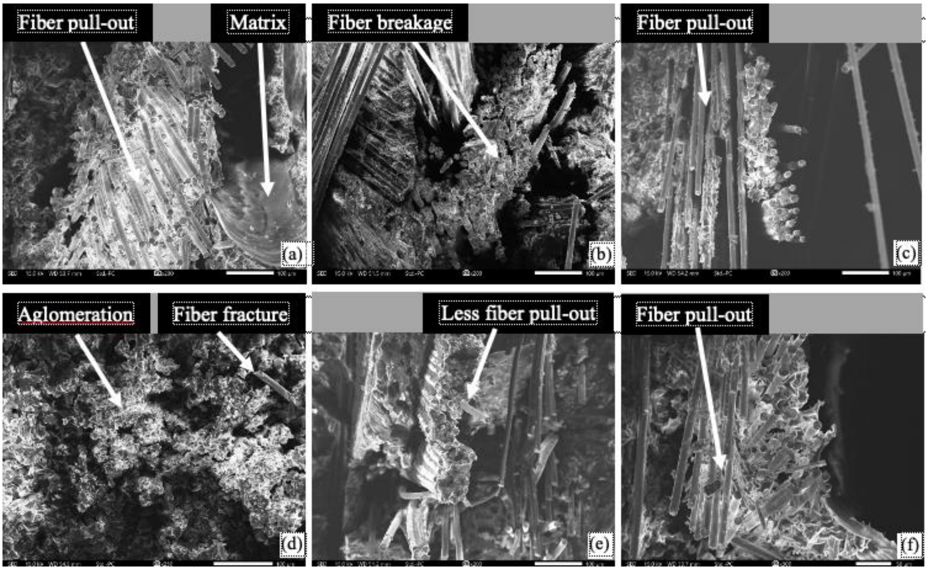


Fig. 2. SEM image of GFRP composite material: (a) C; (b) C41; (c) C42; (d) C43; (e) C44; (f) C45

4 Conclusion

The GFRP composite with 10%wt of nAFPP (without SS) has the highest impact strength among the other filled composites, and the lowest impact strength occurs on the composite with 5%wt of nAFPP and 5%wt of SS. Almost of the fracture surfaces of the composites are categorized as failure type of fiber pull-out. But, the surface fracture on the composite with 5%wt of nAFPP and 5%wt of SS is dominated by the agglomeration of particles. The use of sodium silicate tends to reduce the impact strength of the composite and it is showed agglomeration. The composite without filler shows good interfacial bonding between the matrix and fibers. However, the other properties of the composite with fillers are better, such as fire-resistance and hardness.

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