Physical and Mechanicals Characteristic of the Nano Particulate TiO_2-Epoxy Composite

Ilhamdi[1*], A Nugroho[2], D Hidayat[2] and R A Nur[1]
[1] Mechanical Engineering Department, Faculty of Engineering, Andalas University, Padang, Indonesia 25163
[2] Indonesian National Institute of Aeronautics and Space, Bogor, Indonesia 16350

*Corresponding e-mail: ilhamdi@eng.unand.ac.id

Abstract. Using nanoparticle as filler in polymer composite material is not widely reported yet. In this study, nano particle of TiO_2 (4%, 8% vol.) was added in epoxy resin matrix through casting method; a liquid homogenized mix of epoxy- TiO_2 was carefully poured into a simple die for air dried-up. The composite is characterized by physical test of density, and mechanical test such as tensile, compression, flexural and shear test. The results show that actual density of the composites is 1.111, 1.219 and 1.309 g/cm^3 with addition of 0%, 4% and 8% vol. TiO_2, respectively. These values are a less than theoretic density. The difference is related to the estimated porosity. Each of mechanical properties has its own trend regard to content of TiO_2. Maximum tensile strength is 27.8 MPa on 4% Ti specimen. Further increasing of TiO_2 made tensile strength and modulus elasticity decreased. Compressive stress is gradually decreased with increasing content of TiO_2; decreased from 60 to 52 MPa. The addition of TiO_2 by 4% decreased flexural strength, but further addition of TiO_2 by 8% had increased the flexural strength. Specimen with no TiO_2 had provided maximum flexural strength of 40 MPa. Shear stress has same trend as compressive stress; gradually decreased from 14.4 to 9.2 MPa.

Keywords: nanoparticle, composite material, porosity, tensile, compression

1. Introduction
Gasoline vehicles innovation affected by two main issues i.e. global warming and natural resources deposit. The global warming issue is closed related to CO_2 gas emission coming from gasoline vehicles [1]. A great reducing of petroleum-based deposit natural resource issue becomes popular since crisis of 1970's [2]. These issues indirectly demand a more efficient use of petroleum for the vehicles. The engineers had been developed a less weight vehicles to achieve this demand. Ideally, reducing weight of the vehicles should be with no or less sacrifice on mechanical aspect of the vehicles material. It is seemed that lightweight metal or composite material can satisfies this purpose. A composite has more flexibility in physical and mechanical properties than metal [3]. Composite is also could be categorized as green material [4].

With a comparable strength to metal, and less density, composite become a promising material for structural purposes material such as in automotive and aero vehicle. In archipelago country that have some narrow area, small island, forestry area and watery area, a light aero vehicle is preferable than a common aeroplane. One of the light aero vehicles is unmanned aircraft vehicle, UAV. This UAV is useful to surveillance purposes of forest, farming and disaster mitigation [5]. So that, UAV that capable for a longer travel time and wider covered area is preferable.

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IOP Conf. Series: Materials Science and Engineering 1062 (2021) 012028 doi:10.1088/1757-899X/1062/1/012028

The light term in the composite is come from polymer-based matrix material that naturally light material. Polymer nanocomposite is made from nanoparticle powder (as filler) and polymer matrix. Commonly, nanocomposite has better properties than conventional composite. This superiority is depending on structure, composition and properties of filler and matrix [6].

In this study, nano powder TiO_2 of 0, 4 and 8% volume percentage are introduced into epoxy resin. In the further research this powder will be used as a filler on the fibre reinforced composite, so its content should be not in a large number, namely less than 10%. TiO_2 is widely used because of its mechanical, optical, dielectric, anti-corrosion and biocompatibility. Epoxy has good dimension stability, high modulus, thermal and chemical resistance that better than other polymers such as polyester or vinyl ester, but relatively brittle material and expensive [7]. It would be interesting to know this composite characteristic, before to developed as floating material of the amphibian aircraft vehicle.

2. Methodology

2.1. Material and specimen
Composite was made of from epoxy resin and TiO_2 powder. Volume fraction of TiO_2 is 0%, 4% and 8%. TiO_2 powder has particle size of 30 - 50 nm, with density about 4.25 g/cm^3. Epoxy and TiO_2 powder were mechanical stirring mixed for 60 minutes at 600 rpm, meanwhile an open simple die was rub with wax. Then a homogenized mix was poured into die. The complete dried up composite was achieved after 3 days. The boundary between composite and die that formed with wax, enable easy take off composite from die. Then composite surface was mechanically smoothed with sand paper.

Density testing specimen has area dimension of 10x10 mm2, and the thickness refer to thickness of the composite. Testing was repetition for 10 times. Tensile testing specimen was made according ASTM D638; with total length of 165 mm, gage length of 50 mm, gage width of 13 mm and thickness of 7 mm as shown in Figure 1. The compressive testing specimen was made according to ASTM D6641; total length of 140 mm, width of 13 mm and thickness of composite of 7 mm. Flexure test of three points bending specimen was made according to ASTM D790; width length of 112 mm and width of 27 mm. The shear testing specimen was made according to ASTMN D5379; length of 76 mm, width of 20 mm, thickness of 7 mm, at half of length has V-notch of 90^o at both side of wide.

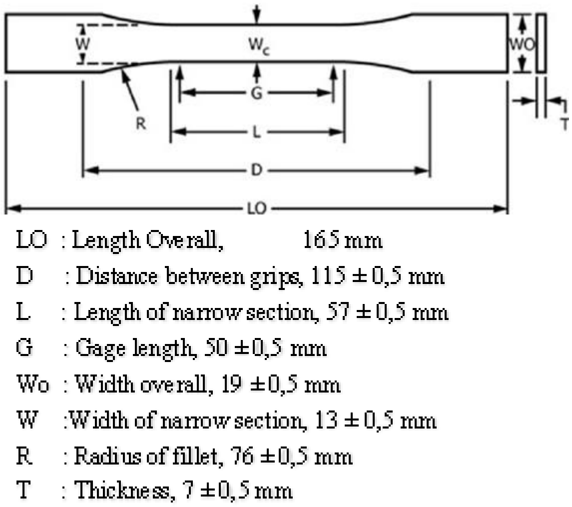

Figure 1. Tensile testing specimen dimension.

2.2. Experimental
Measuring density was conducting 10 times using densitometer machine. Specimen was weighed before and during immersion in water that put on the plate of densitometer. Mathematically actual density of

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specimen calculated as weight before immersed multiplied with water density divide by difference between weight before to during immerse, as shown as equation 1. Condition for density test are at room temperature 24.5oC and relative humidity of 38.8%.

$$\rho_{actual} = \frac{w_{before}}{w_{before} - w_{during}} \rho_{air} \quad (1)$$

Other, theoretical density is calculated by fraction volume of epoxy and TiO2 multiplied with their density as common composite equation. Difference between theoretical and actual density to theoretical density marked as porosity that existed in the composite.

Tensile testing conducted with condition; initial specimen length distance of 115 mm, travel speed of 5 mm/min, at room temperature of 22 ± 2 ºC and relative humidity of 47 ± 10 %. Compressive testing was conducted with condition; initial sample length distance of 12.7 mm, travel speed of 2 mm/min, at room temperature of 23± 3 ºC and relative humidity of 50 ± 10 %. Condition for flexural testing; initial sample length distance of 121 mm, travel speed of 5 mm/min, and the same temperature - relative humidity with tensile testing. In shear testing, a specimen was properly stapled on the grip by jig to avoid slip during the test as shown in Figure 2. All the mechanical tests were done on UTM Tensilon, and repeated for 7 times.

Figure 2. Setting for Shear Test.

3. Results and Discussion

3.1. Density test

Densitometer showed the actual density of the composite on its monitor at the end of testing. Complete result can be seen in the Table 1. It is shown that increasing content of TiO_2 made composite become more heavier, and the existence of porosity also increased. It implies that more defect introduced during the addition of TiO_2, but also resulting denser composite.

Table 1. Density measurement results (density in g/cm3, porosity in %).

Content of TiO2	Actual density	Theoretical density	Porosity
0%	1.111 ± 0.005	1.17	5.04
4%	1.219 ± 0.006	1.29	5.74
8%	1.309 ± 0.004	1.42	7.58

3.2. Tensile test

Tensile strength of composite increased with addition of 4% TiO_2, but further addition TiO_2 (8%) had decreased composite strength, as shown in Figure 3. Composite with no TiO_2 (epoxy only) has tensile strength, modulus elasticity and elongation at break in the range of 21.5 – 27.4 MPa, 1,900 – 2,200 MPa and 1.3 – 1.6 %, respectively. Their average value is 25.7 MPa, 2,100 MPa and 1.5%, respectively. Their low in elongation showed a typical brittle material characteristic. Addition 4% volume of TiO_2 increased tensile strength up to 27.8 MPa, modulus elasticity up to 2,400 MPa, but decreased elongation at break down to 0.95%, all in average.

Compare to epoxy only material, their change in all parameters showed moving behaviour from brittle to more ductility. However, in addition of 8% TiO_2 tensile strength and modulus elasticity bounce back to 20.5 MPa and 2,300 MPa, respectively. Other hand, elongation is the same grade with previous addition, about 0.97%. Over all, highest in tensile strength and modulus elasticity was found in the specimen with 4% TiO_2.

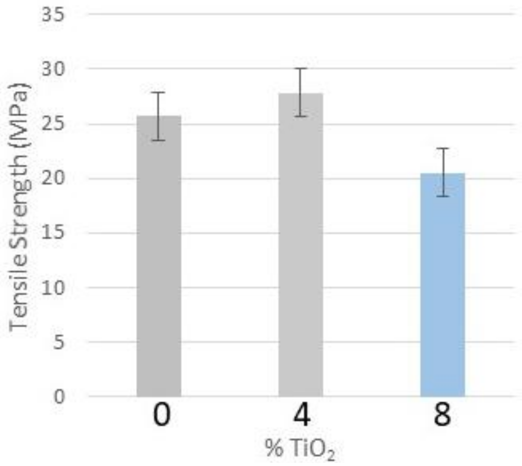


Figure 3. Tensile strength of the composite.

3.3. Compressive test

Compressive strength of composite was gradually decreased with addition of TiO_2, as shown in Figure 4. Epoxy only material has compressive strength, modulus elasticity and elongation at break in the range of 60 – 63.5 MPa, 500 -1,000 MPa and 3.6 – 4.2 %, respectively. Their average value is 61.4 MPa, 700 MPa and 3.8%, respectively. Addition 4% volume of TiO_2 decreased compressive strength to 57.6 MPa, but increased modulus elasticity up to 1,200 MPa, and decrease elongation at break to 3.4%, all in average.

Further addition of TiO_2 (8%) resulted continue decreasing of tensile strength to 51.9 MPa, also decreased modulus elasticity to 900 MPa. On other hand, elongation was in the same grade with initial material, about 3.9%. Over all, highest compressive strength was found in the epoxy only specimen.

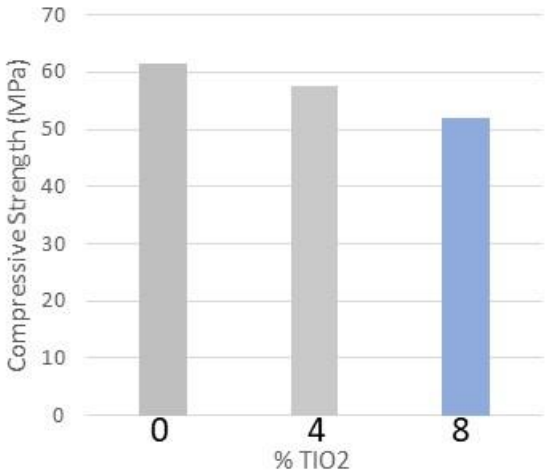
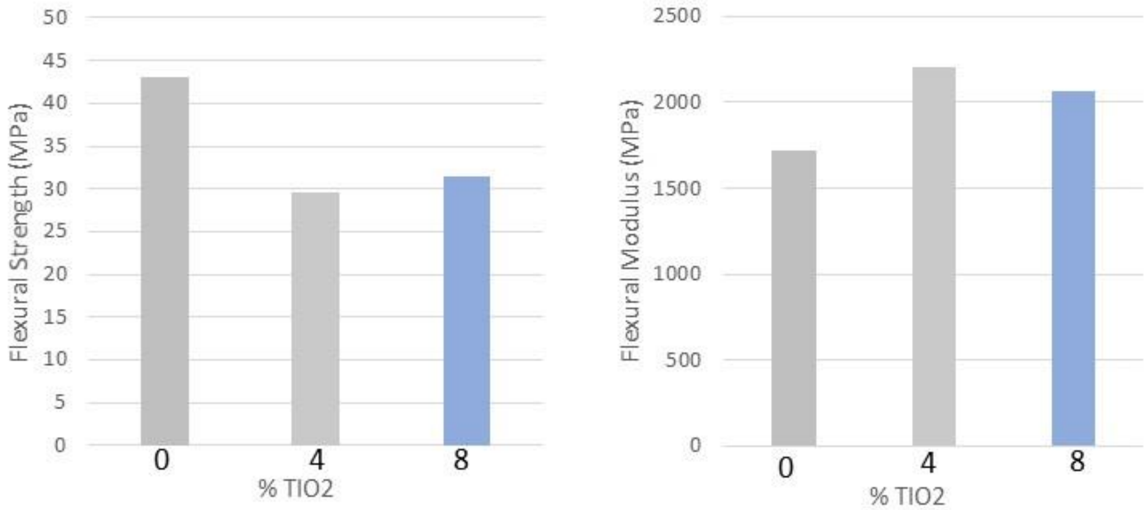


Figure 4. Compressive strength of the composite.

3.4. Flexural test

The highest flexural modulus of the composite of 2,100 MPa was found in the specimen with addition of 4% TiO_2. This composite has relatively same strength with addition of 8%; 29 compare to 32 MPa MPa. High flexural strength means low flexural modulus. It is seemed that the optimum is resulted by composite 4% TiO_2. The complete result can be seen in Figure 5.



(a) (b)

Figure 5. Flexural properties of the composite; (a) flexural strength.(b) flexural modulus.

3.5. Shear test

The same behaviour with compressive strength, shear strength was also gradually decreased with more addition of TiO_2, namely decrease from 14.4 to 7.3 MPa, as shown in Figure 6. The same trend was found in break strain from 1.14 to 0.43%. But, modulus elasticity of the composite was irregular changed; increased from 600 to 900, then dropped back to 600 GPa. Compilation of the results indicated that the best condition in composite 4% TiO_2; shear strength of 13.1 MPa, that comparable with epoxy only, highest modulus elasticity of 900 GPa, and moderate break strain of 0.894%.

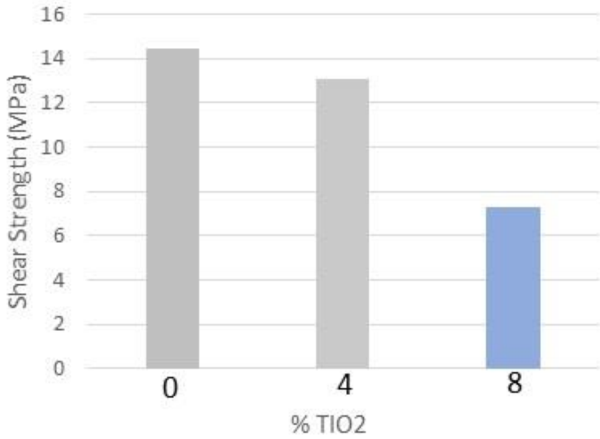


Figure 6. Shear strength of the composite.

3.6. Discussion
The 4% vol. TiO_2 is seemed provide the best combination of physical and mechanical properties. This composition provide moderate density of 1.2 g/cm^3, higher than epoxy only material but still in the range of lightweight material. This value is even much less than magnesium and its alloys, of 1.7 g/cm^3. Magnesium alloys are popular lightweight metal. Composite with 4% TiO_2 is kind of lightweight material with 5.7% porosity. A more proper preparation and/or better production technique of composite is needed to reduce the porosity. Remarkable properties of this composite are tensile strength of 27.8 MPa, compressive strength of 57.6 MPa, Flexural modulus of 2.2 GPa, and shear strength of 13.1 MPa.

Increase in tensile strength in this kind of composite is also reported by A Chaterjee et al which completing with thermal and viscoelastic [8], A. Turaif et al [9], Mirmohseni et al [10]. But, no confirmation about compressive strength and shear strength of this composite from other researcher. In the term of flexural properties, decrease in flexural modulus might related to reaction of TiO_2 nano particle that may have agglomerated inside composite. This will have reduced interface area between matrix and particle that reduces load transfer from matrix epoxy to the filler [11].

4. Conclusions
Addition TiO_2 as filler in epoxy matrix composite is not always results a higher mechanical performance. Among the variation of TiO_2 addition in the composite, the 4% vol. TiO_2 is seemed provide the best combination of physical and mechanical properties i.e. moderate density of 1.2 g/cm^3, highest tensile strength of 27.8 MPa, highest modulus elasticity of 2,400 MPa, moderate compressive strength of 57.6 MPa, moderate flexural strength of 29 MPa, highest flexural modulus of 2,200 MPa. and high shear strength of 13.1 MPa. Value of 5.7% of porosity in 4%vol. In the future, porosity might be decreased with a better production technique.

Acknowledgments
Author's gratitude addressed to Faculty of Engineering Andalas University whom provide financial support for publication through Hibah Publikasi Prosiding contract No. 040/UN.16.09.D/PL/2020.

References

[1] C O Ijagbemi, Oladapo B I, Campbell H M and Ijagbemi C O 2016 *Pro. Eng.* **159** 124 – 132
[2] A N Oumer, Hasan M M, Baheta A T, Mamat R and Abdullah A A. 2018 *Renew. and Sust. En. Reviews* **88** 82-98
[3] W D Callister 2007 *Mat. Sci. and Eng. : An intro.* John Wiley & Sons, Inc.
[4] J William 2003 *Acta Mat. Prog. In Struc. Mat. for Aerospace S*
[5] A S Budiyantara et al. 2013. *APISAT-2013*
[6] Hader et al, 2018 *Ultra. - Sonochem.* **2** 861-873
[7] D Pinto, Bernardo L, Amaro A and Lopes S 2015 *Construc. and Build. Mat.* **1** 506-524
[8] A Chattterjee and Islam M S 2008 *Mat. Sci. Eng. A* **487** 574-585
[9] H A Al-Turaif 2010 *Prog. in Org. Coat.* **69** 241-246
[10] A Mirmohseni and Zavareh S 2010 Mat. and Des. **31** 2,699-2,706
[11] V Prasad et al 2018 *Mat. Today Pro.* **1** 24,862-24,870