ANALYSIS OF PHYSICAL AND MECHANICAL PROPERTIES OF MULTIWALLED CARBON NANOTUBES (MW-CNTs) REINFORCED MINERAL COMPOSITES AS AN ENVIRONMENTALLY FRIENDLY MACHINE BASE STRUCTURE

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The Rigidity, absorption resistance, and vibration damping are important factors for the formation of static components and structures with excitation force loads. The development of new materials from composites for metal substitution has achieved better properties. The use of rocks with reinforcement CNTs can produce higher damping properties than metal casting, but young modulus is low. The Composite polymer material made from volcanic rock can be cast with epoxy with a variation of the aggregate ratio using compressive press able to improve mechanical properties. The volcanic rocks used in this study are granite, silica, and volcanic sand, using carbon nanotubes MW-CNTs as reinforcement. This research was conducted to produce structures with high strength and rigidity. The material are classified dimensions coarse (0,2-0,5 mm), medium (20 μ m-50 μ m), and fine (0.125mm/0.50 mm). Based on SEM/EDX test results of granite, silica, and volcanic sand have high silica content (with the sharp crystalline form that has the potential to strengthen the composite bond. The fly ash has high silica content, with round and fine crystals form. The specimen formation method refers to the dimensions of the composite specimen bending test according to ASTM D 645. The combination of materials that warns hardness and elongations, in separate tests of volcanic sand and granite which has the highest hardness, the use of CNTs can increase the hardness of 15% in each specimen, increase bending testing at 220% to 300%, prove that the inside of the crystalline bond forms ductile properties.

Keywords: CNTs-MWNT, Granite, Volcanic, Stiffness, Base Structure .

1. INTRODUCTION

The basic structure of the machine, the dynamic component housing must have high static damping properties to reduce the energy arising from high excitation and vibration forces. The demands of the structure of the base machine are required to have high rigidity, good damping and resistance to withstand the excitation force due to cutting forces and component movements, [1]. The development of environmentally friendly material technology is aimed at minimizing the use of metals for the structure of the engine base, housing and machine components using casting from composite and plastic materials [2]. Composite materials developed using materials that have physical and mechanical properties that are capable of forming components with high damping, namely rocks with high silica content. Research on the use of granite and silica for machine structure materials is able to withstand the tensile force of 168.92-200 MPa [3]. The rigidity of the structure and damping factor made from granite rocks is 0.5-1.3 higher than metal casting, but it still needs to improve its elasticity and modulus. [4]. The development of composites is directed to be able to improve the properties

of damping and rigidity for candidate structures and base machines to be able to reduce external forces. Another requirement is that the material must be impermeable and not easily absorb liquid, (absorption).

The improvement of mechanical properties to be developed is composite polymers with raw materials of granite, silica and volcanic sand reinforced with carbon nanotubes (CNTs) with epoxy fillers. CNTs are made as composite reinforcement because the mechanical strength is 15-20 times stronger than steel but lighter (only 20% of steel), capable of forming the highest bond applied in dimensions under 100 nanometers. [5]. In studies that have been carried out on other composites, the addition of carbon nanotubes (CNTs) by 1% can increase tensile strength, increase stiffness by 40%, tensile strength by 25%, [6], forming by casting methods on structures can reduce production stages by 30 %, [7]. The addition of carbon nanotube elements in composite polymers can improve mechanical properties and stiffness, but it still needs to be improved to reach industry-standard conditions. The use of carbon nanotubes in several studies has been proven to improve mechanical properties, the addition of 1% CNT can increase tensile strength, [8], increase rigidity by 40%, tensile strength by 25%, [9], increase stability during the production process, [10], [8]. The casting process to produce high bonding and precision shapes with the Squeeze casting method, [11]. In previous studies, the rocks used were rocks with high silica content, [3]. In this study, the basic material used is the igneous rock extruded by a volcano, consisting of granite, silica sand and Merapi sand with special physical and chemical properties.

2. LITERATURE REVIEW

2.1. Mineral Casting as Structure Machine

The formation of components and the basic structure of the machine using mineral stone material has been developed as an alternative to the substitution of the metal casting process in a still limited function. The process of making composites is carried out to obtain mechanical properties and other technical requirements according to the load to be applied. The selection of factors that influence the bonding of composite molecules is examined from the research carried out including; the ratio of aggregates to epoxy, variations in rock dimensions (granite, silica sand and volcanic sand, fly ash), and casting methods. Dimension variations are made to create space between molecules so that the reinforcing and filler elements are optimally able to fuse to produce composites with high mechanical properties. The dimension variations consist of coarse, (c), medium (M) and fine (f), intermolecular reinforcement using carbon nanotubes type Multiwalled Nanotubes (MWCNT), fly ash is taken from light coal combustion ash with carbon content above 2%, dimensions (20 μm -50 μm). Structural rigidity is needed to reduce vibration and excitation due to the dynamic movement of components. The type of material affects the resistance to damping and affects rigidity. The structure which has high rigidity will increase the ability and durability of the machine,[4]. The sequence of processes of forming the machine structure and housing using a composite polymer shown in Figure 1.

(a) FEA component design (b) raw material (c) mixing (d) mold (Squeeze casting) and (e) steel bar reinforcement, (f) heat treatment room, (g) vertical structure, (h) horizontal machine base/housing.

Figure 1. The steps of forming machine structure using mineral casting/composites.

2.2.. Mechanical Properties of Carbon nanotubes (CNTs)

Carbon nanotubes have very high mechanical properties, in some tests showing their properties close to their theoretical value, high mechanical properties resulting from the form of C-C bonds. The atomic structure of CNTs is divided are; Single-Walled Nanotubes (SWNTs), Double-Walled Carbon Nanotubes (DWNTs), Multi-Walled Nanotubes (MWNT), [5]. The mechanical properties in the formation of composites using CNTs are the Modulus Young [E] characteristic, for types (SWCNTs) to reach 2.8-3.6 TPa and 1.7-2.4 Tpa. The value of type MWCNT reached 1470 Gpa-950 GPa .[12], [13]. Based on the high E value and other mechanical properties, the nanotube has the potential to be used as an ideal reinforcement in composite materials.

The challenges in creating good molecular bonds between nanotubes and polymer matrices continue to be investigated to obtain mechanical properties according to the functions and loads at work. Research on polymer-based composites (microfibres), shows that the reinforcing function takes effect an important role in the formation of structures. Morphologically CNTs have very smooth atomic surfaces, so an appropriate mixing method is needed to obtain the structural rigidity properties. Previous studies using CNTs with epoxy matrices were able to improve mechanical properties (shear stress) using MWCNTs. According to these conditions in the formation of mineral casting made from granite, silica sand and Merapi sand will be examined its superior properties for machine structure candidates.

3. MATERIALS AND METHODS

3.1. Material

Raw materials for making structures static and housing for dynamic components use minerals that have mechanical properties in the form of fly ash, granite, silica sand, and volcanic sand, raw materials are prepared with dimensional dimensions of 100 mesh, 200 mesh and 400 mesh. Based on previous research, it was found that influential parameters produce structures that have high rigidity. This type of material affects the resistance to damping and affects the stiffness. The aggregate mixed with epoxy resin, reinforcements using carbon nanotubes MW-CNTs. The characteristics and crystalline shape of the raw material can be seen in the test results of SEM (Figure 9). The Materials are grouped according to dimensions size (coarse (0,2-0,5 mm), medium (20 μ m-50 μ m), and fine (0.125mm/0.50 mm). The forming of materials for structure, the grouping is done by sieving up to 400 mesh. The density of the material used is shown in Table 1.

Table 1 . Mineral density to be used in the formation of composite polymers

No	Material	Density (kg/dm ³)
1	Sand of silica	1,201
2	Vulcanic sand	1,650
3	Fly ash	0,641
4	Granite sand	1,675
5	CNTs-MWNT	1,602

3.2. Methodology

3.2.1. Specimen Preparation

Specimen standard refers to rigidity test standard (ASTM D 695, ASTM C 642) for composites with dimensions; (P x L x T): 200 x 20 x 20 (mm), [14] [15]. The dimensions ; coarse (0,2-0,5 mm), medium (20 μ m-50 μ m), and fine (0.125mm/0.50 mm).

3.2.2. Design of experiments

The use of mixing parameters is made separately for each material to determine the basic properties of raw materials and as a control variable. Formation of specimens according to ASTM D 645 standard, shown in Table 2.

Table 2. Design of specimens according to rigidity test standards (ASTM D 645)

No	Design of Specimen/Code	(C) : (M) : (FFA): [CNTs] : Fillers (epoxy) % wt (weight)	Thickness (mm)	Width (mm)	Length (mm)	volume (cm ³)	Weight (gr)
1	Granite sand : Resin (fillers) 80: 20, [GSR-1]	80% wt (50 :25 :25): 20 % wt	20	20	200	80,00	161,02
2	Granite sand : Resin Fillers 75: 25, [GSR-2]	75% wt (50:25:25): 25 % wt	20	20	200	80,00	161,20
3	Granite sand : Resin Fillers Ratio 70: 30, [GSR-3]	70% wt (50:25:25): 30 % wt	20	20	200	80,00	167,10
4	Silica sand (white) : Resin fillers Ratio : 80: 20, [SSR-1]	80% wt (50:25:25): 20% wt	20	20	200	80,00	166,05
5	Sand (Silica) : Resin fillers Ratio (75: 25), [SSR-2]	75% wt (50:25:25): 25% wt	20	20	200	80,00	167,00
6	Sand (Silica) : Resin fillers Ratio (70: 30), [SSR-3]	70% wt (50:25:25): 30% wt	20	20	200	80,00	167,40
7	Volcanic sand : Resin fillers Ratio (80: 20), [VSR-1]	80% wt (50:25:25): 20% wt	20	20	200	80,00	173,00
8	Volcanic sand : Resin fillers ratio (75: 25), [VSR-2]	75% wt (50:25:25): 25% wt	20	20	200	80,00	167,00
9	Volcanic sand : Resin fillers ratio (70: 30). 1 % CNTs, [VSR-3]	70% wt [(50:25:25), (1% CNTs)] : 30 % wt	20	20	200	80,00	177,00
10	Silika (C): Granite (M): Volcanic sand (F): ratio Resin fillers 25%, 1 % CNTs, [SGVR]	75% wt (33:33:33): (25 % wt	20	20	200	80,00	171,00
11	Granite [(C): M):(F+FA)]: CNTs (1 %) : Epoxy (25%), [GCE]	(49:25:25):(1) : 25	20	20	200	80,00	157,00
12	Silica Sand [(C): M):(F+FA)]: CNTs (1 %) : Epoxy 25%, [SCE]	(49:25:25):(1) : 25	20	20	200	80,00	159,00
13	Vulcanic Sand [(C): M):(F+FA)]: CNTs (1 %) : epoxy 25%, [VSCE]	(49:25:25):(1) : 25	20	20	200	80,00	145,00
14	Vulcanic Sand C: Silica (M): granite dan FA (F) : CNTs (1%) : fillers epoxy 25%, [VSGC]	(30:30:30):(10) : (25)	20	20	200	80,00	176,00
15	Granite C: Silica (M): Vulcanic Sand (F) : CNTs (1%): fillers epoxy 25%, [GSVC]	(33:33:33):(1) : (25)	20	20	200	80,00	177,00
16	Silica (C): Granite (M): Vulcanic Sand (F) : fillers epoxy 25%, [SGVE]	(33:33:33):(1) : (25)	20	20	200	80,00	178,00

Note: Coarse (C): Medium (M): Fine and Fly ash (FFA): [CNTs]: Fillers (epoxy)% wt (weight)

3.2.3. Test Type

The type of test used to study mechanical properties is carried out by testing the mechanical properties as follows:

1. Bending test
2. SEM-EDX Test
3. Hardness test
4. Rigidity Test/damping test
5. Absorption Test

3.2.4. Damping test

The damping test is used to determine the material characteristics of the ability to withstand the load/impact due to the effects of motion and excitation force. The rigidity measurement method using Labview is as follows in Figure 2.

Figure 2. Damping test methodology (lab view).[16].

Measurements are made by impacting the same load on a specimen connected to a vibration sensor (accelerometer). Display the amplitude on the screen using Labview software.

4. RESULTS AND DISCUSSION

4.1. EDX Test Result

The content of each raw material used contains elements that have the potential to make composites with adequate mechanical properties for the formation of mineral-based composites polymers. Based on the EDX test it is known that the constituent elements of each raw material. The data shows that the dominant element is silica SiO_2 , with the largest content in granite and silica sand (54-55%), in volcanic sand at 41.17% and the smallest in fly ash (30.31%). Element Al_2O_3 alumina with a percentage of 14-22%, the rest is containing a metal element with an amount of 1-10%. This analysis is needed to determine the function and effect of the constituent elements each raw material has on bonds. The constituent elements of each material will show energy and potential in the process of forming the stiffness and mechanical properties to be tested. The EDX diagram shows the composition with the percentage of each element as shown in Figure 3.

Figure 3. % Elemental composition of mineral casting raw material

The Composite polymer bonding was analyzed from its constituent elements, to determine the correlation of SEM and EDX. Based on the EDX test it was also known the potential and influence of the element types in the analysis of the bond strength of mineral casting composites. The fly ash energy graph is shown in Figure 4,5,6 and 7.

Figure 4. EDX data forming elements of fly ash

Figure 5. EDX data forming elements of sand of granite

Figure 6. EDX data forming elements of sand of volcanic

Figure 7. EDX data forming elements of sand of silica

4.2. SEM observations

4.2.1 SEM Test Equipment Specifications

The morphology using SEM Image with a magnification of 10,000x, 20 KV. 1 μ m.

4.2.2 SEM Test Results

CNT morphological forms in other materials are characterized using Scanning Electron Microscopy (SEM), to determine the molecular shape, constituent elements, material potential and behavior in the formation of composites. SEM material test results are shown in Figures 8.

SEM of Fly Ash (FA):

The image shows the shape of the fly ash crystal, most of the shapes are uniform crystal structures with small-large round shapes. The Crystals have a smooth side, including anhydrite minerals, quartz, limestone, hematite, opal-CT, calcite and gelignite. Fly ash crystals are symmetric in shape with a sphere, with a size that is mostly 5-7 μ m, blunt crystal side, catalysts are needed in accordance with the nature and shape of fly ash molecules in order to be able to increase the molecular bonding ability of aggregate polymer composites. Fly ash has a cavity between molecules, the dark area shown in the crystal increases the potential of the particle insert in the formation of composite bonds.

<p>SEM of Granite Sand:</p> <p>The test feature performed shows the fracture angle of the micro-pore wall. Crystal cracks formed due to the grinding process for preparation. Some triangular features reflect the sharp shape of the tip of the pyramid. The content of silica granite powder contains 55% silica, 20% sodium oxide. The Granite grains are gradually not uniform, their shape varies from the largest size to 15 μm, and the smallest is 0.2 μm. Spiky crystal shape, with many microcrystals with smaller dimensions. The shape of the pointed crystal forms strong bonds between molecules. Granite rocks form cavities on the sides of the crystal, large and small variations are very high, will form an empty space and increase bond potential.</p>
<p>SEM of Volcanic Sand;</p> <p>From the shape of the crystal structure of volcanic sand, morphology and irregular shape with the crystal side tending to be sharp, the initial dimensions of measurement are 400 mesh / 37 μm, based on their immunity. The shape of volcanic powder particles varies greatly, from most of which are angular and sharp in shape, therefore, this micro-structure can produce more space between the particles in its structure so that it makes it easier to form bonds with other elements. The hardness of volcanic sand will increase the hardness of composites, bonding with polymers with very fine dimensions can increase ductile.</p>
<p>SEM Image of Silica Sand:</p> <p>Based on SEM images, it appears that the structure has an irregular side, the shape of the crystal is not uniform in size, the difference in dimensions is very large, with a high degree of density. The crystal side tends to be sharp. The shape of the pointed crystal side will increase the bonds between molecules in the process of aggregate formation. The condition of the structure describes the constituent elements according to EDX data. The solid structure requires varying dimensions to form cavities for bonding space with other elements.</p>
<p>SEM Image of CNTs-MWNT</p> <p>Morphology of carbon nanotubes Shows that Carbon nanotubes have diameters between 0.8 μm to 3 μm. From the picture, it can be seen that the presence of dark dark elements indicates the existence of large inter-molecular cavities. The size of fine and non-uniform crystal granules increases the ability of particles to bind to other molecules. Large cavities, finely stringy crystalline shapes will increase the formation of strong bonds and encourage composites to be ductile and solid. CNTs are very fine molecules by forming a net, the resulting shape effect will increase the bonding properties between composite molecules. The fine mesh shape of MWCNTs is a determinant of strong bonding in composites.</p>

Figure 8. Crystal Morphology results of Scan Electron Microscopy (SEM) of fly ash, the sand of granite, volcanic, and silica.

4.3. Hardness and Bending Test of Composite Polymers

4.3.1. The Hardness and Bending Test Results

The formations of specimens 1-8, tests which are standardized for mechanical properties without mixing and adding CNTs, while 9-15 tests the properties of aggregate polymers by combination and mixing of materials, while specimens 16 mix raw materials without reinforcing CNTs. Specimens are formed from dimensional variations and aggregate ratios with resins without the addition of reinforcing CNTs. Figure 10 shows that the original nature of the composite has a lower violence value compared to specimen reinforcing CNTs. The increase in individual material hardness and the average in the 3 specimens showed a significant difference, the hardness increased by 30% with the addition of CNTs. The effect of the combination of dimensions affects the hardness of the composite on the specimen can increase hardness. The influence of CNTs and dimensional variations are also able to remind elongations, this proves that the interior has also increased ductile properties, this is indicated by bending tests, on specimens with reinforcement CNTs increased 600% from specimens without reinforcement.

Each specimen formation was tested for hardness and bending, the average yield of 16 specimens tested was shown in Figure 9.

Figure 9. Correlation of surface hardness with specimen formation design

. The hardness graphic patterns and bending test values show that by mixing polymer CNTs, with their flexural properties, they are able to increase the hardness of the material on the outside and increase the ductile on the inside. The bending test and the change in length of each specimen are shown in graph 10.

Types of treatment on specimens (mixing, ratio and reinforcement using CNTs)

Figure 10. Correlation graph of the bending stress value and mean ΔL (ASTM C 642)

The same phenomenon was observed for Young's modulus of the normalized composite with a pure matrix is presented in Figs. 10. The results show that Young's modulus increases with an increasing number of CNTs, the best results are shown in experiments with granite and volcanic sand, an increase in modulus in line with tensile strength. The same modulus and tensile strength observed show higher tensile strength. At 1% by weight of the young modulus CNT increased by 25.95% compared to pure changes in the mechanical properties of each aggregate with a combination of material dimensions and ratios (aggregate: resin: CNTs), can be seen in changes in hardness, elongations, and bending as shown the graphs in Figures 9 and 10.

4.3.2. Effect of elements to absorptions and rigidity

Based on the initial test as a reference, for the factors and levels used, the constituent materials used as concrete have an influence on the mechanical properties of the specimens. To make different mechanical parts, most machine tools are designed and developed based on functional considerations for industrial applications. Data on the results of the test for the absorption of liquids in polymer mineral stone composite materials in specimens 9-15, with high bending and hardness, can be seen in Table 3.

Table 3. Testing of oil and water absorption on material composites (ASTM C-642)

No of Specimen	Design of Specimen/Code	[Coarse (C) : Medium (M) : Fine dan Fly ash (FFA):] [CNTs] : Fillers (epoxy) % wt (weight)	Means of % Water Absorptions	Means of % oil Absorptions
9	Volcanic sand : Resin fillers ratio (70: 30). 1 % CNTs, [VSRC]	(49:25:25):(1) : 25	0,00381	0,01047
10	Silika (C): Granite (M): Volcanic sand (F): ratio Resin fillers 25%, 1% CNTs, [SGVR]	(49:25:25):(1) : 25	0,00381	0,01047
11	Granite [(C): M):(F+FA)]: CNTs (1 %) : Epoxy (25%), [GCE]	(49:25:25):(1) : 25	0,00028	0,00663
12	Silica Sand [(C): M):(F+FA)]: CNTs (1 %) : Epoxy 25%, [SCE]	(49:25:25):(1) : 25	0,01786	0,00448
13	Vulcanic Sand [(C): M):(F+FA)]: CNTs (1 %) : epoxy 25%, [VSCE]	(30:30:30):(10) : (25)	0,00275	0,00941
14	Vulcanic Sand C: Silika (M): granite dan FA (F) : CNTs (1%) : fillers epoxy 25%, [VSGC]	(33:33:33):(1) : (25)	0,01075	0,01190
15	Granite C: Silika (M): Vulcanic Sand (F) : CNTs (1%): fillers epoxy 25%, [GSVC]	(33:33:33):(1) : (25)	0,02128	0,01136

The development of environmentally friendly structures has an economic impact because of low prices, in fulfilling machines in the global market, is the machining process with high cutting speed, low energy and precision static function of the base frame that is optimal by using CNTS reinforcing materials to be able to form materials with mechanical properties which has high rigidity, low density and ability to withstand fluid absorption, [16] [17], [18]. The ability of materials to not easily absorb liquid fluid is one of the requirements for machine tool structure components/housing components. The absorption resistance tested in oil and water carried out is 0.01 / only a maximum of 1% so that it can be used as material for structures for static function/housing components. The results of absorption test specimens for oil and water are shown in Figure 11.

Figure 11. Water and oil absorptions material (%) according to aggregate (ASTM C 642) [14]

In the use of composite materials, to make changes/modifications to the material and structural configuration models, in addition to the selection of basic materials, which will improve the ability of the structure of static functions. The use of software analysis will be compared with the results of experiments to determine the dominant factors that influence structural stiffness.[19],[20]. Damping test results with LABVIEW can be seen in Figure 12 as follows;

Figure 12. Damping test at material concrete composite strengthened CNTs specimen 9 dan 15 (ASTM C 642) [15], [19].

The damping tests are carried out using sensors that will receive the vibrational effects caused when the external force is applied through the screen with a LabVIEW. From Figure 13 on rigidity measurements, the best nature of damping is measured by the absorption of energy exerted from the externally applied force, the shorter the waveform and the faster it decreases means that the damping shows better. In the picture above is the best damping test that occurs in specimens with treatment numbers 9 and 15.

4.4. Discussion

4.4.1. Analysis of the effect of mixture and reinforcement types on hardness, and bending stress

Based on preliminary testing, the factors and levels of granite material with epoxy polymer mixing of 20% have the highest mechanical properties with a flexural stress of 32.62 MPa with an average hardness of 93.70 HRA, with mixing ratios based on groups (Coarse (50%): Medium (25%): Good (25%)) Mixture of 4 ingredients with (Coarse (50%): Medium (25%): Medium (25%)), in specimen 15 it is used as a reference for mixing base material with fine granite has the highest flexural stress and the best extension, so that the best mechanical properties, the optimization design of silica material is reduced by only 20% of the aggregate, increasing the volume of granite by 50%, volcanic sand by 30% Fly ash as a binder will be used as a percentage in fine groups amount 5%, with these results, fly ash is the material with the least effect on mechanical properties. Specimen 15th is used as a reference for mixing base material with fine granite which has the highest and best flexural stress, resistance to fluid absorption. The most optimal composition of the use of mineral casting with CNTs-MWNT reinforcement is a mixed experimental design (Silica C): Granite (L): Volcanic sand (P): CNT: 25% epoxy filler, with the highest bending stress of 59.9 MPa. The highest mechanical properties for bending tests are used to make machine structures that have high rigidity for static components and candidates to be tested to achieve technical requirements for machine structure materials, [20],[21].

4.4.2. Analysis of absorption and rigidity

The structure of the machine has to have high machinability properties, the ability to withstand vibrations due to excitation forces in the machining process. From the research data, the mechanical properties produced can increase significantly by using CNTs. Absorption test data on the specimens showed good density, it was proven that all the test specimens of absorption values were still below 1%. The mechanical properties of composites must still be improved in order to achieve the technical property requirements for structures reaching components that work at dynamic loads. The mechanical properties generated in the study are in accordance with other research trends, [5],[6], as rigidity structure machine base, [20], [22]. The Rigidity of the best specimens obtained in specimens treatment 9, 10 and 15, the more damped the graphs formed will be steeper which shows good rigidity, the waveform from high to low the closer means the material is able to absorb energy better, [7, 8].

5.CONCLUSIONS AND FUTURE WORK

5.1. Conclusions

The development of non-metal/composite structures and high-performance thermoplastics is an environmentally friendly industrial target as an alternative material for static structures and dynamic loads because it is capable of process reduction and is increasingly economical. Based on studies that have been done and the results of the study show high potential for the use of rocks with special properties, especially volcanic igneous rock as a material that has mechanical properties that are suitable for the specific function of the structure. From research data using granite, silica and volcanic sand reinforced MWCNTs and epoxy matrices known the influence of factors on mechanical properties as follows;

- a. The effect of mixing method with dimensional variations, the ratio of aggregates to resins and the addition of MWCNTs can increase the highest hardness of 106 HRA without reinforcing CNTs at 73 HRA, strengthening to 33.3%.
- b. The bending test value increases the flexural stress up to 220%, the highest is granite, silica sand, and silica material is reduced by only 20% of the aggregate, increasing the volume of granite by 50%, volcanic sand by 30%, can increase ductility up to 300%.
- c. The ability of the material for absorption to meet the technical requirements needed for, the average resistance to the absorption capacity in oil and water carried out, is 0.01 to 1% so that it can be used as material for the engine base structure.

5.2. Future Work and Suggestions

The use of CNTs can significantly increase bending, therefore the most appropriate aggregate composition is needed to produce optimal machine structure. Improved mechanical properties still need to be improved to achieve the mechanical properties required for more precise machine structures. Based on the EDX test results and the composition of each specimen there is volcanic sand and granite which has a good hardness in separate conditions, so that candidate specimen can be used as a reference to develop a structural ma-

terial. Emphasis on specimens needs to be controlled to produce specimens with machine structure requirements, the formation of ductile properties needs to be tested with temperature treatment in the formation process with high pressure at sintering temperatures. The use of a multilayer coating method needs to be further investigated to improve ductile properties.

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