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Effect of nano SiC addition on mechanical properties of Al-nano SiC composite materials/SS304 woven wire using stir casting method

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Abstract
The wide variety of applications in various industries, such as automotive, aerospace, construction, and electronics, aluminum is one of the metals that needs to improve its mechanical properties. This study aims to determine the effect of adding reinforcing powder using the stir casting method on the mechanical properties of the Al-nano SiC/SS304 Wire Woven Composite material. The method used in this study is an experiment with the addition of a matrix to the composite material. The addition of nano metal was carried out to modify the mechanical properties of the aluminum material. Variation of the composition of each specimen using the volume fraction of nano-SiC (1%, 3%, 5%) and 4% Mg and the addition of woven SS304 wire on the tensile strength and hardness tests. The highest tensile test results for the 5% volume fraction variation were 149 MPa and the hardness test was obtained at 69 HRB for the 5% volume fraction variation.

Keywords:
Aluminium, composite, stir casting, nano-SiC

1 Introduction

Aluminum is one of the most abundant and natural metal materials in the earth's crust [1]. In the modern era, use of aluminum metal continues to grow and is much needed. This is because aluminum has the properties of being easy to work with, produce, shape, resist corrosion, and is a good conductor of electricity and heat [2][3][4]. Aluminum has a purity level of 99.0%-99.9%. The density of aluminum is lighter but its structural strength is lower than some types of metal, so mechanical properties of aluminum need to be improved to achieve the desired use in automotive industry [5][6]. The development of aluminum research has been carried out, one of which is Al-nano SiC alloy material.

Improving the mechanical properties of aluminum can be done by adding alloying materials, heat treatment and the stir casting process [7]. Several studies have been carried out including the addition of micro-Mg material to aluminum which can increase the tensile strength value up to 161.95 MPa [8]. The effect of heat treatment on the Al-Si-Cu alloy material carried out by [9] experienced an increase in hardness properties up to 80 BHN. While the 250 rpm strir casting process can improve the mechanical properties of Al7075-SiC with a tensile strength of up to 271 MPa and a Brinell hardness of 118 BHN [10].

Improving the mechanical properties of aluminum material can also be done by adding reinforcement with woven wire [11]. The use of aluminum as the main matrix as a composite structure is a Metal Matrix Composite (MMC) material which has developed into Aluminum Metal Matrix Composites (AMMC). The results of its development have been used in the aerospace, defense and automotive industries [12][13]. The mechanical properties of AMMC can be improved by the method previously mentioned, namely by increasing the percentage composition of reinforcing materials such as Silicon Carbide (SiC) in the stir casting treatment as evidenced by surface phenomena and tensile strength and hardness [14].

The chemical composition of AMMC is composed of aluminum as a matrix with copper (Cu), Silicon Carbide (SiC) and Magnesium (Mg) as aluminum matrix reinforcement. Magnesium strengthens the AMMC material as a composite by adding other materials such as steel wire to strengthen its mechanical properties, which involves the wettability of the metal matrix together with reinforcement such as wire and can reduce porosity. SS304 woven stainless steel wire has low cost and good wettability of aluminum matrix and can increase tensile strength up to 20% in metal composite preparations [8][15].

Based on this background, this research was carried out to manufacture Al-nano SiC/SS304 woven wire composites with the aim of increasing the mechanical properties by analyzing the effect of variations in the addition of SiC reinforcement and Mg addition on the manufacture of Al-nano SiC/SS304 woven wire composites. The mechanical properties in question are the tensile strength value and the resulting hardness value.

2 Research Method

The method used for this research is experimental method. This method was carried out in the metal casting process with stir casting and testing of composite specimens of Al-nano SiC/SS304 Wire Woven with volume fractions (1%, 3%, 5%) SiC, and 4% Mg and using SS304 woven wire. The composition of nano SiC in the aluminum matrix is (1%, 3% and 5%) and 4% Mg and the addition of woven SS304 steel wire. Manufacture of test specimens is in accordance with ASTM B557M-02a standard for tensile test and tested with ASTM E10 standard for hardness test.

2.1 Tools

2.1.1 Composite Making Tool

a. Furnace

The smelting furnace shown in Fig. 1 with the furnace specifications:

Max temperature : 900°C
Crucible capacity : 2 kg

Fig. 1. Furnace tool.

b. Specimen mold

Specimen molds with a capacity of 250 g shown in Fig. 2.

Fig. 2. Tensile test specimen mold.

c. Stirrer

Fig. 3 shows the mixer, namely the Modern M-2310 with the specifications:

Power : 135 Watt
No-load speed : 10000-35000 rpm
Collet chuck capacity : 3 mm

Fig. 3. Stirrer M-2310.

d. Tachometer

The tachometer tool used has specifications:

Standard : SAE SE300
rpm : 30,0~99999
rms : 0.600~1999.0
Count : 0~99999 Torch
Battery : R6P/LR6X2
Dimension : 210 × 60 × 55 mm
Mass : 218 g

e. Additional tools

Additional tools for manufacturing composite materials are shown in the Table 1.

Table 1. Composite manufacturing add-on

Name	Type	Quantity
Argon gas	UHP	1 tube
Sandbox	Iron plate	48x10^4 mm^3
Sandpaper	P300	3 Sheets
LPG	tube	3 kg
Paintbrush	2 inch	1 item
Heating torches	Torch KT 07C	1 item
Thermogun	Digital	1 unit
Scales	Digital 500g	1 unit
Hacksaw	Hack saw	1 item
Spoon	Hand ladle	1 item

2.1.2 Al-Nano SiC/SS304 Woven Wire Composite Finishing and Observation Tool

Testing the suitability of the physical characteristics of the material is carried out with the tools in Table 2.

Table 2. Al-nano SiC/SS304 woven wire composite testing equipment

Nama	Type	Manufacturer	Country
Lathe	Horizontal	CA6250	Germany
Vernier calipers	Manual 0,02 mm	Mitutoyo	Japan
Optical microscope	BX41 manual	Olympus	Japan
Scanning Electron Microscopy (SEM) Tool	FLEXSEM 100	HITACHI	Japan

2.2 Composite Materials

a. Pure Aluminum

Pure aluminum (99.0%) is shown in Fig. 4.

Fig. 4. Pure Aluminum (Al).

b. Magnesium

Shown in Fig. 5 the magnesium metal used with specifications:

Condition : Brand new
Symbol : Mg
High purity : 99.99%

Fig. 5. Magnesium (Mg).

c. SS304 woven wire

SS304 woven wire is shown in Fig. 6 with a diameter of 0.3 mm with 30 wire mesh used as reinforcement.

Fig. 6. SS304 woven wire.

2.3 Composite Manufacturing Process

The process of making the Al-nano SiC/SS304 woven wire composite was carried out by the stir casting method. The first process to be carried out is to determine the weight of pure Al based on the independent variables and then to calculate the volume fraction.

2.3.1 Specimen Preparation

Specimen preparation starts from weighing pure aluminum, then adding SiC and Mg volume fractions followed by preparing SS304 woven wire. The specimens used in the test are based on the numbers in Table 3.

Table 3. Tensile testing specimens and hardness testing

Sample	Total volume fraction of SiC	Total volume fraction of Mg
A	1%	4%
B	3%	4%
C	5%	4%

a. Casting of tensile test specimens in the mold by adding SS304 woven wire reinforcement. Woven wire and prints are arranged according to Fig. 7.

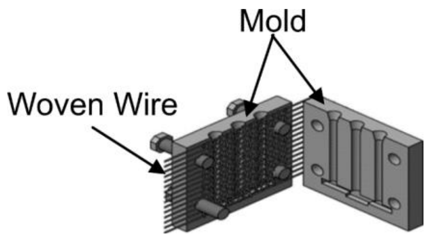
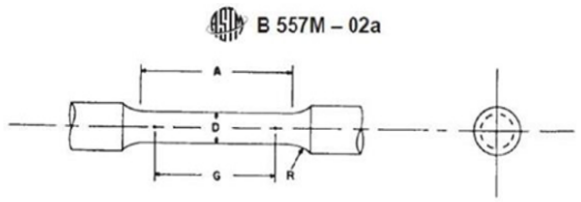


Fig. 7. Composite casting with SS304 woven wire reinforcement.

Prior to carrying out the tensile test on the Al-nano SiC/SS304 woven wire composite, the test specimens were shaped with a lathe to accurately adjust according to ASTM B 557-02a dimensions in Fig. 8.



Nominal Diameter	Dimensions, mm			
	Standard Specimen	Small-size Specimens Propotional to Standard		
	12.5	9	6	4
G - Gage length	62.50±0.10	45.00±0.09	30.00±0.06	20.00±0.04
D - Diameter (Note1)	12.50±0.25	9.00±0.10	6.00±0.10	4.00±0.05
R - Radius of fillet, min	9	8	6	4
A -Length of reduced section, min (Note 2) 75	75	54	36	24

Fig. 8. ASTM B557M-02a tensile test specimen standard.

b. Casting of hardness test specimens with metal molds in accordance with ASTM E10 standards is illustrated in Fig. 8. Meanwhile, the dimensions of the specimens used for the Brinell hardness test are shown in Fig. 9.

(a) (b)

Fig. 9. Illustration of mold for Brinell hardness test specimen: (a) mold, (b) specimen dimensions.

2.3.2 Stir Casting Process

The stir casting process is carried out when the metal is melting with the following processing steps:

a. Turn on the smelting furnace by heating it to remove the water content in it then put pure Al into the crucible where the temperature is continuously increased to 780ºC.
b. Addition by incorporating 4% Mg in melted pure Al and holding time for 30 minutes.
c. Then, stirring the molten metal is carried out simultaneously, nano SiC is added into the molten metal. The method for obtaining a tensile strength above 100 MPa is the stirrer is turned on at a speed of 450 rpm with a stirring time of 45 seconds, besides that degassing is carried out by flowing argon gas into the crucible [16] [17].
d. After the stirring process is complete, the stirrer is removed.
e. Disposal of slag in molten metal.
f. Pouring the specimen into the mold, where the mold is heated and has been arranged woven SS304 wire as reinforcement.
g. After the specimen freezes, it is removed from the mold.
h. Furthermore, testing the characteristics of tensile strength and hardness test.

2.4 Testing Process

2.4.1 Tensile Test

Tensile test of composite Al-nano SiC/SS304 woven wire Terno Grocki tensile tester. Specifications for test equipment with a maximum loading capacity of 10,000 kN. The tensile test yields stresses and deformation distances during tension.

2.4.2 Hardness Test

The hardness test on the Al-nano SiC/SS304 Wire Woven composite was carried out using the ASTM E10 standard and using the THI20B Hardness Tester with the Brinell Hardness test method. The indenter tolerance standard used is a ball diameter with a dimension of 2.5 mm with a tolerance of ± 0.003 mm [18].

3 Results and Discussion

3.1 Tensile Test

In this study, the tensile test of the Al-nano SiC/SS304 Wire Woven composite aims to determine the increase in the tensile strength value of the composite material caused by the addition of reinforcement material in the form of nano SiC. The test results will be compared with other studies and analysis will be carried out. The results of the tensile test of the Al-nano SiC/SS304 wire mesh composite are shown in Fig. 10.

Based on Fig. 10 the presence of nano SiC in composites with aluminum matrix can affect the mechanical properties of the Al-Nano SiC/SS304 Wire Woven composite. The highest tensile strength was found in specimens with a variation of nano SiC content of 5% with a value of (149 MPa). Fig. 10 shows that the tensile strength value increases with the addition of nano SiC. The increase in tensile strength is in line with the study of adding SiC particles to Al 6061 alloy, where the tensile strength value of the composite is affected by the increase in the percentage of SiC composition in aluminum. According to [15] these results are due to SiC particles having the ability to withstand the load distributed by the Al 6061 alloy. Therefore, it can be concluded that the tensile strength increases with the addition of reinforcement in the form of SiC in the aluminum matrix. This is due to the wettability of magnesium which can bind between the matrix and the reinforcement so that it can increase the tensile strength of the composite. Aluminum matrix has good dislocation ability so it can spread in all directions.

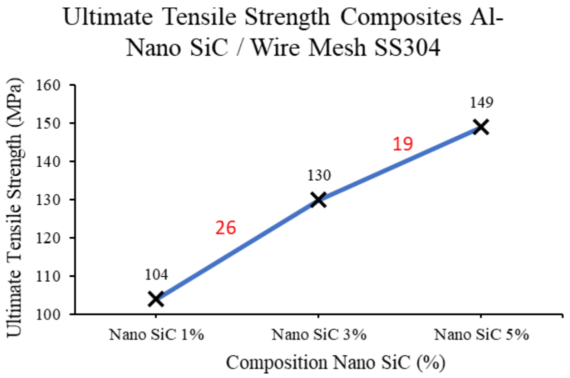


Fig. 10. Tensile strength of Al-nano SiC/SS304 wire mesh composite.

The modulus of elasticity for the Al-nano SiC/SS304 Wire Woven composite is shown in Fig. 11.

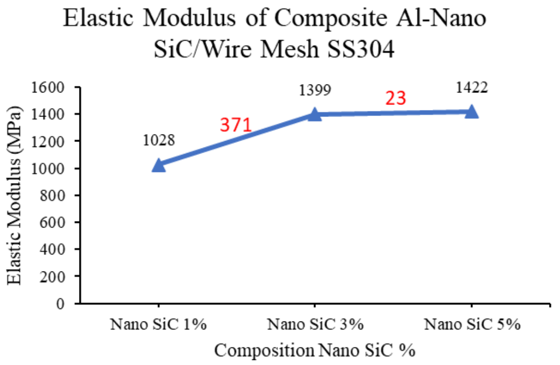


Fig. 11. The modulus of elasticity of the Al-Nano SiC/SS304 wire mesh composite.

In Fig. 11 the highest modulus of elasticity occurs in the Al-Nano SiC/SS304 woven wire composite with the addition of 5% nano SiC. The addition of Mg as a wetting agent to the composite plays a role in unifying the contact angle between the cast material and the substrate, while SiC and aluminum have an active role in chemical reactions that produce a positive effect on silicon on the contact angle [19]. Wettability occurs due to the liquid being able to wet the ceramic as a solid phase of reinforcing particles which involves surface chemical properties and surface tension. So that the state of increased wettability makes the matrix and reinforcement stick together.

Research conducted by [14] also showed that the addition of 3% nano SiC to the SiCp/Al 6082 composite had a higher elastic modulus value compared to the Al 6082 alloy and had a decrease in porosity due to the addition of nano SiC. The increase in the modulus of elasticity was in line with the increase in the percentage of nano SiC reinforcement in the Al matrix. So, the value of elastic modulus can be influenced by the addition of composite constituent materials to provide a value of stiffness and elastic properties of different materials.

3.2 Hardness Test

The results of the hardness test are based on Fig. 12. In Fig. 12 the hardness value of the composite with the addition of nano SiC to the Al-nano SiC/SS304 wire mesh composite has a significant difference with the highest hardness value of 69 HRB. The increase in hardness value was also experienced by research conducted by [15], where each additional percentage of SiC has an increase in hardness value with the highest hardness value of 45 HRB. While the hardness test in the study by [1][14] also showed that an increase in the addition of SiC had an effect on increasing the hardness value of 30%-50%. So that the addition of reinforcement in the form of SiC nanoparticles influences the increase of the hardness value of the composite.

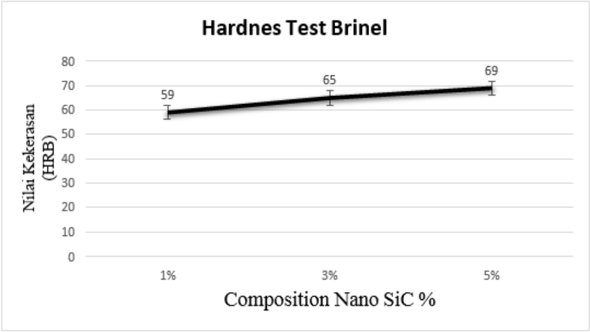


Fig. 12. Hardness value of Al-nano SiC/SS304 wire mesh composite.

The hardness value of the matrix area which experienced an increase was caused by the added reinforcement in the form of nano SiC. The more reinforcing particles are added, the more the stiffness level of the composite will increase [20]. So that it can withstand quite good indentation loads. Another study [21] found that the hardness value increased with the addition of SiC.

Increased hardness of the composite due to the wettability of the Al matrix against nano SiC/SS304 woven wire. Increased wettability can occur with the mechanism of the process of reducing the surface layer of SiC particles when stir casting takes place. Good wetting, stirring process can bind between reinforcement in the form of nano SiC/SS304 woven wire with matrix. So that the SiC particles cannot move position. The condition of not moving the particles is due to the adhesion between the SiC particles and the matrix, and the load received by the composite is passed on to the reinforcement. Good wetting at the interface, the more load is transferred to the reinforcement, can increase the hardness value of the composite.

The results of the research obtained were that the hardness value of the aluminum composite material increased along with the addition of the reinforcement given. This is in accordance with the literature which explains that the reinforcement added to the composite with increasing weight is directly proportional to the increase in hardness of the aluminum composite material [7][22]. Nano SiC added from 1%, 3%, and 5% resulted in a significant increase in the hardness value of the composite. The highest hardness value occurred in the sample with the addition of 5% nano SiC with a value of 69 HRB.

When viewed from the value of the strength and hardness of the composite, the addition of nano SiC can affect the characteristics of the composite. This is because the physical properties of SiC can increase or decrease the mechanical properties of the composite, both tensile strength and hardness, as shown in Fig. 13.

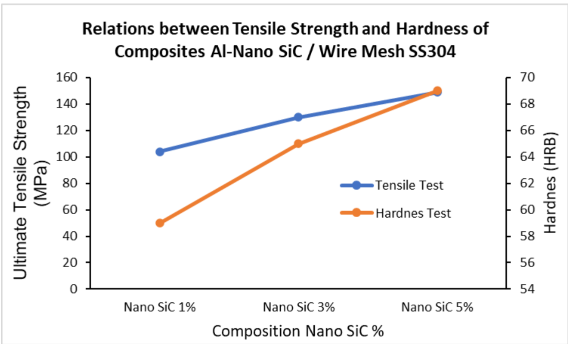


Fig. 13. Correlation between the tensile strength and hardness values of the Al-nano SiC/SS304 wire mesh composite.

4 Conclusion

Based on the research that has been done, it can be concluded that the addition of nano-SiC has an effect on increasing the hardness of the Al-nano SiC/SS304 woven wire composite. The highest hardness and tensile strength values were sequentially 69 HRB and 149 MPa achieved by the addition of 5% nano-SiC.

Subsequent suggestions for the development of this research required the addition of heat treatment processes, casting and coating methods in further research which aims to improve and enhance the mechanical properties of the composite. Microscopic observations are needed to help clarify the analysis of the results of the mechanical tests carried out.

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