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Hardness Improvement of Aluminum Reinforced with Carbon Nanotubes through Forging and Friction Surfacing Process

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Abstract. This research deals with the improvement of hardness property on the composite material made from aluminum matrix reinforced with carbon nanotubes (Al-CNTs). There were two experiments conducted to enhance hardness property; forging and friction surfacing process. An axial mechanical force forged the Al-CNTs composite up to 40% of height of a cylindrical aluminum. A thermo-mechanical force was also applied in producing Al-CNTs coating by the friction surfacing process using Al-CNTs composite rod. Then, the hardness property obtained from these two processes was investigated. Results of the experiments showed that the hardness of Al-CNTs after the forging process improved 40–50% due to high amount of dislocation during forging which avoids deformation. This was indicating that 1 wt% CNTs does not decrease the hardenability of aluminum alloys. Meanwhile, the hardness Al-CNTs coating was not altered too much by the process of friction surfacing. This is because that the homogenous dispersion of the CNTs have occurred during the stir casting process.

1. Introduction

Aluminum alloys are mostly selected in engineering applications when required to meet a material with lightweight and high strength properties. However, low hardness and high friction coefficient have limited the application of aluminum alloys in many sliding and rubbing components. The way to enhance the hardness of aluminum is by adding particulate reinforcement in the aluminum matrix as well as by surface modification.

It was reported that hardness increases with the increase of reinforcement content due to the high hardness and strength of the reinforcement phase. The addition of silicon carbide [1] and alumina [2] to aluminum alloys improved the hardness and wear resistance. Many kinds of particulate reinforcements have been successfully used to improve tribological properties of aluminum alloys such as aluminum nitride [3], granite [4], glass [5], titanium dioxide [6]. Also, several surface modification techniques such as high energy laser melt treatment [7], high energy electron beam irradiation [8], plasma spraying [9] and friction surfacing [10] have been developed to deposit metal matrix composites on aluminum alloy surfaces.

Unlike other surface modification processes aforementioned, deposition of metal matrix composite in friction surfacing is carried out at a temperature below the melting point of aluminum alloys. Therefore, the presence of undesirable and detrimental phases [11] can be avoided. In friction surfacing, an axial force pressed a high rotational speed consumable rod on the surface of a moving substrate, which generates frictional heat energy in the interface to soften the rod. Thereby, a viscoplastic shearing layer is continuously deposited between the rod and the substrate (Figure 1).



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Recently, research dealing with the effect of nano reinforcement such as carbon nanotubes (CNTs) to enhance mechanical properties has been extended to aluminum and its alloys. Such aluminum matrix with CNTs reinforcement has been introduced as a composite with high mechanical properties as well as wear resistance [12].

In this present work, the hardness of aluminum-carbon nanotubes (Al-CNTs) composite after subjected to mechanical force such as forging process and thermo-mechanical force like friction surfacing process was investigated. The composite of Al-CNTs was produced using the optimum process parameter of stir casting method that has been investigated in our previous research (not published yet).

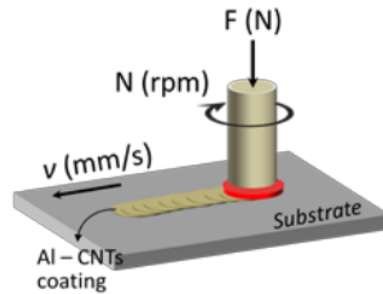


Figure 1. Friction surfacing process

2. Experimental

2.1. Casting Process

A consumable rod shown in Figure 2 made from Al-CNTs composite was produced using stir casting process (Figure 3). The matrix and reinforcement used in this study were AA6061 alloys and multiwall carbon nanotubes (MWCNT), respectively. The chemical composition of AA6061 characterized by XRF can be seen in Table 1.

Table 1. Chemical composition of AA6061

Element	Al	Mg	Si	Fe	Cu	Cr	Zn
wt%	Balance	0.9	0.7	0.6	0.3	0.25	0.2



Figure 2. Consumable rod



Figure 3. Stir casting apparatus

The MWCNT has an outer diameter >50 nm, length $0.5\text{--}2.0$ μm , and purity $> 7\%$. The stir casting process was done by heating AA6061 in the crucible up to 750°C . After melting, argon gas was given to clean the slag. Then the molten aluminum was stirred for 5 minutes at a speed of 500 rpm while entering 0.5 and 1.0 wt% of MWCNT powder. Then, the molten aluminum was poured into heated metal molds forming a casted aluminum rod. The pouring temperature was 750°C . Finally, the rod was processed to meet the dimension of the consumable rod using a turning machine.

2.2. Friction Surfacing Process

An axial drilling-milling machine (Figure 4) was employed to deposit the rod material to be coating onto a substrate of steel plate. The consumable rod made from Al-CNTs composite was 15 mm in diameter. The rod was mounted in the drill chuck of the machine. The rotary speed selected was 3000 rpm. The substrate of the steel plate was mounted in a vise of the machine. The coating was deposited on it by rotating consumable rod on the moving substrate. It is possible to deposit a thin layer of coating by utilizing heat energy generated by friction between the consumable rod and the substrate.



Figure 4. Drilling-Milling machine used for friction surfacing process

2.3. Forging Process

The samples of the as-cast rod were subjected to mechanical force. An axial compression force from a universal testing machine forged the samples up to a 40% reduction of height dimension in order to investigate the hardenability of Al-CNTs composite. After forging, the hardness of the samples was tested.

2.4. Testing Process

Then, the consumable rod, the friction coatings, and the residual rod were subjected to hardness test using Rockwell hardness test with HRF scale, indenter diameter is 1.588 mm with a load of 60 kgf.

3. Results and Discussions

3.1. Effect of Forging on the Hardness of Al-CNTs Composite

The hardness value of the forged rod as well as the as-cast rod (before forging) is shown in Figure 5. It was revealed that all of the forged rod samples showed higher hardness than the as-cast rod. The hardness significantly increased to about 40–50%. This is due to the high amount of dislocation during forging which avoids deformation [13].

This result indicates that the addition of CNTs to aluminum matrix up to 1 wt% does not decrease the hardenability of Aluminum alloys. The Al-CNTs composite even can be hardened by subjecting to mechanical force.

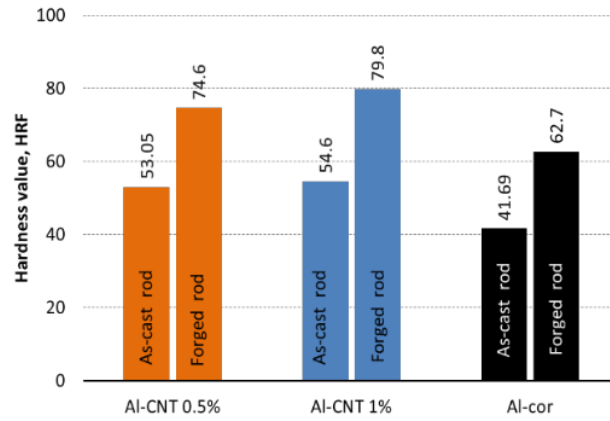


Figure 5. The hardness value of Al-CNTs composite

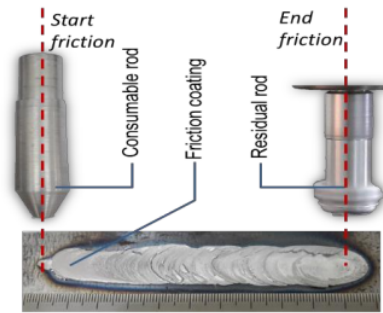


Figure 6. Friction surfacing coating

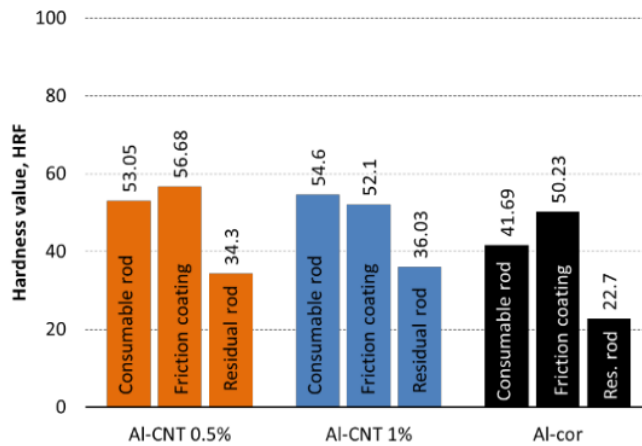


Figure 7. The hardness value of friction surfacing products

3.2. Effect of Friction Surfacing on the Hardness of Friction Coating

The hardness value of friction surfacing products: consumable rod, friction coating, and the residual rod (Figure 6) are shown in Figure 7. The friction coating deposited from the consumable rod made of Al-cor showed a significant increase in hardness value. On the other side, there were no significant changes in hardness values of friction coatings for both of the consumable rods composite. The increasing hardness of friction coating was due to homogenous fine-grained coating formed during the visco-plastic deformation [14] and may eliminate the defect or imperfection formed during solidification. Meanwhile, the Al-CNTs composites have only light respond with thermo-mechanical force. In fact, the enhancement of mechanical properties for Al-CNTs composite relies on the homogenous dispersion of the CNTs [10]. The stir casting method used to produce the Al-CNTs composite rods has already well dispersed the CNTs in the aluminum matrix. Therefore, the effect of friction surfacing on distributing CNTs homogeneously was not significant. As consequent, the hardness values did not significantly alter. In addition, the hardness of all rods (residual rod) after the friction surfacing process was decreased. Residual rods experienced conductive heating from the friction process. This may cause the strengthening precipitate dissolved to the aluminum matrix that brought about softening the rods.

4. Conclusion

Aluminum reinforced with carbon nanotubes has good hardenability through the forging process. Its hardness improved significantly. Meanwhile, its hardness was not altered too much by the process of friction surfacing.

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