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Effect of Hot Rolling and Cold Rolling on Mechanical Properties and Electrical Conductivity of Composites of AlZrCe Alloy and Al_2O_3 Particle

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Abstract

Hot rolling and followed by cold rolling have been carried out on samples of metal matrix composites (MMC) of AlZrCe alloy reinforced with alumina (Al203) nanoparticles. The samples are produced using stir casting with a chemical composition of Zr 0.15%, Ce 0.2% (weight fraction) and Al203 1.2% (volume fraction). The rolling process above is carried out using a rolling mill which has a square-shaped roller gap profile with various sizes. The rolling process of the sample begins with hot rolling at a temperature of 450 °C to reduce cross sections to 51% and proceed with the cold rolling to reduce cross sections to 70%. Changes in the microstructure of these samples were observed using optical microscopy and scanning electron microscopy (SEM). Changes in mechanical properties were observed by tensile test and hardness test. The electrical conductivity was measured using a micro Ohm meter. After hot rolling, the tensile strength of the samples significantly increased from 60 MPa to 180 MPa, the hardness value increased from 45 HV to 85 HV and the electrical conductivity increased from 51.3% IACS to 54.6% IACS. After the cold rolling, the tensile strength of the samples increases from 180 MPa to 326 MPa and the hardness increases from 85 HV to 130 HV. However, the electrical conductivity of these samples decreased slightly from 54.6% IACS to 54.2% IACS. The properties above show that this composite has good prospect to be applied as a high-strength conductor.

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1. Introduction

The use of Aluminum metal has been increasing lately. Aluminum alloys are getting widely used as a substitute for steel and wood in building construction applications. Some of the advantages of Aluminum include good corrosion resistance, low specific gravity, and also good electrical conductivity [1]-[6]. Besides that it has also lower specific gravity, and it is cheaper than copper [2], [6]. Currently Aluminum is also applied as a conductor for high voltage transmission networks [2] - [8]. To further increase the use of aluminum, its physical and mechanical properties can be improved by adding alloyed elements to pure

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aluminum as well as various mechanical and thermal treatments [1] - [9]. Addition of these alloying elements will form a solid solution or precipitate in the form of inter-metallic compounds [2], [3], [6]. Efforts to increase the strength of aluminum and alloys can also be done by making composite metal matrices (MMC) from aluminum with the addition of fibers or reinforcing particles [9]-[12]. Aluminum as a matrix is reinforced with ceramic particles such as Al2O3, and SiC [9], [10] . The process of making MMC is usually done using the stir casting [9], [11] or metallurgical powder process [10].

As a conductor for high voltage transmission, aluminum conductors receive a relatively high heat load which can reduce their tensile strength2884. Hence, to increase its thermal resistance, pure aluminum is usually added with a certain amount of zirconium (Zr)[4]-[6]

Erturk et Al.[4] and Knych et al. [6] conducted a study of the thermal resistance of Al-Zr alloys with Zr contents to 4.46% mass. The addition of Zr will reduce the electrical conductivity of Aluminum, but by providing heat treatment to the alloy after wire drawing, this treatment will increase the electrical conductivity of the alloy to 54% IACS. Meanwhile Medvedev et al. [2] added that a combined rare earth (RE) alloy of Lanthanum (La) and Cerium (Ce) with compositions from 2.5% to 8.5% processed by high pressure torsion (HPT) to produce an ultrafine grain structure which significantly will increase the strength of the alloy, but simultaneously decrease the electrical conductivity. Then by providing heat treatment, the thermal conductivity of alloy can be increased. Kirman et al. [3] conducted a study of making conductors from AlZrCe alloy composites reinforced with Alumina particles by stir casting method, with Ce 0.1%, Zr 0.12%, and alumina particles 1.2% volume fraction, this study produced alloys with electrical conductivity about 50% IACS. The mechanical properties of the alloy can also be increased by plastic deformation process, such as, hot rolling, extrusion, and wire drawing. Common processes for production of conductor wire are started from continuous cast, hot rolling, and wire drawing [8].

The purpose of this research is to observe the changes in the mechanical properties and electrical conductivity of composite rods from AlZrCe alloys reinforced by alumina particles processed by hot-rolling and followed by cold rolling.

2. Research Method

The samples were rods of a composite of AlZrCe alloy reinforced by Alumina particles called as matal matrix composites (MMC), which were produced by the stir casting method. The AlZrCe alloys have a chemical composition as shown in Table 1. The alumina particles (Al2O3) is a nano particles with composition of 1.2% of volume fraction. The samples with a cross section area of 10x10 mm2 and a length of 200 mm were heated to a temperature of 500 °C in a muffle furnace. The samples were taken from the furnace and immediately rolled at a temperature of 450 °C (hot rolling) reduced cross section area to 7x7 mm2. Furthermore, the sample is processed by cold rolling reduced the cross section area to 4x4 mm2.

Hot and cold rolling processes were done by rolling mill machine which has two high roller mill with roll diameter of 140 mm and rolling speed of 5 m/min. The rolling mill has various profile gap sizes as shown in Figure 1. Hot rolling process used a 7x7 mm2 gap profile size that reduced cross section area of 51% changed cross section area from 100 mm2 to 49 mm2. The cold rolling process used a roller gap with a size of 5x5 mm and 4x4 mm which results in a cross section reduction of 49% and 67%.

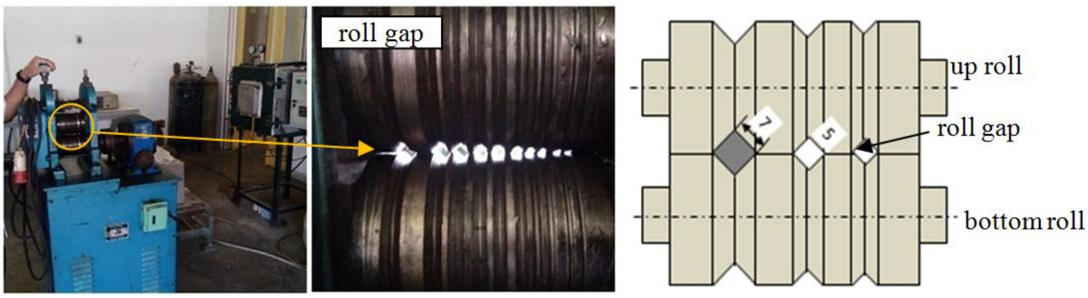

Figure 1. Rolling mill for hot rolling and cold rolling with several size (square) profil gap

Table 1. The chemical composition of the AlZrCe alloy matrix was reinforced by Al_20_{3np} of 1.2% in volume fraction.

Alloy	Al	Si	Fe	Cu	Zn	Zr	Ce	Other
% weight	balance	0.025	0.072	0.001	0.013	0.148	0.205	<0.1

The microstructure were observed using optical microscopy (OM) and Hitachi SU31500 scanning electron microscopy (SEM). The metallographic samples were cut from as cast, hot rolled and cold rolled materials that parallel to rolling direction. The samples were prepared by standar procedure and etched in a

Keller reagent solution (50 ml aqudes, 50 ml HNO3, 10 ml HCl, and 10 ml HF)[13]. The distribution of alloy was investigated by the energy dispersive spectrometer (EDS) system of SEM.

Hardness tests and tensile tests were carried out to investigate the mechanical properties of the samples. Hardness tests were performed on metallographic sample with a 1.5 N load for 5 seconds that were of 5 points in each samples. Tensile properties was tested using Shimadzu 250 kN universal testing machine at tensile speed of 5 mm/s on a length of the samples 200 mm. Conductivity of samples was measured using a micro ohm meter on samples in the form rod or wire rod.

3. Results and Analysis

Microstructure

The microstructures of the composites of AlZrCe alloy reinforced by alumina nanoparticle (MMC) is shown in Fig. 2. The as-received of composites were as-cast which its microstructure is a dendritic structure (Fig 2a). It partly is seem elongated which unidirectional and the other is equiaxed. It is commonly in as-cast of metal that pecessed by gravity casting [2], [9], [11]. At the grain boundary of the microstructure is seem a dark section which indicates alumina particles and intermetallic compounds that are compounded with cerium [4], [9]. In the hot rolling process, the grain was deformed and followed by recrystallization [3], [6], [13], [14]. Figure 2.b shows microstructure of the composites after deformed by hot rolling at a temperature of 450 °C with a rolling reduction of 51%. The microstructure tends to be slightly elongated in accordance with rolling direction (RD) which grain size relatively is uniform and so smaller than the microstructure of as-cast samples. In the grain boundary area new smaller grains are seen indicated recrystallization and grain growth. Figure 2.c shows the microstructure of cold rolled the composite after hot rolling. The microstructure gets thinner and looks like a line that extends in the rolling direction.

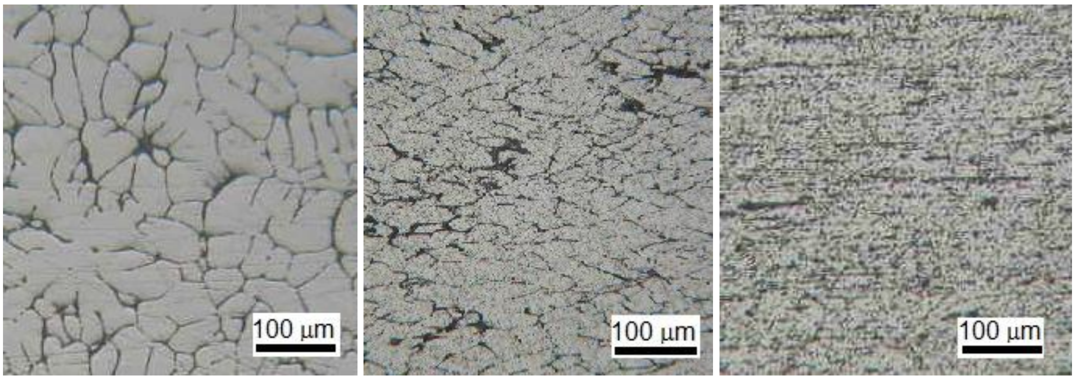

Fig.2. Optical micrographs of composites of AlZrCe (Zr = 0.15%, Ce = 0.2%) alloy reinforced by nanoparticles of Al203 (1.2% volume fraction) (a) as-received (as-cast), (b) after hot rolling (450 °C, r = 51%), and (c) followed cold rolling (r = 70%) in rolling direction.

RE metals such as cerium and lanthanum are generally insoluble in aluminum, usually in small quantities they will become precipitates that gather at grain boundaries [2]. Zirconium has a solubility of up to 0.23% in aluminum [4-6], but with the addition of cerium the solubility is reduced and formed Al3Zr compound which it stays at the grain boundary. Meanwhile, a limited amount of alumina particles will always be at the grain boundary. Figure 3 shows the microstructure of SEM results and analysis with SEM EDs AlZrCe alloy composite samples reinforced alumina particles. Table 3 shows the chemical composition of the spectrum from the SEM EDs analysis. The images and tables show that cerium, alumina particles and some other metals (Fe) are at the grain boundary.

Some previous studies [3]- [6] showed that at the boundary of the grain formed deposits in the form of inter-metallic compounds. A.E. Medvedev, et al. [3], who conducted a study of Al-RE alloys processed by HPT, showed inter-metallic compounds in the form of $Al_{11}(La + Ce)_3$, which were identified using XRD analysis. While for Zr alloys formed Al_3Zr as previous studies [4]-[6].

Mechanical Properties

The hardness of the composite samples of Al-Zr-Ce / Al2O3 alloy can be seen in Figure 4. The as-cast of the alloy has a hardness of about 45 HV. The hardness of the alloy increased to 70 HV by hot rolling with 51% reduction, then increased significantly to 130 HV after proceeded by cold rolling with 70% reduction. The hardness of the alloy increased to 70 HV by hot rolling with 51% reduction, then increased significantly to 130 HV after proceeded by cold rolling with 70% reduction. On the hot rolling, the alloy undergoes grain refining, re-crystallization, and grain growth which causes the average grain size to be much smaller and the porosity of the as-cast is much reduced. After cold rolling, the hardness is significantly increased due to strain hardening [1], [3], [6].

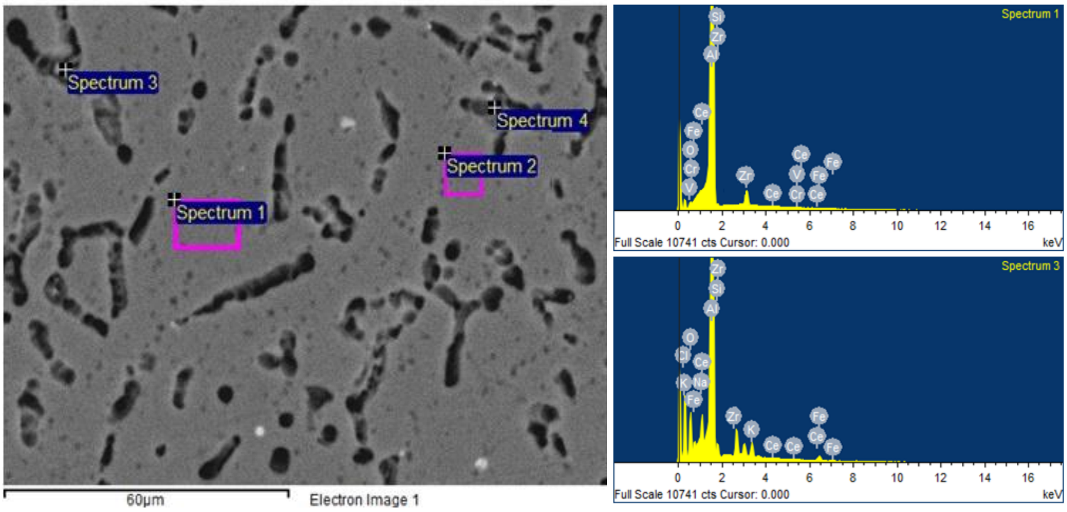

Fig.3. SEM micrograph of composites of AlZrCe alloy reinforced Al203 nanoparticle in cross section after hot rolling (a) and its EDs analysis.

Tabel 2. Chemical composition of microstructure of AlZrCe alloy reinforced Al_20_3 nanoparticle in corss section after hot rolling analized by SEM EDs in several point refered at Fig.3. (spectrum 1 and 2 in grain area, spectrum 3 and 4 in grain boundary)

Element	% weight			
	Spectrum 1	Spectrum 2	Spectrum 3	Spectrum 4
O (Al2O3)	0.29	0.21	7.56	6.43
Al	99.34	99.45	90.62	92.50
Si	0.06	0.03	0.75	0.50
Fe	0.07	0.10	0.82	0.34
Zr	0.22	0.21	0.17	0.11
Ce	0.02	0.00	0.08	0.12

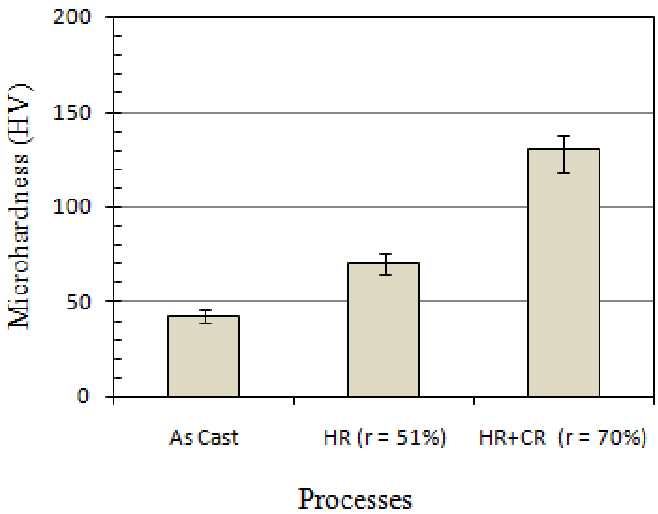

Figure 4. Hardness of MMC samples of of the MMC samples of AlZrCe alloys reinforced by alumina particles before and after hot rolling (50% reduction) and cold rolling (70% reduction).

Figure 5 shows the tensile test results of MMC samples of AlZrCe alloys reinforced by alumina particles. The as-cast tensile strength of the composite is around 60 MPa. After hot rolling process, the tensile strength of the As-Cast sample increased from 61.7 MPa to 179.3 MPa and became 313.7 MPa after being followed by a cold rolling process. Meanwhile elongation increased from 5% to 10% after the hot rolling process and dropped significantly to after 4% after the cold rolling process. Pure aluminum has a tensile strength of up to

190 MPa after a cold rolling process [4]. Meanwhile after the HPT process, Al-2.5RE has tensile strengths up to 290 MPa, and Al-8.5RE has tensile strengths up to 637 MPa [2], [3]. AlZrCe alloy composites have a fairly good tensile strength, although they are still under Al-RE 8.5, but they are economically cheaper.

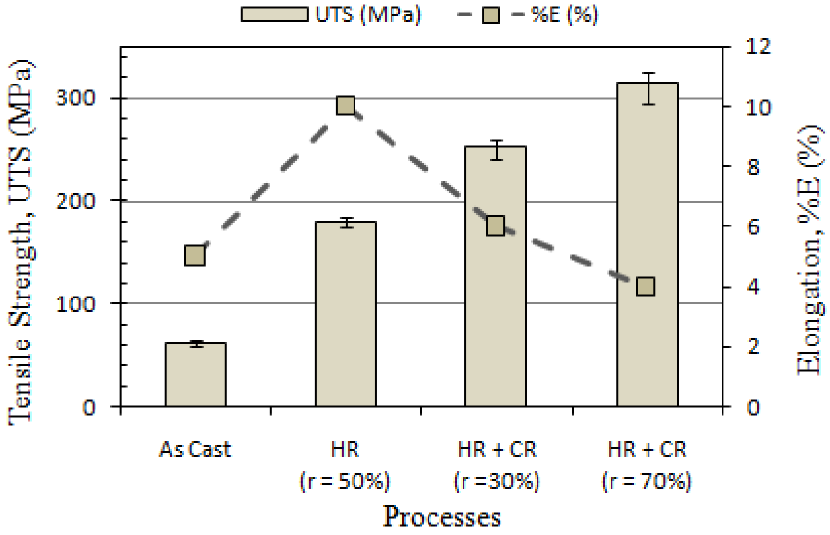

Figure 5. Tensile strength and elongation of the MMC samples of AlZrCe alloys reinforced by alumina particles before and after hot rolling (50% reduction) and cold rolling (70% reduction).

Electrical Conductivity

Figure 6 shows the test results of composite electrical conductivity. It can be seen that the resistivity value drops from 34 μΩm to 31 μΩm after hot rolling process and slightly rises to 32 μΩm after cold rolling process. Decreasing the resistivity value will increase the electrical conductivity. It was seen that the electrical conductivity of the composite was 51.23 %IACS before hot rolling, and increased to 54.61 %IACS after being processed hot rolling. The electrical conductivity of the composites was slightly decreased to 54.22 %IACS after been followed by cold rolling. During hot rolling, the structure was deformed in a rolling direction which was followed by recrystallization and grain growth [6], [14], [15]. So that the structure is more homogeneous and the existing porosity is much reduced which increases electrical conductivity of the composites [1], [6]. While the cold rolling process causes strain hardening which causes conductivity to drop [3]. This conductivity value is close to the Al-2.5RE alloy result from HPT [3], [4] which is 56% IACS, and above Al-8.5RE which is 39% IACS. But the Al-RE conductivity value increases after being annealed at 230 °C [3].

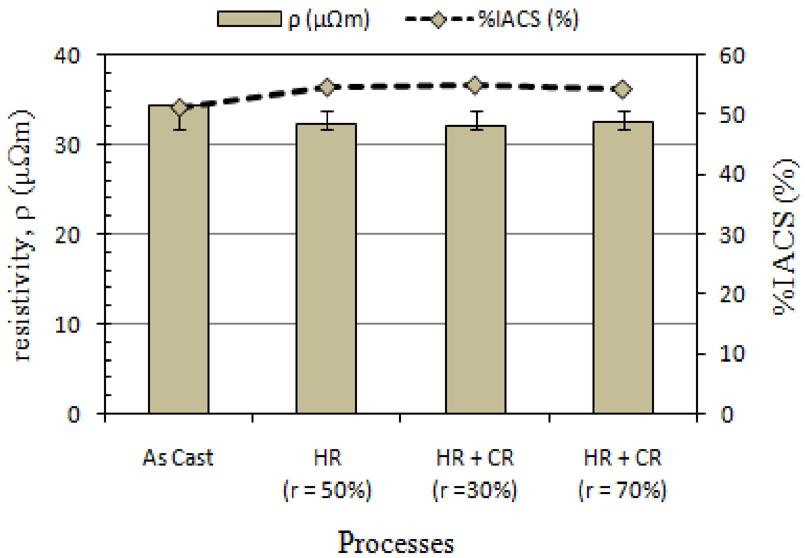

Figure 6. Electrical conductivity of the MMC samples of AlZrCe alloys reinforced by alumina particles before and after hot rolling (50% reduction) and cold rolling (70% reduction).

4. Conclusion

The metal matrix composites of Al-0.15Zr-0.2Ce reinforced with Al2O3np produced by stir casting was processed by hot rolling at 450 °C with 51% reduction followed by cold rolling to 70% reduction. Mechanical properties and electrical conductivity of the composites significantly changed after processed by hot rolling and cold rolling. The tensile strength was increased from 61 MPa to 179 MPa and 326 MPa after hot rolling and followed by cold rolling. The hardness was increased from 42 HV to 70 HV and 130 HV after hot rolling and cold rolling. Electrical conductivity of the composites was increased from 51.23% IACS to 54.61% IACS after processed by hot rolling and slightly decreased to 54.22% after cold rolling. The composite of the alloy has a potential to be applied as a high strength conductor

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