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EFFECT OF GRAPHITE REINFORCEMENT ON MECHANICAL AND CORROSION PROPERTIES OF AL6061 PROCESSED BY EQUAL CHANNEL ANGULAR PRESSING

VIVEK KUMAR

JOINT DIRECTOR, LABOUR RESOURCES DEPARTMENT, GOVT. OF BIHAR

ABSTRACT

The impact of graphite reinforcement on the mechanical and corrosion characteristics of AL6061 alloy, which is produced using ECAP, is investigated in this work. The AL6061 matrix was stir cast with graphite particles added at three different weight percentages (3%, 6%, and 9%). Grain refinement and improved material characteristics were achieved by subjecting the produced composites to ECAP. We followed ASTM guidelines while testing mechanical properties including hardness, tensile strength, and corrosion. The alloy's mechanical strength and corrosion resistance were found to be significantly enhanced by adding graphite reinforcement and then treating it using ECAP. Based on the results, ECAP-processed graphite-reinforced AL6061 composites are a good fit for high-stakes structural and engineering projects because of their improved performance.

Keywords: Graphite Reinforcement, Equal Channel Angular Pressing, Mechanical, Corrosion Resistance, Weight.

I. INTRODUCTION

The structural, aerospace, and automotive industries make heavy use of aluminum and its alloys, particularly those in the 6xxx series like AL6061, due to the material's low weight, high strength-to-weight ratio, and corrosion resistance. For many technical applications, the precipitation-hardened alloy AL6061 is the material of choice because to its excellent weldability, moderate to high strength, and remarkable resistance to corrosion. Severe plastic deformation (SPD) techniques and the addition of suitable reinforcements have been the focus of modern materials science efforts to enhance this alloy's mechanical and corrosion properties. Among these techniques, Equal Channel Angular Pressing (ECAP) stands out. Without altering the material's macroscopic shape, it may enhance mechanical performance and smooth out grain patterns. A novel approach to producing high-performance metal matrix composites (MMCs) is to use reinforcing materials such as graphite, which has exceptional thermal, corrosion-resistant, and lubricating characteristics. To force a billet through a die with two intersecting channels of equal cross-section, a methodology known as ECAP has been studied in detail as an SPD method. This procedure uses extreme shear strain to refine grains significantly and create ultrafine-grained (UFG) or even nanostructured materials. A number of physical and chemical properties are impacted by grain refining, including strength, hardness, ductility, fatigue resistance, corrosion behavior, and the Hall-Petch mechanism. Since ECAP refines and uniformizes AL6061's grain structure, it often improves the material's ductility and mechanical strength. You can't always rely on ECAP to improve corrosion resistance since, depending on the environment; the larger grain boundary area might potentially operate as active sites for corrosive assault. Hence, reinforcing with graphite or another material may have a major effect on corrosion behavior, wear, and lubrication.

Graphite is a layered carbon crystal that is both highly conductive to heat and intrinsically resistant to corrosion. Because of its desirable properties—lower friction, higher wear resistance, and better machinability—it has attracted attention as a reinforcing element in metal matrices. Particles of graphite, when mixed with AL6061, serve as solid lubricants and enhance the composite's tribological performance. In addition, the processing technique and distribution of graphite within the matrix determine whether its electrochemical inertness and protective layer-forming capabilities impact corrosion dynamics favorably or adversely. A synergistic effect optimizing mechanical and corrosion characteristics may be possible because to the uniform dispersion of graphite achieved by ECAP processing. Graphite reinforcement has a complex impact on the mechanical characteristics of AL6061 that has been treated using ECAP. Graphite particles' Orowan strengthening, load transmission mechanism, and grain refinement caused by ECAP all work together to control the composite's mechanical behavior. How well stress is transferred and how well cracks are prevented are both affected by the interfacial bonding of the graphite and the aluminum matrix. Improved yield strength, tensile strength, and hardness may be achieved by carefully distributing and optimizing the volume percent of graphite in an aluminum matrix, according to studies. Overall mechanical improvement is contributed to by the combination of graphite's reinforcing action and ECAP's increased dislocation density.

However, the corrosion behavior of ECAP-processed graphite-reinforced AL6061 is multi-faceted and affected by variables such microstructural homogeneity, galvanic connection between the graphite and the aluminum matrix, and environmental influences. Although graphite's lack of reactivity provides some protection against corrosion, poorly regulated galvanic interactions may cause localized corrosion due to its higher electrochemical potential than aluminum. Depending on the processing settings and the number of ECAP passes, the ECAP process may either reduce or increase these impacts by refining grains and changing the distribution of second-phase particles. For this reason, it is crucial to analyze the surface morphology, electrochemical impedance, and polarization resistance of ECAP-processed AL6061 composites thoroughly in order to comprehend the consequences of graphite reinforcement. A potential strategy to improve the mechanical and corrosion characteristics of AL6061 alloy is to combine graphite reinforcing with ECAP processing. Composites based on aluminum may be enhanced by combining grain refinement with graphite's intrinsic characteristics; these composites might find use in challenging engineering settings. It is important to carefully analyze processing settings, reinforcing features, and the resultant microstructure in order to achieve an appropriate balance between mechanical strength and corrosion resistance. In order to shed light on the creation of next-generation aluminum matrix composites with customized performance qualities, this research intends to methodically investigate these interconnected consequences.

II. LITERATURE REVIEW

Rusin, N. et al., (2020) Researchers looked at how two-phase sintered Al-Sn composites changed structurally during ECAP (equal channel angular pressing) using method A, which did not include rotating the sample between passes. During ECAP processing, the samples' flow planes developed a macrostructure with alternating thin interlayers of Al and Sn. The geometry of ECAP was discovered to be able to represent the law of changes in the parameters of the composites' structure. During the first two passes, the composites' strength increased and their macro structural characteristics changed the most. An increase in the depth of subsurface layer deformation and a reduction in distance between tin interlayers, sources of solid lubricant, are the results of aluminum interlayer thinning. Dry friction on steel further reduces the wear intensity of sintered Al-Sn composites when the sliding direction is perpendicular to the interlayers of the elongated phase. It was found that the composite with the maximum wear resistance included around 40% Sn.

Khan, Mahmood et al., (2019) there are many uses for lightweight aluminum matrix composites in the aerospace and automotive industries. Graphene Nano platelet (GNP) composites made of aluminum alloy were produced using a powder metallurgy process. The composites were loaded with varying amounts of GNPs, ranging from 0.1 wt% to 3 wt%. To ensure that the GNPs were evenly distributed throughout the Al6061 matrix, two different exfoliation procedures were used. To achieve densities close to those predicted by theory, pressure-less consolidation and sintering were used. To study the role of GNPs in Al6061 matrix strengthening, samples were compared under both manufactured thermal conditions and artificially aged T6. Utilizing X-ray diffraction, optical, and scanning electron microscopy, the development of the microstructure was validated. Due to the conductive network around the matrix grains, the electrical conductivity increased as the quantity of GNPs rose up to 1 wt%. Up to 1 weight percent GNPs in the matrix alloy, the mechanical characteristics showed an increase of 93% in hardness, 61% in compression strength, and 92% in flexural strength. The characteristics were degraded due to agglomeration at 3 weight percent GNPs. In order to learn about the GNPs' behavior, the related strengthening process, and the altered fracture morphology, the damaged surfaces were studied.

Bongale, Arunkumar et al., (2018) Powder metallurgy and equal channel angular pressing (ECAP) was used to create nano metal matrix composites. The matrix phase consisted of 6061 aluminum alloy, and the reinforcements were 2, 4, and 6 weight percent of silicon carbide nanoparticles, respectively. Using a high-energy planetary ball mill, the elemental Al6061 alloying components were combined with the estimated weight percent of SiCnP. The resulting composite powder is packed onto a one-dimensional compaction die and then run through ECAP as much as three times. Archimedes' principle was used to assess the porosity and density of the samples. To test the composites' wear characteristics under varying loads and speeds, a pin-on disc system is used. According to the results, the wear rate of the composites is reduced by adding weight percent SiCnp, but it rises when the load and speed are increased. Surface micrographs taken with a scanning electron microscope revealed several wear mechanisms that were responsible for specimen wear under various testing circumstances. Additionally, it was discovered that increasing the number of runs through ECAP and the weight percent of SiCnp both contributed to a higher composite hardness value.

Lokesh, T & Mallik, Ujjawal. (2016). The current research used the stir casting process to create an aluminum metal matrix composite with an Al6061 matrix and SiC (10-30μm) particle reinforcement of variable proportion (2-10wt.%). As the weight percentage of SiCp increased in as cast Al6061-SiC composites, a notable improvement in hardness and tensile strength was seen. In order to achieve microstructure homogeneity, the cast composites were annealed at 400 °C for 4 hours. For Equal Channel Angular Pressing (ECAP), specimens have been made from these composites. The ECAP procedure was performed at ambient temperature with a 120° channel angle die and Bc route for each pass. We assess how ECAP changes the Al6061-SiC composite's microstructure and mechanical characteristics. Grain size of the matrix alloy was found to be significantly reduced after the ECAP process, while the size and distribution of reinforcement particles remained same. In accordance with ASTM guidelines, the hardness and tension tests were carried out at room temperature. Both the basic Al6061 material and cast Al6061-SiC composites were used to compare the findings. Ultimate tensile strength and hardness are both greatly enhanced in composites that undergo ECAP processing.

Sharma, Pardeep et al., (2015) the effects of adding graphite particles to AA 6082 metal matrix composites made using the traditional stir casting process on their characteristics are the subject of this study. The reinforcement percentage was adjusted in a 3% increment from 0% to 12%. Adding graphite particles reduced micro-hardness by 11.11% and macro-hardness by 10.44%, according to the data. With a fall in percentage elongation from 8.7 to 6.8, the ultimate tensile strength likewise reduced by 5.88%. As the weight percentage of graphite particles rose from 0% to 12%, the porosity grew from 0.37% to 2.27%, while the density fell 4.1%.

Muthazhagan, Chinnasamy et al., (2013) the mechanical characteristics of Al (6061)-B4C-Graphite after standard heat treatment are the focus of this work. The two-step stir casting process is used to create metal matrix composites (MMC) made of aluminum. A variety of volume percentages of aluminum reinforced with 5%, 10%, and 15% boron carbide and 5%, 10%, and 15% graphite were used to create the composites. Traditional heat treatment was used to improve the mechanical characteristics of the produced composites. The mechanical characteristics of aluminum-boron carbide composites were examined in relation to the presence of graphite reinforcement. Research on the microstructure was also conducted. Ductility, hardness, and ultimate tensile strength are all drastically reduced as the graphite percentage in the aluminum matrix increases. The composites' hardness was actually enhanced by the inclusion of boron carbide.

III. MATERIAL AND METHODS

Materials Used

Here are some quick facts about the primary materials and reinforcements utilized in composite synthesis:

- **Aluminium 6061 Alloy**

Among the 6000 family of precipitation-hardened aluminum alloys, 6061 stands out for the presence of magnesium and silicon. The ingredients are listed in Table 1.

Table 1: Composition of Al6061

Component	Amount (weight %)
Aluminium	95.8 - 98.6
Silicon	0.4 – 0.8
Magnesium	0.8 – 1.2
Iron	Max. 0.7
Copper	0.15 - 0.40
Zinc	Max. 0.25
Titanium	Max. 0.15
Manganese	Max. 0.15
Chromium	0.04 - 0.35
Others	0.05

- **Reinforcement- Graphite (Gr)**

Table 2, displays the chosen graphite's major features.

Table 2: Key properties of Graphite

Property	Commercial graphite
Bulk Density (gm/cm^3)	1.3 - 1.95
Porosity (%)	0.7 - 53
Modulus of Elasticity (GPa)	8 - 15

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Compressive strength (MPa)	20-200
Flexural Strength (MPa)	6.9-100
Coefficient of Thermal Expansion ($x10^{-6}$ °C)	1.2-8.2
Thermal conductivity (W/m.K)	25-470
Specific heat capacity (J/kg.K)	710-830
Electrical resistivity (Ω.m)	$5x10^{-6}$-$30x10^{-6}$

IV. COMPOSITES PREPARATION

The first preparation in the stir casting process involves collecting the raw ingredients, which include graphite and Al6061, and then cutting the Al6061 into little pieces weighing around 250 grams. For various formulations, measure the alumina by weight.

In order to eliminate any gas or moisture from the surface of the casting reinforcements, the equipment, including the stirrer and the permanent mold, were heated to 200oC prior to casting. To reduce flaws in the coating layer, a degassing tablet is added to the crucible along with the necessary quantity of Al6061 and heated to 700oC in a resistance furnace. This will remove any volatile components from the melt that may have been present during casting. Porosity and blow holes are casting faults that the tablet aids in removing from the melt. The Al6061 matrix is then reinforced with graphite of varying compositions, with weights of 3%, 6%, and 9%, respectively. A distinct vortex was created by adding the Gr microparticles to a mixture that was heated to 750°C and then vigorously swirling it constantly for 15 minutes.

We poured the molten slurry into the cast-iron mold when it reached the pouring temperature of 8500C and gave it a few minutes to harden. Once it has solidified completely, it is removed from the mold and machined in accordance with ASTM specifications. After that, it goes through a series of tests before being put through equal channel angular pressing (ECAP) by use of a cylinder-shaped die with a 90-degree passage. The specimens that have been cast and those that have been subjected to 900 equal channel angular pressing are now tested separately.

Micro structural characterisation was performed on the material's top, middle, and bottom portions to identify the distribution of second phase particles. Following this, specimens are produced in accordance with ASTM standards for a variety of mechanical property testing. We will measure the degree to which the matrix behaves better after Equal channel angular pressing and use the results of these experiments to assess the mechanical quality. At last, the examined enhancements in attributes are attained.

Details of Equipment

The following items were used throughout the project: -

- Resistance Furnace
- Electric Oven
- Two disk Polishing Machine
- Computerized optical microscope
- Brinell's hardness machine
- Die
- Universal Testing Machine
- Salt spray Chamber
- Electronic Weighing Machine
- Crucible
- Stirrer
- Plunger of the equal channel angular pressing die

Both the front and side views of the die, which has a path through which the cast material is driven out, are shown in Figure 1. This die is used for Equal Channel angular pressing. It is clear that the cylinder has a hole in the top and sides that join to make the 900. This hole allows materials to flow through it, which enhances its characteristics and decreases residual stresses and burrs caused by casting.

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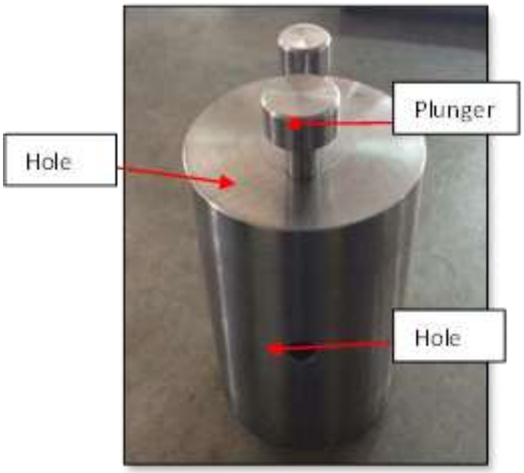

Figure 1: Die for Equal channel angular pressing

Figure 2 shows the draught model of the die and plunger with dimensions, and the material details are as follows.

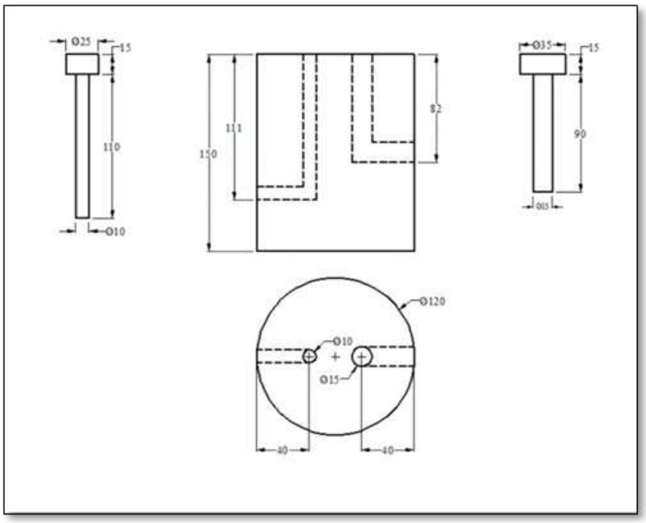

Figure 2: Dimension of die and plunger

V. RESULTS AND DISCUSSION

- **Hardness Test**

Using a steel ball indenter at an applied stress of 60 kgf at 50X and dwell duration of 10 seconds for each sample at various sites, the Brinell hardness test was performed on all compositions. It is clear that the composite subjected to equal channel angular pressing has a higher hardness than its cast matrix counterpart. The graphs further show that when the graphite weight percentage rises, the hardness drops, while the graphite weight percentage increases. As seen in Figure 3, the addition of graphite reinforcement causes a drop in hardness. The graphite particles' pliability is to blame for this hardness decrease; equal channel angular pressure causes the cast material's hardness to rise.

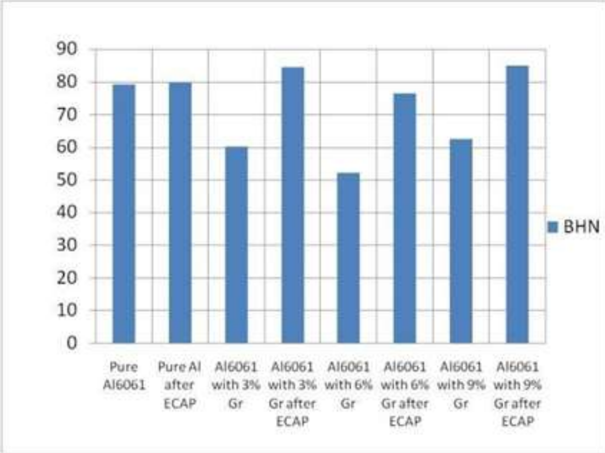

Figure 3: The Brinell hardness number (BHN) of different composites prepared under study

Findings and observations are in agreement with those of other researchers. Some researchers have shown that composites reinforced with hard particles are noticeably harder than those without.

- **Corrosion Test**

For the salt spray test, the cast materials are weighed and the results are provided in Table 3. For the equal channel angular pressing test, the cast materials are tested and the results are displayed in Table 4. After the Equal channel angular pressing operation, the specimens' weight has risen, but only little. We employ the ASTM B 117-2007 test procedure.

Table 3: Results of corrosion test before Equal channel angular pressing

Before Equal channel angular pressing					
		Weight In grams			
Date	**Total Hours**	**Pure Al**	**Al with 3% Gr**	**Al with 6% Gr**	**Al with 9% Gr**
21.06.2017- Initial		1.4117	1.4789	1.3123	1.4025
21.06.2017	12	1.3461	1.3617	1.2974	1.3317
22.06.2017- Final	24	1.2221	1.3717	1.1147	1.2716

Table 4: Results of corrosion test after Equal channel angular pressing

After Equal channel angular pressing					
		Weight In grams			
Date	**Total Hours**	**Pure Al**	**Al with 3% Gr**	**Al with 6% Gr**	**Al with 9% Gr**
21.06.2017-Initial		1.1471	1.5741	1.6002	1.5789
21.06.2017	12	0.9614	1.4476	1.4476	1.4964
22.06.2017- Final	24	0.7117	1.3717	1.3711	1.3141

VI. CONCLUSION

Improvements in mechanical and corrosion characteristics were seen after processing AL6061 alloy with graphite reinforcement using Equal Channel Angular Pressing (ECAP). The combination of graphite's lubricating and corrosion-resistant properties with the refined grain structure obtained by ECAP improved hardness, tensile strength, and corrosion resistance. The performance benefits of the tested compositions were found to be proportional to the percentage of graphite reinforcement, with a middle ground at moderate values. A viable option for advanced engineering and industrial applications, the research demonstrates that adding graphite and treating it using ECAP may greatly increase the structural performance of AL6061.

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