Effect of Equal Channel Angular Pressing (ECAP) on Wear Behaviour of Stir-Casted Al3003/B4C-Gr Composite

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ABSTRACT:

In the past few years, the urgent need for low-cost, high-performance, and good-quality materials has given impetus to research in the area of composites using pure metallic constituents and these are manufactured with various proportions to obtain lightweight metallic composite structure. It was observed the findings of various researchers indicate that severe plastic deformation occurs in the composite structure when subjected to the non-uniform load, Further by adapting the ECAP technique for manufacturing of metallic composite structure. It was observed that the improvement in the mechanical properties such as strength, corrosion, and wear resistance. The same can also be achieved by adopting high-pressure techniques and these can produce microstructures with grain size in submicrometer and nanometre range that will exhibit good wear resistance with better strength and lower cost.

The objective of the present work is to develop a lightweight metal composite structure having better wear resistance of Al3003 with B4C and Graphene at 0.5% & 0.25% as a hybrid composite. The above hybrid composite is manufactured by the conventional (stir casting) technique and also by the ECAP technique with high-performance and low-cost metallic composite and also to compare both of these techniques on wear resistance.

The wear resistance of the hybrid metal matrix composites is predicted by performing a dry-slider wear test using a pin-on-disc wear tester and to study wear resistance parameters such as load, time, and speed on machining of Al3003 hybrid composite and also prediction of process parameters on wear resistance under severe plastic deformation state and also normal state by the Taguchi L9 orthogonal array which is one of the optimization technique for design of experiments.

Keywords: Stir Casting, Wear Resistance, Severe Plastic Deformation, Equal Channel Angle Pressing(ECAP), Machining Parameters, Taguchi, Design of Experiments.

1. INTRODUCTION:

Materials with greater strength, lower cost, and lighter weight are required for engineering applications. Due to their exceptional mechanical qualities, such as hardness, high strength, lightweight, heat resistance, low cost, wear resistance, and weight ratio to strength, Metal Matrix Composites (MMC) has been used for over thirty years. The most typical MMC consists of an aluminum matrix supplemented with B4C and nanoscale Graphene particles. The composite is then challenging to machine. These Al-based B4C-Graphene nanoparticle composites are being employed more and more in drive shafts, turbocharger impellers, space structures, automotive pistons, bearings, cylindrical liners, connecting rods, and piston rings. The production of MMCs can be done in various ways with several techniques, The Stir Casting Technique is well-liked. It is ideal because it is less expensive, achieves high mechanical properties, and makes it simple to manage variables like stirring speed and pouring temperature. By adding B4C and Graphene to Al alloy, mechanical qualities have been improved. Variable weight percentages of Graphene and fixed weight percentages of B4C are used for all castings. The casting's mechanical characteristics and the stir casting technique revealed characteristics including tensile strength, BHN hardness, and impact test. Due to their severe abrasiveness.

One of the effective techniques for enhancing grain refinement in metals and alloys is severe plastic deformation (SPD). A new technique, developed by Russian scientists in recent years, involves manufacturing bulk specimens with ultrafine-grained (UFG) microstructure SPD processing. Materials that have undergone SPD processing not only exhibit the distinctive physical and mechanical characteristics that are inherent in UFG materials, but they also have significant advantages over other approaches, particularly the bottom-up method. One of the SPDs used to create bulk UFG materials is Equal Channel Angular Pressing (ECAP). During the process, a sample is pressed into a die with an equal cross-sectional area and the necessary angle. During this operation, the grain is refined using a basic shear. Many investigations established that, when compared to their coarse-grained equivalents, UFG microstructures generated by ECAP generally result in high yield strengths measured at ambient temperature. Numerous studies have looked at the microstructure and mechanical characteristics of the ultrafine-grained aluminium alloys and low-carbon steel produced by ECAP, and they have concluded that this process is effective for producing UFG bulk materials. The Taguchi method is employed for optimization, and the S/N ratios are compared between wear resistance before ECAP to wear resistance after ECAP.

2. LITERATURE REVIEW:

In this study [1] three different reinforcement materials including ZrO_2, ZrO_2 + Al_2O_3, and 40FZA with varying propositions as 5,10 and 15 % were used. On both experimental and computational analysis, it is clear that the presence of 15% particles reinforced with 40FZA in Al6061 results in better strength, toughness, and strong resistance to wear and corrosion. It is found [2] that one of the most basic processes is stir casting. for Al castings and Al6061 is reinforced with Al Oxide particles (0-4wt%) giving the hardness, tensile strength, and compression tests conducted. The values are compared with pure Al alloy casting. So that the wt% of Al Oxide increases the mechanical properties also increase in metal matrix composites. In this journal [3] the MMCs with 0.33%, 0.55%, and 0.77% of Graphene nanoparticles prepared by the stir-casting technique and are tested for mechanical properties then 0.77wt% of graphene nanoparticles composite is recommended for optimum results. It is found [4] The Stir casting method is being used to build Al MMC enhanced with Al_2O_3 and fly ash. The use of fly ash increases microhardness and Rockwell hardness while decreasing density. In this paper [5] Due to their better strength-to-weight ratio, wear resistance, and high-temperature resistance, Metal Matrix Composites (MMCs) are becoming more and more common in aerospace and automotive applications. In this study, the Stir Casting Technique was used to examine the Microstructure and Mechanical Properties of Aluminium 2024, Graphene, and Boron Carbide (B_4C) composites with various weight percentages of 0.25%, 0.5%, 0.75%, and 1% Graphene and 10% Boron. SEM was used to investigate structural characteristics, a universal testing machine to ascertain mechanical characteristics, and a Brinell hardness test machine to ascertain hardness. It is found that [6]Metal Matrix Composites (MMCs) are increasing due to their less weight and high thermal conductivity. However, aluminum has less wear resistance and a high thermal expansion coefficient, leading to wear during service. This research investigated the hardness and wear behavior of Al7075 with Boron Carbide 5% and Graphite particles as reinforcements. In this paper [7] An efficient production method for generating ultrafine-grained materials is equal-channel angular pressing. The specimens were pressed through up to four passes via route BC in order to evaluate the wear characteristics of the Al 7075 alloy on the impact of grain refinement during ECAP at room temperature. Using a pin-on-disk machine, dry sliding wear tests were performed under various weights of 10, 20, and 30N at a constant sliding speed of 0.23 ms-1. Microstructural investigations were conducted using scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The impact of load and the ECAP procedure on mass loss was discussed in terms of microstructure and wear mechanisms. A comparison of the specimens' wear resistance revealed that the production of extremely tiny grains during ECAP

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significantly boosted wear resistance. In this article [8] Equal-channel angular pressing (ECAP) is a useful processing technique for introducing significant grain refinement, frequently to the submicrometer level, in a variety of metals. Studies show that ECAP produces microstructures in single crystals and polycrystalline materials that are identical. By incorporating experimental findings, a model for grain refining is created.

The literature review mentioned above leads to the conclusion that much research is being done on the manufacturing and wear resistance of Al MMCs with Boron carbide and graphene as reinforcements. This study uses the design of experiments to investigate the impact of wear resistance before and after ECAP of Al3003 reinforced with B4C and Graphene particles.

3. MATERIALS & METHODOLOGY:

There are two phases in every composite material. While the reinforcing phase gives the composite more strength, the matrix phase acts as a supporting material. The aluminum 3003 alloys were used in this study to mix Boron carbide (B4C) and graphene nanoparticles.

3.1 Methodology:

Initially, Al3003 alloy was introduced into a graphite crucible with electrical furnace assistance and melted at 800°C. 3 grams of C2Cl6 was added to the melt after it had melted in order to release any trapped gases. 2 grams of potassium Hexa Fluoro Titanate (K2TiF6) was mixed with the reinforcement in the proper ratio before being heated in a preheater die for 2 hours to eliminate any foreign particles, minimize moisture content, and enhance wettability. Flux powder or molten salts, such as K2TiF6, are utilized to enhance the wettability of the matrix and the reinforcement materials. Throughout 4 phases of stirring with the Aluminium alloy melt while the stirrer was moving at 400 rpm, preheated reinforcement was added. Step-by-step reinforcement addition enhances the matrix's distribution and produces better properties. To ensure that reinforcement is distributed evenly all through the melt, the stirrer was stirred within the melt for 10 minutes. After stirring, the molten material was allowed to rest for 5 minutes in the furnace to allow the particles to settle before being Figure 1 depicts the pour into the heated die casting.

3.2 Principal processing of ECAP:

Processing by ECAP is now an established procedure for use with metals and it is an attractive technique for several reasons. First off, using and setting up an ECAP die are both rather simple. Second, extremely high strains can be induced by repeatedly pressing the same sample or by creating unique multi-pass dies, rotary dies, or side-extrusion equipment. Thirdly, it is simple to scale up the ECAP samples to create relatively large bulk materials, and these large samples have the potential to be used in a variety of applications ranging from the biomedical to the aerospace industries.

Fourth, while though ECAP is commonly used on samples that are in the form of bars or rods, it can also be applied to samples that are in the form of plates. As an illustration, a recent paper described the use of ECAP on an aluminium plate. Fifth, ECAP may be introduced into traditional rolling mills for continuous processing or into the ECAP-compliant wire production process. It is appropriate to analyse processing concepts using ECAP in light of these numerous benefits. The ECAP technique is schematically illustrated in Fig. 1.

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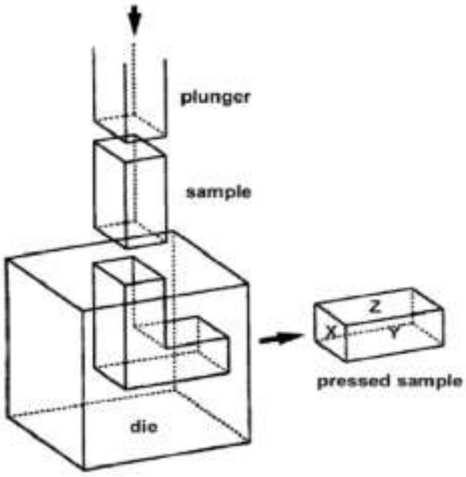

Fig.1. Schematic diagram of ECAP procedure.

A die is made up of a channel that is abruptly bent across a 90° angle, as shown in Fig. 1. A sample is cut to size to fit the channel, and a plunger is used to press the sample through the die. The figure makes it abundantly evident that the sample's cross-sectional dimensions are the same before and after pressing, permitting the use of the same sample for additional pressings. It's important to keep in mind that processing by ECAP differs dramatically from Fig. 2 since the same cross-sectional area is retained.

Fig.2. Extruding of Al3003 from the Die

the three orthogonal planes X, Y, and Z are defined as well as the basic idea of ECAP processing. Fig. 3. The four processing methods in ECAP are traditional industrial processes like rolling, extrusion, or drawing, where the sample dimensions get smaller with each succeeding pass. In Figure 3, three orthogonal planes—X, Y, and Z—are depicted. X is the transverse plane that is perpendicular to the flow direction, Y is the flow plane that is parallel to the side face at the point where the material exits the die, and Z is the longitudinal plane that is parallel to the top surface at that same place.

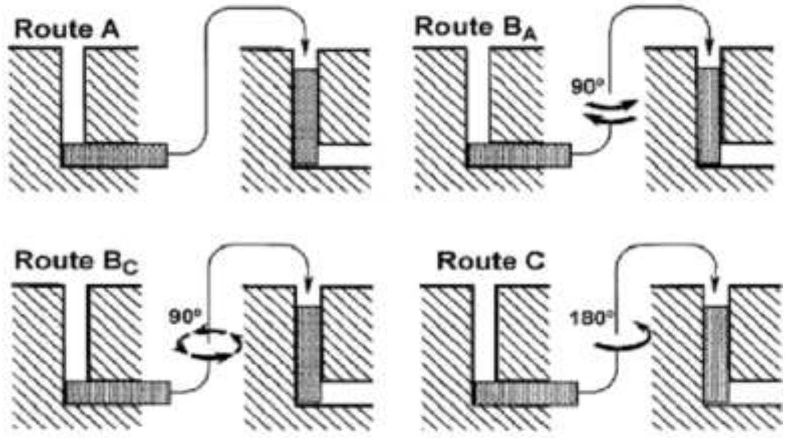

Fig.3.Orthogonal planes of the ECAP processing.

The angle,, between the two parts of the channel (90° in Fig. 1), as well as the angle of curvature,, which represents the outer arc of curvature where the two channels intersect (0° in Fig. 3), both have a significant impact on the strain imposed on the sample during each passage through the die. With this configuration, it can be demonstrated from first principles that the imposed strain on each pass is roughly equal to 1, with only a small, almost negligible dependence upon the arc of curvature,. ECAP is typically conducted using a die with a channel angle of = 90 to achieve the best results. Rotating the samples about the X-axis in between pressing sessions can introduce different slip systems when samples are pressed repeatedly.

In reality, ECAP uses four different processing paths, as follows: Route A repeatedly presses the sample without rotation; Route BA rotates it by 90 degrees in alternating directions between passes; Route BC rotates it by 90 degrees in the same direction between passes; and Route C rotates it by 180 degrees between passes.

The various processing routes are schematically depicted in Fig. 3, and it is important to understand the differences between them because they introduce various shearing patterns into the samples that affect both the individual grains in polycrystalline matrices and the macroscopic distortions of the ability to produce an ultrafine-grained microstructure that is relatively uniform and equiaxed. It should be noted that there are numerous processing methods available when using plate samples. For example, in tests on pure aluminium plates, the sample was rotated by 90 degrees between passes using the processing route BCZ, where the Z or vertical axis acted as though it were perpendicular to the plane of the plate.

3.3 Wear Resistance and Sample Preparation:

As the primary ECAP material, Al-3003 alloy was used in the studies. Table 1 displays the Al-3003 alloy's chemical makeup. The extruded rods were annealed for one hour at 415°C before ECAP, and they were then cooled in the furnace. Al-3003 rods were bent into cylindrical samples with a 19.1 mm diameter and 140 mm height, which were then put through an ECAP die with a channel that had an outside curvature angle of 20° and an angle of 90°.

The illustration of an applied die is shown in Figure 2. Using processing route BC (a 90° clockwise rotation around the sample axis between each pass), all billets were pressed up to four times at room temperature with a pressing speed of less than 0.5 mm per second. and depicted in Figure 4.

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Fig.4.Ware test specimens before ECAP.

3.4 Design of Experiments:

In every sector, it is challenging to produce high-quality and productive goods. To achieve this, the design of experiments (DOE) method is primarily utilized to generate efficient combinations of process parameters while simultaneously minimizing the number of trials. In this work, a mathematical model based on Taguchi and 9 trials were created to investigate how process factors affect machining features. This method is one of the best ones for creating the mathematical model. According to the literature, the factors that have the biggest effect on wear characteristics are Speed, Load, and Time, which are used as input variables. Table 1 lists the input variables along with their values. Level values are taken into consideration based on machine capacity. L9 orthogonal array, which consists of 3 columns and 9 rows, is taken into consideration in this project. If you want accurate findings from any optimization method, you need to run more experiments. Each parameter has three levels of values specified. MINITAB-21 was used to calculate the relationship between the parameters. This is employed, particularly for DOE applications. The relationships between input and output variables were looked into. Each experiment's wear is calculated, and after that, The S/N ratio is expanded to include the entire set of information.

3.5 Machining parameters and their Levels

S.No	Parameters	Unit	Level 1	Level 2	Level 3
1	Speed N	rpm	197	287	383
2	Load L	N	10	20	30
3	Time t	Min.sec	8 min 20 sec	11 min 7 sec	16 min 40 sec

Table.1. Machining parameters and their levels.

4. Experimentation:

4.1 Wear Resistance:

Wear resistance is the capacity of a material to endure material loss brought on by mechanical activity. Although a material may not be particularly hard, it might nonetheless be robust and wear-resistant, and vice versa for hard materials. Tribological characterisation methods like the pin-on-disc sliding wear test are often used to assess the coefficient of friction and the wear mechanism of diamond films. For the study of sliding wear and friction qualities, hard coatings, which are intended to increase the lifespan of any component, are of enormous practical value. With the help of a pin-on-disc sliding wear test, the NCD coatings' frictional characteristics were identified. The disc spun about a vertical axis with the pin held stationary over it in the predetermined configuration. During the wear test, loads can be applied manually or pneumatically. In addition to providing for control of the speed of the revolving disc during testing, electrically controlling the motor speed enables continuous speed monitoring. The friction force that existed at the time of the test was measured using a torque transducer. Flat-ended pins constructed of WC-Co that were either NCD-coated or left bare were used in the experiments, which were run at a sliding speed of 250 rpm. The disc is composed of 1541 AISI carbon steel and has a diameter of 55 mm and a thickness of 4 mm. With an accuracy of 0.1 mg, weights were measured before and after the wear test and pins and discs were ultrasonically cleaned in ethanol.

Fig.5.Ware monitor machine(Pin on disc sliding ware machine).

5. RESULTS AND DISCUSSION:

The input variables are determined by the response, The S/N ratio and ANOVA tools were used to analyze the data. All the outcomes for the various experimental configurations were presented in Table 2.

Table 2: S/N ratio and ANOVA tools

S.No	SPEED	LOAD	TIME	Wear before ECAP	S/N ratio for before ECAP	Wear after ECAP	S/N ratio for after ECAP
1	192	10	16.40	0.02	33.9794	0.01	40.0000
2	287	10	11.07	0.03	30.4576	0.02	33.9794
3	383	10	8.20	0.02	33.9794	0.01	40.0000
4	192	20	16.40	0.03	30.4576	0.02	33.9794
5	287	20	11.07	0.05	26.0206	0.03	30.4576
6	383	20	8.20	0.04	27.9588	0.01	40.0000
7	192	30	16.40	0.05	26.0206	0.01	40.0000
8	287	30	11.07	0.04	27.9588	0.02	33.9794
9	383	30	8.20	0.05	26.0206	0.03	30.4576

5.1 Machine parameters' impact on Wear After ECAP:

The S/N ratios response table for Wear After ECAP in Table 3 indicates that Speed has the biggest influence, followed by Load and Time.

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Table 3:Response Table for Wear After ECAP and S/N Ratios (Smaller is better)

Level	**LOAD**(*L*)	**SPEED**(*N*)	**TIME**(*S*)
1	37.99	37.99	36.82
2	34.81	32.81	32.81
3	34.81	36.82	3.99
Delta	3.18	5.19	5.19
Rank	3	1	2

The Wear After ECAP major impacts plot in Figure 5 shows that Wear After ECAP improves as Speed values rise. However, increase in Load and Time results in higher Wear Rate. The ideal machining settings were identified from the major effects plot for SN ratios, and they are

Load(L)- 30 N; Speed(N)-287 rpm; Feed Rate(f)- 180 sec;

Figure 5 shows the main effect plots for S/N ratios and data mean graphs for Wear After ECAP Signal to Noise Ratios, which state that smaller is better.

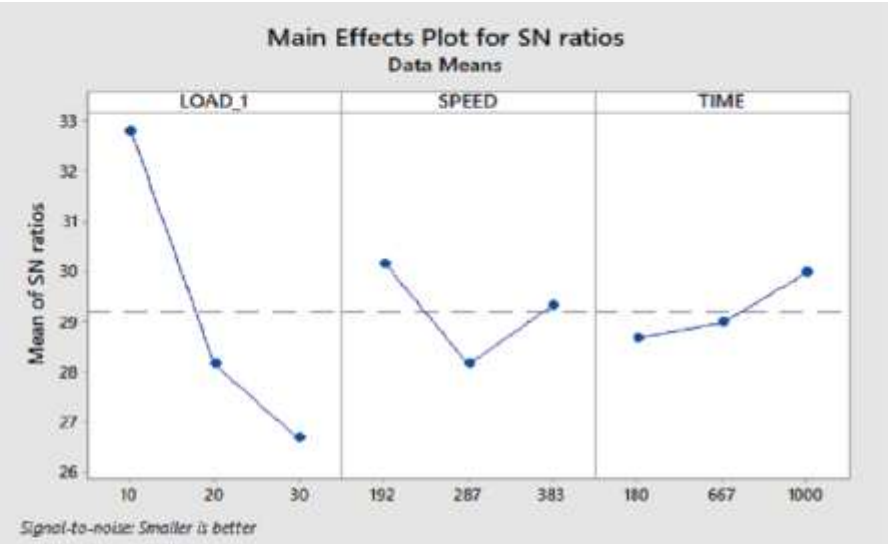

Fig. 5: Wear After ECAP Main Effect Plot

5.2 ANOVA FOR Wear after ECAP:

The main factors that significantly effecting the Wear After ECAP are Speed, Load, and Time. ANOVA was done to study the effect of the Wear Test process variables. The outcomes of the ANOVA are displayed in Table 5. From the Analysis of variance results, it concludes the Residual error is 20.72% of the total contribution and the most influencing parameter is Speed and Time followed by Load.

Table 4: Analysis of Variance for Source Wear After ECAP

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**Contribution%**
Load	2	20.24	20.24	10.12	0.17	0.585	14.71%
Speed	2	44.40	44.40	22.20	1.56	0.391	32.28%
Time	2	44.40	44.40	22.20	1.56	0.391	32.28%
Residual Error	2	28.50	28.50	14.25	-	-	20.72%
Total	8	137.54	-	-	-	-	100.00%

Note: DF stands for "Degrees of Freedom," Seq SS for "Sequential Sum of Squares," Adj SS for "Adjusted Sum of Squares," Adj MS for "Adjusted Mean Squares," and P for "Percentage of Contribution."

5.3 Regression Analysis:

Regression Equation for Wear after ECAP (R2 =79.30%)
WEAR AFTER ECAP= 0.0078 + 0.000333 LOAD + 0.000017 SPEED - 0.000003 TIME

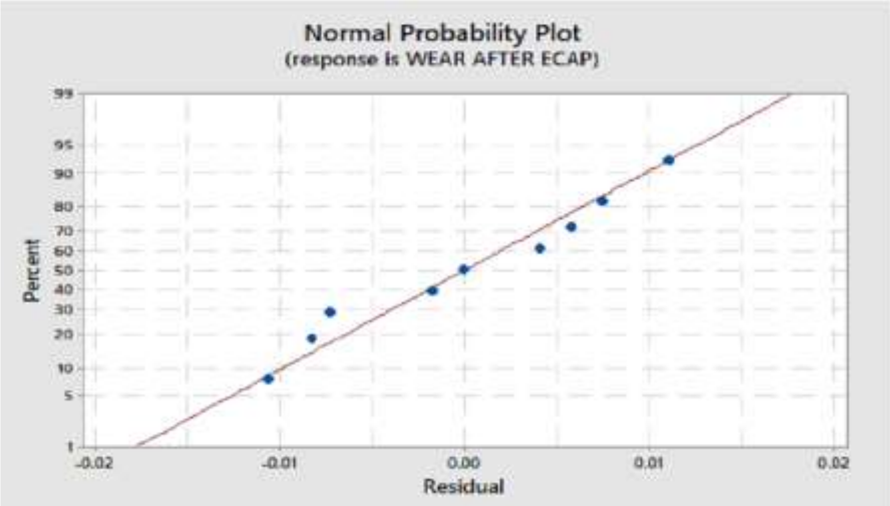

Fig. 7: Regression Normal Probability Plot for Wear After ECAP

5.4 Optimum Predicted Values for Wear After ECAP:

The optimum predicted values are shown in Table 7 Wear After ECAP

Table 5: Optimum Predicted values for Wear After ECAP

S.No.	Factor	Level	Value
•	Load *L*	3	30
•	Speed *N*	2	287
•	Time *t*	1	180
Prediction			
•	**S/N Ratio**	32.6918	
•	**Mean**	0.0244	

6. CONCLUSION:

According to the research, The current investigation draws the following conclusions from the experiments: Stir casting was a successful method for producing Al 3003 composites. Gr particulate distribution in the matrix is largely uniform. However, while adding 0.5 weight percent B4C and 0.25 weight percent Gr to the matrix alloy, porosity and particle clustering increase the strength of an alloy. Additionally, by incorporating B4C-Gr reinforcement particles into the Al3003 matrix, the composite's wear resistance is enhanced. The shielding effect of these particles against wear propagation lowers the rate of wear and boosts wear resistance.

Al 3003 composites are significantly affected by the B4C and Gr reinforcement in terms of the ultimate tensile strength as well as the percentage elongation in the as-cast condition.

Al 3003-(0.5% B4C and 0.25% Gr) wt.% composites' ECAP was completed successfully in up to three passes. Comparing the composites to Stir-casted composites, their hardness and strength nearly increase by 1.85 times. After the ECAP process, the size of the particles does not change, but they are distributed uniformly throughout the matrix. Additionally, there has been a noticeable decrease in the grain size of the matrix alloy. With little change in hardness and ductility, the studied composites' 4 weight percent of Gr exhibited the highest value of ultimate tensile strength through the ECAP Process. Significant plastic deformation of the material occurs during the ECAP process, improving the microstructure and distributing the B4C-Gr reinforcement particles evenly throughout the matrix.

The composite consequently becomes harder, stronger, and more resistant to wear. When comparing the two methods, the billet produced by the ECAP technique performs better in terms of wear resistance and high performance than the Stir casted method. Regression normal probability graphs for wear following ECAP and wear following ECAP main effect are displayed.

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