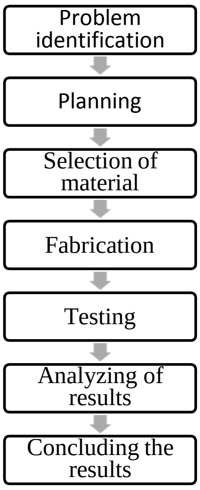
A study on the influence of quenching heat treatment on hardness properties was carried out by Hammar Ilham Akbar et al. They used AL6061 composite reinforced with Al2O3. The proportion of Al2O3 was 10 wt.%. Quenching was done with cooling agents such as oil, water, and salt solution (Brine). It was found that the cooling rate has a great effect on hardness characteristics. It was also found that brine quenching with a higher cooling rate produces higher hardness and distortion [6]. S. Arun Kumar et al. fabricated an Al7075 composite reinforced with Si3N4 through stir casting to study the effect of porosity. The reinforcements were added in the proportion of 4%, 8%, and 12%. The specimens were heat treated using a muffle furnace at various temperatures such as 150oC, 250oC, 350oC, 450oC, and 550oC for 5 hours. It was inferred that porosity resulted in a reduction of mechanical properties to a greater extent which can be reduced through heat treatment [7]. Jitendra M. Mistry et al. conducted a tribological study on heat-treated aluminum composite reinforced with Si3N4. Al7075 is used for the matrix phase of the composite. The proportion of reinforcements was 4%, 8%, and 12%. Fabrication was done through electromagnetic stir casting. It was inferred that wear rate was inversely proportional to sliding velocity and directly proportional to sliding distance and load. Reduction in wear loss was found with the increase in Si3N4 wt.% [8]. Fazludheen Chemmala et al. conducted computer analysis on Al7075 reinforced with Si3N4 to study its mechanical characteristics such as Hardness, Tensile, etc.The proportion of reinforcement added varied from 2%, 4%, and 6%. A study was also conducted on the fabrication of aluminum composites through stir casting. From the study, a considerable increase in mechanical properties was noticed due to the addition of Si3N4 reinforcement [9]. Ravikumar Nagula et al. utilized the Taguchi method in the process of analyzing the wear characteristics of hybrid aluminum composites. Si3N4, Sea snail shells, and Rice husk ash were used as reinforcements. The proportion of Si3N4 and sea snail shells was varied as 2, 4, and 6% wt., while Rice husk ash percentagewas kept constant at 5%wt. It was concluded that sliding speed, load, and percentage of reinforcements had a considerable effect on the coefficient of friction [10].

Fly ash is regarded as a good reinforcement for aluminium since it boosts the mechanical characteristics of the metal while also being very inexpensive. Conclusion: As the weight percentage of fly ash in aluminium composite increases, tensile strength, compressive strength, and hardness all improve. In order to turn industrial waste into industrial wealth, fly ash aluminium composites should be used in industry [11]. Due to its inexpensive initial cost, great foundry castability, and strong mechanical and machining qualities, ZA-27 alloy is now preferred. The ZA27 alloy/graphite particulate composite in this instance has a particle size range of 90-150 um and a composition of 0–5%. It is determined that as the amount of graphite particles in the alloy rises, there is a drop in hardness and an increase in ductility, UTS, and compressive strength after heat treatment at 280°C for 1 to 4 hours [12]. Here, AA606 matrixmaterial and 1-5% MoS2 reinforcement material are used to create a metal matrix composite. It is then heated for 1 hour at 520°C, quenched in water, artificially aged for 12 hours at 180°C, and then cooledwith air. 4% Mos2 reinforced composites had much higher yield and tensile strengths than other materials, but their percentage of elongation property was lower. Additionally, it is noted that after heattreatment, the reinforcement particles are evenly dispersed [13]. Here, a 4-weight percent SiC alloy reinforced with particles with an average size of 650 nm has been studied. The solution is treated at 540 C for 6 hours as part of the age hardening process, which is then followed by water quenching and aging at varying temperatures of 175 C, 200 C, and 225 C for soaking durations of 3, 6 h, and 9 h. SiC is added to the alloy to boost its hardness, but it does not affect the material's wear mechanism. The rate of wear is reduced as the hardness increases [14]. 2–10 wt% of TiC was found in the AMMCs under study. The 2 m/s sliding speed, 2 km sliding distance, and 20 N normal load were used in the wear experiments. The wear rate was noticeably lower for the composite material compared to the matrix material, and the wear resistance of the composites increased with increasing weight percentage of TiC particles. The mechanical characteristics of the TiC-reinforced composite specimens, such as hardness, tensile strength, and percentage elongation qualities, are superior to those of the AA7075 matrix material in both cases [15].

Investigated in this article is the friction and wear behaviour of heat-treated Al 6061 alloy and Al 6061 SiC-graphite. The cast 6061 alloy and its composites underwent a solutionizing process for one hour ata temperature of 803 K, followed by a water quench. After being quenched, the samples were aged artificially at a temperature of 448 K for varying lengths of time between 4 and 8 hours. The hardness result demonstrates that the composites' hardness rose as the weight fraction of graphite particles decreased. Increased reinforcing has a positive impact on the metal matrix composites' wear behaviour by reducing friction and increasing wear resistance [16]. Here, Al, Ni, and Al2O3 powders were combined in different ratios to create dense coatings by low-temperature cold spraying. Aluminides were created using two different post-deposition processes: resistance spot welding and furnace heating. The hardness of the coatings increased to 205.4 HV0.3. All three coatings had equivalent microhardness, with the highest value coming in at 358.4 HV0.3 [17]. In this study, the high- temperature age-hardening behaviour of an aluminum-lithium alloy reinforced with silicon carbide particulates is reported and contrasted with that of a matrix material that has undergone a comparable thermomechanical treatment. According to the DSC and aging results shown here, the addition of SiCp does not seem to alter the matrix's general precipitation process, although strength is preserved for longer periods of time and at higher levels [18]. Here, a basic matrix of A356 alloy is employed, to which Al2O3 and RHA particulates (1Wt%, 2Wt%, 3Wt%, 4Wt% & 5Wt%) are added in equal amounts as reinforcements and corrosion resistance of the generated hybrid composites. The density of hybrid composites made from A356 alloy reduces when RHA and Al2O3 particles in the alloy matrix rise. The heat treatment has a significant impact on the hybrid composites' corrosion resistance [19]. Stir cast Al 6082-SiC-Gr (Al-SiC-Gr) hybrid composites' two-body abrasive wear behaviour was investigated and compared to that of its matrix alloy and SiC reinforced composites. Wear improvementof Al-SiC-Gr composites at greater load and sliding distance was 16.4% and 27% in as cast and T6 heattreated condition, respectively. Due to the creation of a graphitic coating, which functions as a self-lubricant in Al-SiC-Gr composites, the addition of graphite has been found to be advantageous. improved wear resistance with anti-aging therapy. This might be the result of intermetallic precipitatesforming throughout the aging process [20].

III. METHEDOLOGY



IV. EXPERIMENTATION

IV. i. Stir casting

A mechanical stirrer is used in the stir-casting process to create a vortex that mixes the reinforcementwith the matrix material. Due to its low cost, suitability for mass production, simplicity, nearly net shaping, and ease of composite structure control, it is an appropriate procedure for producing metal matrix composites.

The stir-casting equipment includes a furnace, a feeder for reinforcement, and a mechanical stirrer. The ingredients are heated and melted in the furnace. At the bottom of the furnace an opening port is placedfor instant pouring, it is needed to prevent the solid particles from settling in the bottom of the crucible after stirring, in order to create the vortex that facilitates the mixing of the reinforcement materials added to the melted matrix, a mechanical stirrer is used. The impeller blade and the stirring rod make up a stirrer. The geometry and number of blades in the impeller might vary. With an axial flow patternin the crucible with less power consumption. The reinforcing powder is fed into the melt using a feederthat is also linked to the furnace. The blended slurry is then poured into a permanent mould.

IV. ii. Schematic of stir casting

The graphic illustrates the various phases involved in the stir-casting process. The matrix material is added and retained in the bottom pouring furnace, during this time the matrix starts to melt. In order to remove moisture, contaminants, etc., simultaneously the reinforcements are warmed at a specific temperature in a different furnace. After the matrix material is melted at a certain temperature, mechanical stirring is started and creates a vortex, after which the feeder is included in the setup to feedreinforcements at a constant rate into the center of the vortex. The stirring process is then continued forsome time. The liquid mixture is then put into a mould and let to cool down and solidify naturally. Additionally, post-casting procedures like heat treatment, machining, testing, and inspection have beencarried out.

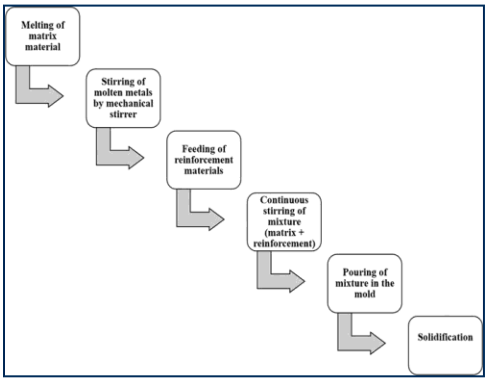


Fig. 1: Schematic of the casting process

Fig.2

Fig.3

Fig.2, Fig3: Casting process

IV. iii. Preparation of specimen

The moulted material is cut into pieces according to the required number of specimens which are required for all the testing procedures. The appropriate material should be compatible with the lathe and the desired specifications. Once the material is placed in the lathe, it is secured using a chuck or a collet. A Centre lathe is used for the process. The next step is to set the cutting tool at the correct angle and position, which is determined by the desired shape and size of the specimen. The cutting tool is then brought into contact with the material, and the lathe is turned on. The cutting tool is used to remove the excess material from the specimen, gradually shaping it into the desired form. Careful attention must be paid to the speed and feed of the lathe, as well as the depth of cut, to ensure that the specimen is shaped accurately and smoothly. Finally, the specimen is removed from the lathe and inspected for any defects or imperfections. If the specimen is perfect then the specimen is ready to be tested. The sampleswere 10 mm in diameter and 30 mm in length.

Fig. 4: Cut specimen

Fig. 5: Turning

Fig.6: Finishing

IV. iv. Hardness Testing (Vickers Hardness)

Vickers hardness test is a method used to measure the hardness of a material. It involves indenting the surface of the material with a diamond indenter in the shape of a square-based pyramid with a 136- degree angle between opposite faces. The hardness is determined by measuring the diagonal length of the indentation left on the material's surface. To perform a Vickers hardness test, the sample is prepared by polishing it to a mirror-like finish. The material is then placed on the stage of the Vickers hardness apparatus, and the load is applied to the indenter. The load is typically between 1 and 120 kilograms- force (KGF), depending on the material being tested.

The indenter is held in place for a specified period, usually between 10 and 15 seconds, to allow the material to deform. After the load is removed, the indentation is measured under a microscope to determine the length of the diagonals. The Vickers hardness number (HV) is calculated using the formula $HV = 1.8544P/d^2$, where P is the applied load in kgf and d is the mean diagonal length of the indentation in millimeters. The Vickers hardness test is a versatile and widely used method for measuring the hardness of metals, ceramics, and other materials. It is particularly useful for measuring the hardness of thin coatings and small parts, as well as for comparing the hardness of different materials.

Table. 1: Hardness of Al7075 alloy and composite specimens.

SPECIMEN	SPECIMEN COMPOSITION	HARDNESSVALUE
1	Al7075	73
2	Al7075+5%silicon nitride	81
3	Al7075+5%alumina	79
4	Al7075+2.5%silicon nitride+ 2.5%alumina	84

Fig.7: Vickers apparatus

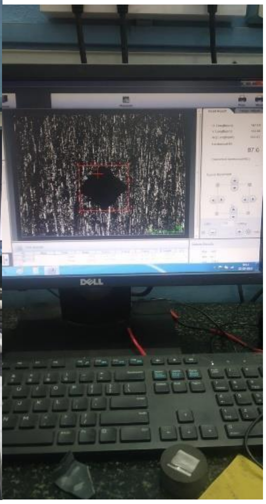


Fig.8: Dimond indentation

IV. v. Heat Treatment

Here, the muffle furnace was utilized for the heat treatment procedure. The fabricated composites weresubjected to heat treatment at different levels of temperatures and time intervals. The specimens are wrapped in aluminium foil and placed inside a ceramic bowl to prevent the formation of an oxide layeron the specimen surface before being put in the furnace. Later the specimens were placed inside the furnace for heat treatment. The aging treatment was conducted at three distinct temperatures (150^{o}, $175^{o}$and 200^{o}), and varying lengths of time (between 2 and 8 hours). After which the specimens were taken out and quenched in the quenching medium. Water kept at room temperature was used as the quenching medium. After being aged, the specimens were polished, and Vickers' hardness test was conducted andthe test results were obtained to determine the impact of heat treatment on composites.

Fig. 9: Muffle furnace

Fig. 10: Specimen inside the furnace

IV. vi. Hardness Testing After Heat Treatment

Heat treatment processes can significantly alter the properties of a material, including its hardness. Therefore, it is important to perform hardness testing after the heat treatment process to ensure that the material meets the required specifications. Overall, hardness testing is an important step in ensuring that heat-treated materials meet the required specifications for their intended applications.

Table 2: Hardness of heat-treated Al7075 alloy and composite specimens at 150°C

S.No.	Composition	Aged at2hrs (VHN)	Aged at4hrs (VHN)	Aged at6hrs (VHN)	Aged at8hrs (VHN)
1	Al7075	78	84.67	91.33	97.3
2	Al7075 + 5%Si3N4	88	93.67	96	103
3	Al7075 + 5%Al2O3	87.33	92	99.7	97.33
4	Al7075 + 2.5%Si3N4 + 2.5%Al2O3	93	95.33	99.67	101

Table 2 shows the hardness values of the specimens subjected to aging treatment at 150 °C. From the results, it is evident that the composite specimens respond faster to aging treatment than alloys. This effect is due to the presence of secondary reinforcement particles such as silicon nitride and alumina particles in the matrix that acts as nucleation sites for the formation of precipitates during aging. Therefore, a higher percentage of precipitate particles can be formed in the composite specimens than in the Al7075 alloy. Al7075 + 5% Si_3N_4 & Al7075 + 2.5%Si_3N_4 + 2.5%Al_2O_3 samples showed higher hardness among the analyzed specimens of about 103 & 101 HV after aging treatment. The formed precipitates also act as barriers to dislocation motion and thus contribute to the hardening of the alloy.

Table 3: Hardness of heat-treated Al7075 alloy and composite specimens at 175°C

S.No.	Composition	Aged at2hrs (VHN)	Aged at4hrs (VHN)	Aged at6hrs (VHN)	Aged at8hrs (VHN)
1	Al7075	91	93.67	96.3	98
2	Al7075 + 5%Si3N4	105.3	107	111.67	114.3
3	Al7075 + 5%Al2O3	97.6	102	108.7	112.3
4	Al7075 + 2.5%Si3N4 + 2.5%Al2O3	115.67	116.3	118	119.67

The hardness values after aging the samples at 175 °C are shown in Table 3. The reading shows that when Al7075 composites are aged at 175 °C, the rate of precipitation in the matrix is faster as compared to aging at 150 °C. Al7075 + 5%Si_3N_4 samples show a hardness value of about 88 HV when aged at 150 °C for 2 hours, whereas it shows a hardness of about 105.3 HV when aging is done at 175 °C. Similar observations are noticed in analyzed samples in all the composite samples. The effect of temperature during aging is not significant in Al7075 alloy in comparison to Al7075 composites. The maximum hardness achieved for Al7075 alloys after aging at 175 °C is 98 HV. Al7075 + 2.5%Si_3N_4 + 2.5%Al_2O_3 showed a maximum hardness of about 119.6 HV after aging at 175 °C for 8 hours. The presence of hybrid reinforcements like alumina & silicon nitride aid in the formation of precipitates during aging.

Table 4: Hardness of heat-treated Al7075 alloy and composite specimens at 200°C

S.No.	**Composition**	**Aged at2hrs (VHN)**	**Aged at4hrs (VHN)**	**Aged at6hrs (VHN)**	**Aged at8hrs (VHN)**
1	Al7075	**94**	**97.33**	**108**	**10.67**
2	Al7075 + 5%Si_3N_4	**109.7**	**112**	**116.67**	**113.33**
3	Al7075 + 5%Al_2O_3	**102**	**107.7**	**118.33**	**112.66**
4	Al7075 + 2.5%Si_3N_4 + 2.5%Al_2O_3	**118.67**	**119**	**123.7**	**120.33**

From Table 4, the peak hardness achieved for both Al7075 alloy and its composites is after aging for 6hours at 200 °C. The hardness values start to decrease when aging is done beyond 6 hours, leading to over aging phenomenon. The aging was not noticed in the 150°C and 175°C due to the lower temperature Therefore the aging time duration has to be restricted to 6 hours when aging is done at 200°C to achieve maximum hardness values. From the results observed, it can be concluded that Al7075 + 2.5%Si_3N_4 + 2.5%Al_2O_3 composite shows a maximum hardness of 123.7 HV when aging heat treatment is done at 200 °C for 6 hours, This aging temperature of 200 °C for 6 hours is the optimum aging cycle for both Al 7075 alloy and silicon nitride, alumina reinforced composites and hybrid composites resulted in superior hardness value when compared to the other composites.

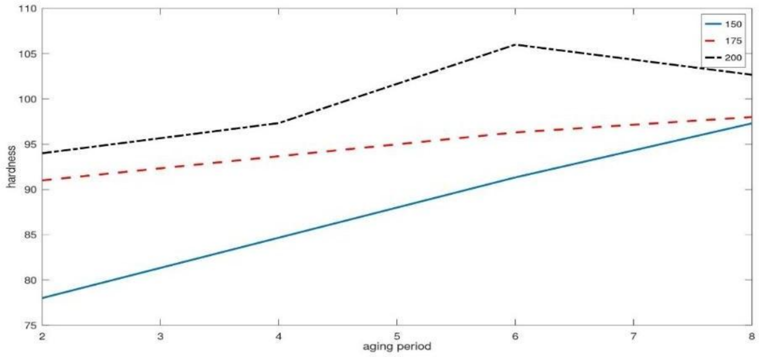


Fig. 11: Comparison of hardness values for Al7075 alloy at different aging duration

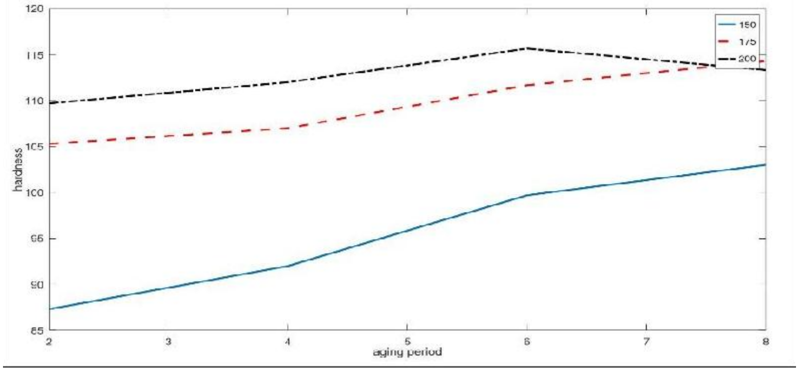


Fig. 12: Comparison of hardness values for Al7075 + 5%Si_3N_4 alloy at different aging duration

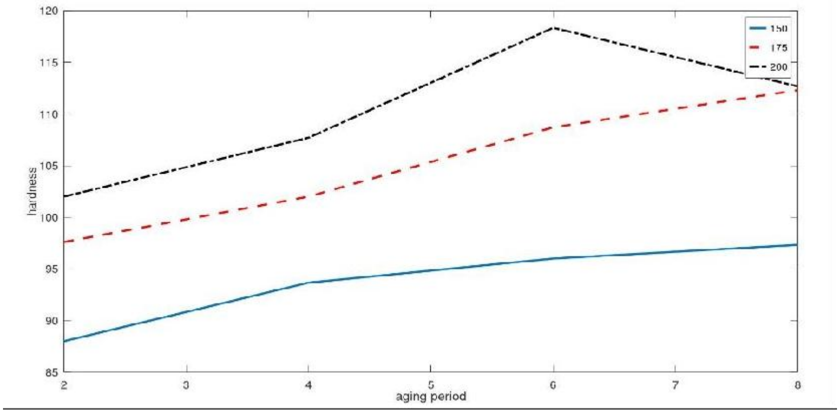


Fig. 13: Comparison of hardness values for Al7075 + 5%Al2O3 alloy at different aging duration

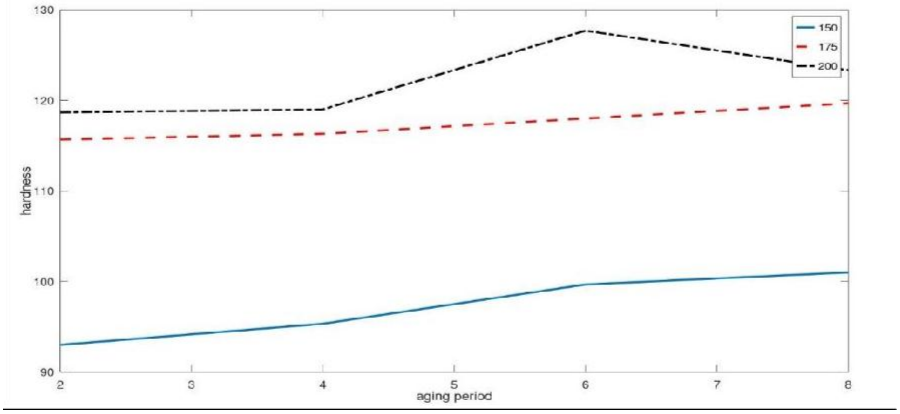


Fig. 14: Comparison of hardness values for Al7075 + 2.5%Si3N4 + 2.5%Al2O3 alloy at different agingduration

IV. vii. Wear Test

A wear test on a pin-on-wear disc apparatus is a method used to evaluate the wear resistance of materials. The wear test is carried out at 20 N load with a sliding distance of 1000m and 300 rpm. It is well known that hardness is directly proportional to wear resistance (i.e. higher the hardness, the higher the wear resistance). Since the hybrid composite (Al7075 + 2.5%Si3N4 + 2.5%Al2O3) portrays superiority in terms of hardness, its wear characteristics were evaluated specifically. The wear studies of the aged specimen for Al7075 + 2.5%Si3N4 + 2.5%Al2O3 sample is shown in Fig 15.

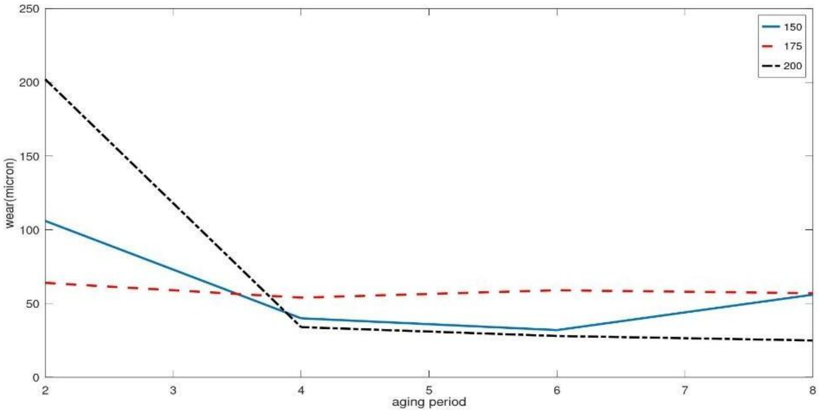


Fig. 15: Wear loss of Al7075 + 2.5%Si3N4 + 2.5%Al2O3

VI. CONCLUSION

The hardness of Al7075 composite specimens reinforced with silicon nitride and alumina possesses higher hardness, Compared with Al7075 alloy this is due to the presence of hard ceramic reinforcementsin the matrix. The optimum cycle for heat treatment of Al7075 hybrid composites is aging at 200 °C for 6 hours. The rate of precipitation during aging is significantly higher in Al7075 composites in comparison with Al 7075 alloy and the hybrid composite with 2.5% of silicon nitride and 2.5 % alumina reinforced Al 7075 composite exhibited a higher response to aging treatment and resulted in maximumhardness of about 123.7 HV.

VII. REFERENCES

[1] S. Arun Kumar, J. Hari Vignesh, and S. Paul Joshua, "Investigating the effect of porosity on aluminium 7075 alloy reinforced with silicon nitride (Si3N4) metal matrix composites throughthe STIR casting process," *Mater. Today Proc.*, vol. 39, no. xxxx, pp. 414–419, 2020, doi: 10.1016/j.matpr.2020.07.690.

[2] R. K. Nagula, "OPTIMIZING WEAR BEHAVIOR OF HYBRID AL7075," vol. 7, no. 15, pp.6341–6357, 2020.

[3] J. M. Mistry and P. P. Gohil, "Experimental investigations on wear and friction behaviour of Si3N4p reinforced heat-treated aluminium matrix composites produced using electromagneticstir casting process," *Compos. Part B Eng.*, vol. 161, pp. 190–204, 2019, doi: 10.1016/j.compositesb.2018.10.074.

[4] P. S. Raghavendra Rao and C. B. Mohan, "Study on mechanical performance of silicon nitridereinforced aluminium metal matrix composites," *Mater. Today Proc.*, vol. 33, no. xxxx, pp. 5534–5538, 2020, doi: 10.1016/j.matpr.2020.03.495.

[5] A. Pramanik, "Effects of reinforcement on wear resistance of aluminum matrix composites,"*Trans. Nonferrous Met. Soc. China (English Ed.*, vol. 26, no. 2, pp. 348–358, 2016, doi: 10.1016/S1003-6326(16)64125-0.

[6] E. Rajkeerthi, C. P. Satyanarayan, M. Jaivignesh, N. Pradeep, and P. Hariharan, "Effect of heattreatment on strength of aluminium matrix composites," *Mater. Today Proc.*, vol. 46, no. xxxx, pp. 4419–4425, 2019, doi:10.1016/j.matpr.2020.09.672.

[7] R. Pramod, G. B. Veeresh Kumar, P. S. S. Gouda, and A. T. Mathew, "A Study on the Al2O3reinforced Al7075 Metal Matrix Composites Wear behavior using Artificial Neural Networks," *Mater. Today Proc.*, vol. 5, no. 5, pp. 11376–11385, 2018, doi: 10.1016/j.matpr.2018.02.105.

[8] A. Lakshmikanthan *et al.*, "The effect of heat treatment on the mechanical and tribological properties of dual size SiC reinforced A357 matrix composites," *J. Mater. Res. Technol.*, vol.9, no. 3, pp. 6434–6452, 2020, doi: 10.1016/j.jmrt.2020.04.027.

[9] H. I. Akbar, E. Surojo, D. Ariawan, and A. R. Prabowo, "Experimental study of quenchingagents on Al6061–Al2O3 composite: Effects of quenching treatment to microstructure andhardness characteristics," *Results Eng.*, vol. 6, no. December 2019, p. 100105, 2020, doi: 10.1016/j.rineng.2020.100105.

[10] F. Chemmala, M. Anoop, P. Sinesh, S. Pc, and A. R. Ek, "Study the Mechanical Behaviour ofAl 7075 with Silicon Nitride by Computer Analysis & Stir Casting," *Int. J. Innov. Sci. Res. Technol.*, vol. 6, no. 6, pp. 293–296, 2021.

[11] S. K. Tiwari, S. Soni, R. S. Rana, and A. Singh, "Effect of Heat Treatment on Mechanical Properties of Aluminium alloy-Fly ash Metal Matrix Composite," *Mater. Today Proc.*, vol. 4, no. 2, pp. 3458–3465, 2017, doi: 10.1016/j.matpr.2017.02.235.

[12] K. H. W. Seah, "composites properties of as-cast and ZA-27 / graphite particulate," *Compos.Part A Appl. Sci. Manuf.*, pp. 251–256, 1997.

[13] E. Subba Rao and N. Ramanaiah, "Influence of Heat Treatment on Mechanical and Corrosion Properties of Aluminium Metal Matrix composites (AA 6061 reinforced with MoS2)," *Mater.Today Proc.*, vol. 4, no. 10, pp. 11270–11278, 2017, doi: 10.1016/j.matpr.2017.09.050.

[14] R. Yamanoĝlu, E. Karakulak, A. Zeren, and M. Zeren, “Effect of heat treatment on the tribological properties of Al-Cu-Mg/nanoSiC composites,” *Mater. Des.*, vol. 49, pp. 820–825,2013, doi: 10.1016/j.matdes.2013.02.026.

[15] R. R. Veeravalli, R. Nallu, and S. Mohammed Moulana Mohiuddin, “Mechanical and tribological properties of AA7075-TiC metal matrix composites under heat treated (T6) andcast conditions,” *J. Mater. Res. Technol.*, vol. 5, no. 4, pp. 377–383, 2016, doi: 10.1016/j.jmrt.2016.03.011.

[16] C. Velmurugan, R. Subramanian, S. Thirugnanam, and B. Anandavel, “Investigation of friction and wear behavior of hybrid aluminium composites,” *Ind. Lubr. Tribol.*, vol. 64, no. 3,pp. 152–163, 2012, doi: 10.1108/00368791211218687.

[17] M. Winnicki, M. Jasiorski, A. Baszczuk, and M. Korzeniowski, “Heat-treatment of aluminium-nickel composite cold sprayed coating,” *Coatings*, vol. 10, no. 6, pp. 1–15, 2020,doi: 10.3390/coatings10060581.

[18] M. J. Tan, L. H. K. Ka, K. Y. Murakoshi, and T. Sano, “Materials Processing Technology HEAT TREATMENTS IN ALUMINIUM-LITHIUM COMPOSITES EXTRUSION,” vol. 48,no. 1995, pp. 747–755, 1995.

[19] H. Gowda and P. R. Prasad, “Influence of Heat Treatment on Corrosion Resistance of A356/RHA/Al2O3 Based Hybrid Composites,” *Mater. Today Proc.*, vol. 4, no. 10, pp. 10870–10878, 2017, doi: 10.1016/j.matpr.2017.08.041.

[20] N. C. Kaushik and R. N. Rao, “The effect of wear parameters and heat treatment on two bodyabrasive wear of Al-SiC-Gr hybrid composites,” *Tribol. Int.*, vol. 96, pp. 184–190, 2016, doi:10.1016/j.triboint.2015.12.045.