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MACHINING PARAMETERS OPTIMIZATION IN TURNING OF ALUMINUM NITRIDE (ALN) PARTICULATE REINFORCED ALUMINIUM MATRIX COMPOSITES

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ABSTRACT

Aluminum composites have gained extensive notice in the material world and replaced the usage of ferrous materials. It was widely accepted in aerospace, space craft and army and navy applications as it is having moderate strength and fewer density. Preferring the operating parameters has an imperative part in producing the components with close tolerance and superior surface finish at the economic rate of machining. Identifying the appropriate machining parameters for a particular material is still the subject of the scientific group of people. The major contribution of the work is to optimize the machine operating parameters to diminish cutting force, flank wear and surface roughness in turning of Al-AlN composites. L27 layout was followed for experimental trails and Taguchi method was employed for optimization. Experimental result demonstrates that the feed rate has strongest effect on cutting forces and surface roughness whereas reinforcement ratio has strongest effect on flank wear.

Keywords: *Alunimium Nitride****,*** *Composites, Turning, Cutting force, Flank wear, Surface roughness, Optimization.*

1. Introduction

The benefits of the contemporary composite material are strength to weight ratio, tailorability and castability. Aluminum composites have enormous potential for weight reduction when compared to ferrous materials [1-2]. The density of aluminum alloy is about 2.7g/cm3 whereas the approximate density of ferrous material is 7.87g/cm3. Corrosion resistant ability of this material is treated as an additional advantage. Desired properties of the composites can be developed by selecting an appropriate blend of ductile and ceramic phases in order to match the applications [3-4]. Composite material has the ability to form complex shape from its liquid state. Though the composites have demonstrated their merits as a potential for weight saving, the recent confront is to manufacture the component in cost effective manner. The existence of the ceramic phase in the material offers considerable inconvenience to convert them into desired size and shape [5-6]. In recent days, the dimensional accuracy and surface finish are believed as criteria for attracting the customer. Machining is an inescapable process in acquiring the dimensional accuracy and surface finish. The ceramic phase present in the material damages the cutting edge of the tool and enhances the cost of tooling. Surface finish of the components plays an influential role in deciding the service life of the components [7-8]. The rough surface often initiates the crack while the component is in loading conditions. Excessive action of the machining load rather than the necessary load induces the residual stress formation on the machined surface. Residual stress formation is unsafe for the component while it is in service. As a result, the cutting force, tool wear and roughness of the surface are considered as an index for assessing the machinability.

Greater machinability offers cost effective machining along with desired surface finish. The volume content and size of the ceramic phase also plays a vital role for deciding the ease of machinability. Relatively larger size particle damage cutting tool and alter the geometry of the tool thereby spoils the machining efficiency and surface finish. Excessive volume content of the ceramic phase develops hardness of the work and unevenness on the work surface. Machining of materials with higher volume of ceramic requires frequent tool re-sharpening in turn extend the manufacturing time. At the same time, the control of

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dimension and surface finish become tedious for machining such a material with strange characteristics. Therefore, the volume content of the ceramic phase are also accounted as factor along with
cutting speed and feed rate of machining. The machining responses to gauge the machinability of the material are preferred as cutting force, flank wear and surface roughness. AlN is recognized as a novel high density wrapping material, since it has tremendous thermal conductivity, fabulous high electrical insulation and smaller dielectric constant [9]. AA 6061 is an undeniable material for shipment, petro chemical and aerospace sectors because of its lesser density, enormous impact toughness, admirable machinability and outstanding corrosion resistance [10].

Fogagnolo et al produced the AlN reinforced composite by the series of process including mechanical alloying Al and AlN powders, cold pressing of the mixtures and hot extrusion process. The developed composite has outstanding distribution of AlN along with greater mechanical properties[11]. Caballero et al developed the Al-AlN composites by reacting the ammonia gas with ball milled aluminum powder in the vacuum atmosphere [12]. Fale et al established a method to fabricate the Al-AlN composites by in-situ reaction of NH_4Cl and CaO with aluminum melt [13]. It seems that the aforesaid process have suffered with the limitations including more number stages and controlling the chemical reaction apart from cost and difficulty for mass production. Among the many process, the stir casting process has plenty benefits such as cost effectiveness, suitability for bulk production, ability to make complicated profiles [14].

However, the attainment of uniform distribution of distribution, porosity and wettability between the matrix and ceramic are herculean task in stir casting process. Uniform feeding of ceramic phase and continuous stirring of melt are considerable activities to overcome these challenges [15]. Nassaj et al achieved the improved wettabiliy of AlN with aluminum by introducing the magnesium powder into the aluminum melt [16]. Ashok Kumar and Murugan produced AA6061-AlN composites by specially made stir casting process with bottom pouring attachment. The characterization report reveals that the reinforcement distributions are homogeneous and clear interface between the ceramic and matrix phase. This micro structural possession brings over 46 % enhancement in tensile strength when compared to matrix alloy[17]. Said et al performed a chip formation study in milling of Al-SiC/AlN composites.

Crescent shaped elemental chips are formed during machining. Scanning electron microscopic study of chip shows that the micro cracks at outer side of chip as a mark of greater shear stress [18]. Tomadia et al developed a mathematical model to envisage the surface roughness by means of regression analysis in terms of coating type, speed of cutting, rate of feed, cutting depth and volume content of reinforcements in milling of Al-Si/AlN composites. The variance analysis indicates that the coating type has momentous consequence in generating surface roughness [19]. Review of literatures illustrates that the turning studies of the Al-AlN composites have received incredibly inadequate notice of the scientific community. Turning is a fundamental machining operation to translate the composite sample into the desired component. Machinabilty characteristics of Al-AlN composite by means of turning operation remain insufficiently understood and must be deliberated further.

2. Materials and Methods

A mould with the dimension of 52 mm diameter and 320mm length was prepared using cast iron. The crucibles are kept in the electric furnace for removing the moisture present in the crucible. After getting heated up the AA6061 aluminum rods were placed in the preheated crucible. Further, the aluminum rods were heated up to 750º C to reach the required fluidity. The preheated and premeasured quantity of AlN powder of 30µm size was introduced into the aluminum melt. AlN-Aluminium melt was stirred thoroughly to get homogeneous distribution of the AlN particle. Finally, the melt was poured into the cast iron mould. After solidification, the composite samples separated from the mould.

The EDAX pattern and microstructure of the 2.5 % reinforced composite was presented in the (Figs.1. & 2.) L27 layout was followed for experimental work and Taguchi method was adopted for optimization. The operating parameters and their levels are illustrated in the Table 1. Photographic view for the experimental setup was exposed in (Fig. 3) Ra values of surface roughness were measured by using surface roughness tester (SJ210 Model, Mitutoyo). Cutting forces were measured by using dynamometer (Kistler type, Model 9257B,Karunya University, Coimbatore) whereas the flank wears are measured by profile projector (Metzer METZ 200 T.T). Surface roughness was measured as µm, flank wear was measured as mm and cutting force was measured as Newton. Surface roughness, cutting force and flank wear for each trail measured and reported for analysis.

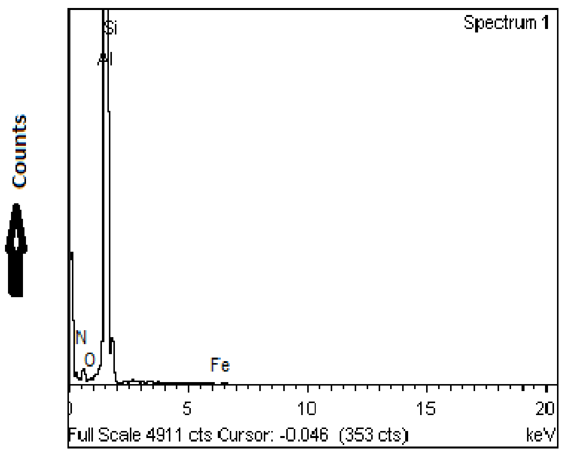

Fig. 1: EDAX pattern of 2.5 % composite

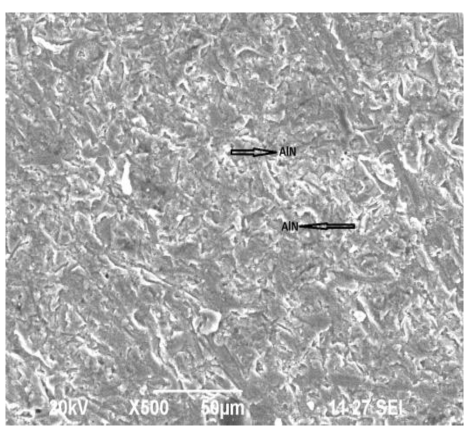

Fig. 2: SEM micro graph of 2.5 % composite

Fig.3: Experimental setup

Table 1. Parameters and their levels

Parameters	Units	Levels		
		Level 1	**Level 2**	**Level 3**
Cutting speed	m/min	50	75	100
Feed rate	m/min	0.1	0.15	0.2
AlN content	%	2.5	5	7.5

3. Results and Discussion

AA6061-AlN ex-situ composites are machined under various parameters and surface roughness, cutting force and flank wear were recorded. These responses analyzed using Taguchi technique using MINITAB-18 package. The optimal combination of parameters and volume content were identified by using response graph. Further, the analysis of variance was carried out to spot the most influential parameter for each response. The (Fig. 4) depicts the response graph generated for the surface roughness. It is understandable from the (Fig. 4) the raise of cutting speed decline the surface roughness. At higher cutting speed, the chip tool contact length would be least. This mechanism diminishes the surface finish at greater cutting speed [20]. A hike of feed rate enhances the surface roughness. The chatter at the machining would be greater when increasing the feed rate in turn move up the surface roughness. The surface roughness was increased by enhancing the volume content from 2.5 % to 5%. On the other hand, the surface roughness decreased by growing the volume content from 5 % to 7.5 %. Analysis of the variance for the surface roughness was performed and presented in the Table 2. Result of the variance analysis illustrates that the cutting speed, feed rate, % AlN influences surface roughness by 24.56%, 66.61% and 7.47% respectively. From the aforesaid result, the feed rate has the strongest influence on surface roughness than cutting speed and volume content of AlN.

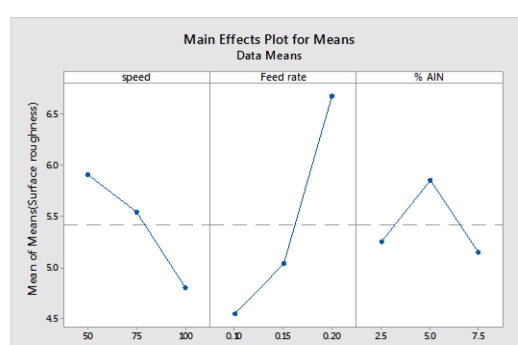

Fig. 4 Response graph for surface roughness

Table 2. Analysis of variance (ANOVA) for surface roughness

Source	DOF	Seq SS	Adj SS	Adj MS	% of contribution
Speed	2	18.6728	18.672	9.3364	24.56
Feed Rate	2	50.6152	50.615	25.3076	66.61
%Al N	2	5.677	5.677	2.8388	7.47
Error	20	0.3293	0.329	0.0412	1.36
Total	26	75.9869			100

The (Fig.5) depicts the response graph generated for the cutting force. It is explainable from the (Fig.5), the lift up of cutting speed turn down the cutting force. Development ductility at the higher cutting speed due to the thermal influence reduces the cutting force. Force along the axis of job would be higher when increasing the feed rate in turn raises the cutting force. The cutting force was decreased by escalating volume content from 2.5 % to 5% whereas the cutting force increased by raising the volume content from 5 % to 7.5 %. Variance of analysis for the cutting force performed and displayed in the Table 3. Result of variance analysis indicates that that the cutting speed, feed rate and % AlN on cutting force 9.78 %, 83.03 % and 2.18 % respectively. It is clear from the above analysis the feed rate has the maximum effect on cutting force than other parameters.

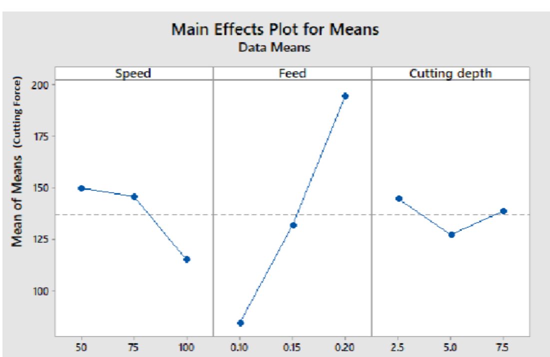

Fig. 5 Response graph for cutting force

Table 3. Analysis of variance (ANOVA) for cutting force

Source	DOF	Seq SS	Adj SS	Adj MS	% of contribution
Speed	2	2158.9	1079.4	539.725	9.768778
Feed Rate	2	18351.2	9175.6	4587.8	83.0371
%Al N	2	482.1	241.05	120.525	2.181448
Error	20	1107.8	553.9	276.95	5.01267
Total	26	22100			100

The (Fig. 6) represents the response graph generated for the flank wear. It is obvious from the (Fig. 6) the lift up of cutting speed from 50 m/min to 75 m/min increases the flank wear whereas the flank wear was reduce when shifting the cutting speed from 75 m/min to 100 m/min cutting force. The reduction of flank at cutting speed may be attributed that the reductions in chip-tool contact length. As the feed rate raises, the flank wear found increased. The friction at the machining interface is more when raising the feed rate. This mechanism turn up the flank wear at greater feed rate. It is observed from the (Fig. 6) an increasing trend of flank wear when raises the volume content of the reinforcement. It may be attributed that the higher reinforcement ratio spoils the cutting edge in turn raises the flank wear. Analysis of variance was performed for the flank wear and tabulated in the Table 4. The analysis exemplifies that the cutting speed, feed rate and %AlN influences the flank wear 4.34%, 14.58% and 76.12% respectively. Further, it can be noted that the reinforcement ratio(%AlN) has the strongest effect on flank wear than cutting speed and feed rate. Higher volume content of the AlN contributing excessive friction to the cutting edge than other parameters.

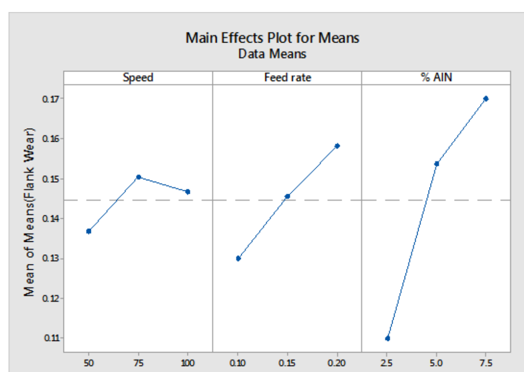

Fig. 6 Response graph for flank wear

Table 4. Analysis of variance (ANOVA) for flank wear

Source	DOF	Seq SS	Adj SS	Adj MS	% of contribution
Speed	2	4.0842	4.0842	2.0451	4.34
Feed Rate	2	13.8469	13.846	6.9235	14.58
%Al N	2	72.3011	72.301	36.1505	76.12
Error	20	2.316	2.316	0.2895	4.96
Total	26	94.9714			100%

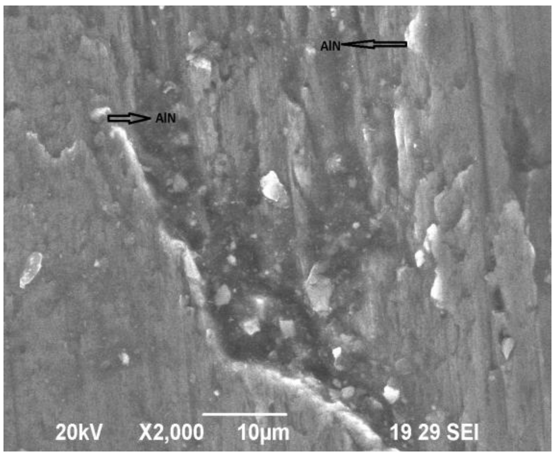

Fig. 7 Machined surface at optimum surface roughness

The surface texture analysis was carried out at optimum turning conditions ie.100m/mim,0.1 feed rate and 7.5 % reinforcement ratio and illustrated in the Fig 7. At 2000 magnification, a deep groove, delamination marks and smearing can be seen in the Fig.7. The influence of thermal heat at higher cutting speed offers considerable ductility to the work piece and facilitate ductile mode of material removal. Existence of the broken AlN particle in the machined surface indicates the good interfacial bonding between the AlN and AA6061 matrix. Smaller chip-tool interface at higher cutting speed dominates the surface generation process despite the consequences of volume fraction of the composite. Further, the lesser feed rate supports for particle fracture rather than the particle pulling. Hence, the minor chip-tool contact, smaller buildup edge formation due to greaterreinforcement ratio, lower tool wear and particle fracture mechanism at 100m/mim, 0.1 feed rate and 7.5 % reinforcement ratio provides optimum surface finish.

4. Conclusion

The turning operation was performed on AA 6061-AlN ex-situ composite and cutting force, surface roughness and flank wear is evaluated under various machining conditions. The optimal run within the levels of parameters were established from the response graph and analysis of variance also performed for each responses. On the basis of response graphs and analysis of variance, the subsequent conclusions are obtained.

- •At 100 mm/min, 0.1 mm/rev feed and 7.5% reinforcement is an optimal run for achieving the surface roughness.
- •At 100 mm/min, 0.1 mm/rev feed and 5% reinforcement is an optimal run for achieving the cutting force.
- •At 50mm/min, 0.1 mm/rev feed and 2.5% reinforcement is an optimal run for achieving the flank wear.
- •Feed rate has the highest influence on cutting forces and surface roughness.
- •Reinforcement ratio has the strongest influence on flank wear.
- •Surface defects like micro groove, delamination and smearing are observed even at optimal machining condition for surface roughness
- •Minor chip-tool contact, smaller buildup edge formation due to greater reinforcement ratio, lower tool wear and particle fracture mechanism supports for better surface finish.

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