Journal of Mines, Metals and Fuels, 71(3): 351-358; 2023. DOI: 10.18311/jmmf/2023/33719

Print ISSN : 0022-2755
Journal of Mines, Metals and Fuels
Contents available at: www.informaticsjournals.com/index.php/jmmf

Analysis of Al-Li Alloy Machinability Characteristics for Better Surface Smoothness using the Taguchi Method

Rajeesh S[1*], Anoop Bagali[2], Bhuvan D[2], Bose JS[2] and Gnyaneshwar Nayak[2]

*[1]Assistant Professor, Department of Mechanical Engineering, Ramaiah Institute of Technology, Bengaluru, Karnataka, India. *E-mail: rajeesh@msrit.edu*
[2]Under Graduate Studens, Department of Mechanical Engineering, Ramaiah Institute of Technology, Bengaluru, Karnataka, India. E-mail: annopbagali97@gmail.com, bhuvand2000@gmail.com, gnynnayak205@gmail.com, bose2000shekar@gmail.com

Abstract

Al-Li alloys are 20% lighter than conventional high-strength aluminium alloys and have higher standards for wear and damage tolerance. However, while possessing a low density, they have excellent yield and strengths. When it comes to use in aerospace and defense applications, it will soon displace other materials as the favoured material. The focus of the current research is on the optimal parameters that influence surface hardness and roughness in a variety of machining operation settings.

Al-Li alloy 2099 (94.309 of Al & 5.691% Li alloy) was machined using Sol XL coolant (1:20 water based) and the following settings: speed range 3000-6000 rpm, feed rate 150-450 mm/min, depth of cut 0.1-0.2 mm. The Taguchi method with the Signal-to-Noise (S/N) ratio for process optimization. was used to record data for the milling of Al-Li alloy with variable factors on a Hartford Omins VMC 1270 CNC machine utilising a 16mm flat Widia ALUFLASH series 3AN9 solid carbide tool. According to the Taguchi method, the cutting parameters of RPM (4000 rev/min), feed rate (300 mm/min), depth of cut (0.15 mm), and coolant gave the best surface smoothness and hardness. Therefore, in order to reduce the expense and duration of the experiment, the optimal setting levels of the process parameters reported in this work might be applied to the machining of Al-Li work pieces that are utilised in aircraft and aerospace components.

Keywords: *Al-Li alloys, Machining Parameters, surface hardness and roughness, Taguchi Method Formation of a large-scale collapse are on the surface, which*

1.0 Introduction

The diversity of materials used in aircraft. Some of the crucial requirements in the material for aircrafts include mechanical, physical, and chemical characteristics like high strength, stiffness, fatigue durability, damage tolerance, low density, high thermal stability, high resistance to corrosion, and oxide resistance, as well as commercial criteria like cost, servicing, and manufacturability. For instance, during service, wings typically endure bending as well as stress, torsion, vibration, and fatigue. As a result, the main restrictions for wing materials are stiffness, tensile strength, compressive strength, buckling strength, and vibration. The most commercially used materials are aluminum alloys, composites, titanium alloys and high strength steels in Boieng 747 and Boieng 787 is shown in Figures 1a and 1b. Forty years ago, more than 70% of material used in an aircraft was aluminum but nowadays less than 20% aluminum is used. The alternative material replacing

---

[*] *Author for correspondence*

aluminum is composites because of development of high-performance composites with improved played a great role in promoting the development of the national economy. At the same time, the development of mineral resources has also brought severe environmental problems to society and mankind (Suand Zhang, 2013). The long-term exploitation of resources in the mining are a leads to the seriously affects the environmental protection and safety production of the mining area. Therefore, it is very necessary to analyze the characteristics of surface collapse in goaf and study the degree of surface collapse damage to guide the safe excavation, surface collapse treatment and sustainable development of mining area.

In many aircraft structural applications, such as the fuselage skin, upper and lower wing skins, and wing stringers, advanced aluminium alloys are a common lightweight material choice. These alloys have a low price, strong ductility, good corrosion resistance, reasonably high specific strength and stiffness, good manufacturability, and outstanding reliability. Between 70 and 80 per cent of the structural weight of aero planes are made up of aluminium. Aluminum can now compete with composites because to developments in heat treatment technologies[1,2].

High strength steels are the least expensive material used in commercial aero planes and have the best dimensional properties at high temperatures in addition to having extraordinarily high strength and stiffness. The major applications in aircrafts are gearing, bearings, undercarriage and other safety critical components. Typically, 5–15% of an airplane's structural weight is made up of steel. Due to its high density and other drawbacks, such as its relatively high susceptibility to corrosion and embrittlement, steel usage is steadily declining.

Bois Brochu et al[3,4,5,6] examined the static mechanical properties of extruded parts made of Al-Li 2099-T83, comprising a cylindrical extrusion and an integrally stiffened panel. When tested for tensile and compressive strength, both types of extrusions show anisotropy.

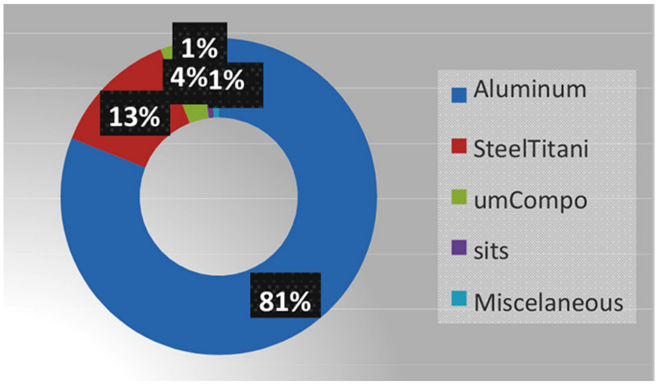

Figure 1a: Material distribution for Boeing 747

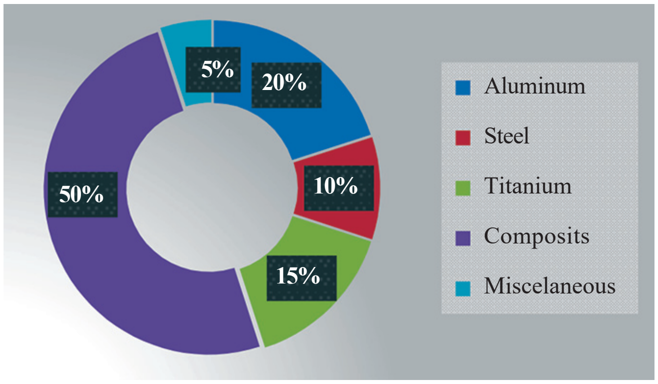

Figure 1b: Material distribution for Boeing 787

Titanium alloys are used mostly in aircraft's airframe, which accounts for 7% of the total weight and engine components, which account for 36% due to high specific strength, moderate thermal expansion, and resistance to cryogenic embrittlement. The limited use of titanium alloys is due to their poor manufacturability and expensive cost (which is typically roughly 8 times that of commercial aluminium alloys).

At mild temperatures, the aerospace composites utilised in the LCA Tejas offer higher specific stiffness and strength than most metals. Improved fatigue resistance, corrosion resistance, and moisture resistance are further benefits of composites. Lay ups can also be customised for the best strength and stiffness in the necessary directions. Fiber reinforced composites and fiber metal laminates are the two high performance composites that are most frequently employed. The structural wing box, empennage, and fuse lage components as well as control surfaces (such as the rudder, elevator, and ailerons), radomes, fairings, etc. are all examples of where composite materials are used in aircraft. One of the biggest barriers to the use of composites is their higher cost when compared to metals.

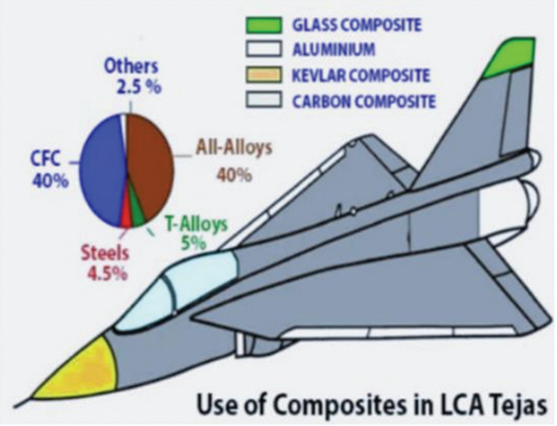

Figure 2: Material distribution in LCA Tejas

According to an analysis by Seth Schlatter et al[7] Al-Li alloys of the first, second, and third generations all had serious problems with their mechanical properties, which led to their limited application. Aluminum-lithium alloys may entirely replace traditional alloys due to these Al-Li alloy problems and the advantages of lower cost.

The main problem with Al-Li alloys, which was addressed by Ali Abd El-Aty et al[8], is anisotropic behaviour. The main causes of the anisotropic tensile properties and workable solutions to reduce anisotropic behaviour are discussed with reference to composition, processing, and interactions between the microstructures, as well as approaches for enhancing the formability, strength, and fracture toughness of Al-Li alloys.

Using variable spindle speed, feed rate, and depth of cut, experimentation was conducted to find the best conditions for machining aluminium 6061 alloys' surface roughness in CNC milling operations by Nathan Hanapalan, G. Thanigaiyarasu et al[9], Arkadeep Bandyopadhyay et al.[10] using Mini Tab 18 software and C.C.Tsao et.al[11] and Maiyar, Lohithaksha[12] using Grey Taguchi method.

Aluminum lithium alloy was machined under liquid nitrogen and air coolant conditions by Haikuo Mou, Xinda Huang et al[13]. Roughness and residual stress are quantified as aspects of surface integrity. The findings demonstrate that the creation of surface finish is mostly influenced by the angle between feed direction and rolling orientation. The outcomes also show that liquid nitrogen has the ability to improve the integrity of the surface, which is followed by an increase in the rate of material removal during face milling of an aluminum-lithium alloy.

Mário C. Santos Jr. et al.[14] claim that the major problems only occur in alloys containing hard SiC or Al_2O_3 particles or alloys with high Si contents (above 7.5%wt.) are Strong ductility and the material's propensity to stick to the surface of cutting tools are the usual causes of issues. This is also the reason for another problem that frequently occurs when drilling these materials: the surfaces of the drills stick to them, especially those made of high-speed steel and cemented carbide (but much less so on drills coated with PCD), clogging their grooves, increasing torque, and possibly even leading to tool failure. Using the appropriate cutting tools, cutting conditions, lubrication, and cooling systems are essential for a successful operation. The ideal tools are made of high-speed steel, PCD synthetic diamond, and N grade cemented carbide (both solid and coating).

M. Azizur Rahman et al.[15] studied the aluminium alloy chip formation in various machining strategies (i.e., micro and macro cutting) in order to create a comprehensive understanding of the chip formation phenomenon and the mechanics of surface production in machining. In both traditional macro and ultra-precision micro machining techniques, experiments were conducted to assess the feed rate response (FRR). In depth research was done to examine the mechanics of material removal using both theoretical and experimental data. The results showed how feed rate affects orthogonal turning by varying chip morphology. The transition from discontinuous to continuous chip production — a notable phenomenon in micro-machining – has been identified for the conventional macro machining of Al alloy.

Rajesh Kumar Bhushan et al[16] made an effort to investigate the effects of cutting speed, depth of cut, and feed rate on surface roughness through the machining of 7075 Al alloy and 10 wt.% SiC particulate metal-matrix composites. The tests were performed using a CNC turning machine with inserts made of polycrystalline diamond (PCD) and tungsten carbide. In comparison with surface roughness at other process parameters taken into account, it was discovered that surface roughness of 7075Al alloy with 10 wt% SiC composite was reduced in the feed range of 0.1 to 0.3 mm/rev and depth of cut (DOC) range of 0.5 to 1.5 mm. The wear of tungsten carbide and PCD inserts was investigated using metallurgical and scanning electron microscopes.

2.0 Materials and Methodology

2.1 Material and Specimen Preparation

Alcoa developed Al-Li Alloy 2099 for use in aerospace and high strength applications where low density, high stiffness, enhanced damage tolerance, great corrosion resistance, and weldability are required. It has high strength, excellent corrosion resistance, and mild fracture toughness. Li additions increase the strength and modulus of Al alloys while decreasing their density. A sample of 1 inch by 1 inch was provided to BUREAU VERITAS, Bangalore, for the chemical composition analysis of the 2099 Al-Li alloy slab. The testing facility where the spectroscopy device was used to evaluate the chemical composition. The chemical composition and mechanical properties along the longitudinal direction of Al-Li alloy 2099 used for testing specimen are given in Tables 1 and 2.

Preparation of Al-Li alloy Specimen: The Hardford Omnis vertical milling center (VMC)1270 machine as shown in Figure used for machining of 2099 Al-Li work piece is because it is able to perform high speed machining.

The Hardford Omnis VMC 1270 is an open-fronted vertical machining centre with four shear box guide ways that have been toughened and machined to improve accuracy and cutting performance. Its heavy duty cast-iron bed is made in one piece for exceptional precision and rigidity. Aluminum alloys can be milled using a variety of cutting tool materials, including tool steel, high speed steel, cemented carbide, and diamond. Due to the relatively short tool life and the strong chemical affinity between ceramic matrix and aluminium alloys,

Table 1: The chemical composition of Al-Li alloy 2099

Element	Manganese	Silicon	Zinc	Lithium	Titanium	Zircon	Iron	Copper	Magnesium
Wt %	0.33	0.053	0.62	1.62	0.018	0.074	0.046	2.69	0.24

Table 2: The mechanical properties of above compositional Al-Li 2099 alloy

	Tensile strength (MPa)	Yield Strength (MPa)	Elongation %	Toughness (MPa√m)	E(tension) (GPa)	Density (g/cm^3)
Thicknessrange (mm) 12.7 to 25.374	560	525	9	-	78	2.63
Thicknessrange (mm) 5.4 to 63.5	595	505	9	30	78	2.63

it is not recommended to mill aluminium alloys using ceramic tools. The similar behaviour is seen when machining aluminium alloys with cubic crystalline boron nitride (CBN) tools[17]. Despite the fact that coated inserts are utilised to slow down tool wear, when the coated insert is made of titanium, this could be detrimental to the tool. Titanium in the coating could lead to tool failure quickly and diffusion.

Widia ALUFLASH series 3AN9 solid carbide end mill as shown in Figure 3 was used for performing slot milling on Al-Li work piece. This tool has the capability of machining of aluminum alloys at higher speeds.

The machining technique uses SolXL, a high performance, water-soluble, and exceptional emulsifying cutting oil manufactured from a fine petroleum base and special emulsifiers. Up to 600 parts per million, it is easily miscible in water and forms a solid, stable emulsion. Rust, bacteria, and biodegradation cannot harm it since it has biocides and inhibitors that prevent them. Despite varying working circumstances from job to job and from water to water as well as the necessity for varied mix ratios, the usual mix ratio used in the machining of Al-Li alloy is 1:20.

Hardford Omnis vmc1270CNC machine slot milling was performed on the 26 mm thick 2099 Al-Li slab using Widia ALUFLASH series 3 AN916 mm solid carbide end mill cutter at different machining parameters in order to evaluate the surface integrity of the slots and to find out the optimal cutting parameters. Nine slots were milled at the top surface of the slab with equal spacing of 14 mm and then another nine slots were milled at the bottom surface with equal spacing of mm as shown in Figures 4 and 5. High spindle speed and seed was employed in order to analyse the effect of high-seed machining on 2099 Al-Li alloy and also very high cutting speeds are needed to get good results during machining of aluminum alloys.

The other experimental variables, including coolant type, cutting tool specifications (number of teeth (3), diameter (16mm), and shape (solid carbide), were considered as

Figure 3: Hardfordvmc1270 nachine

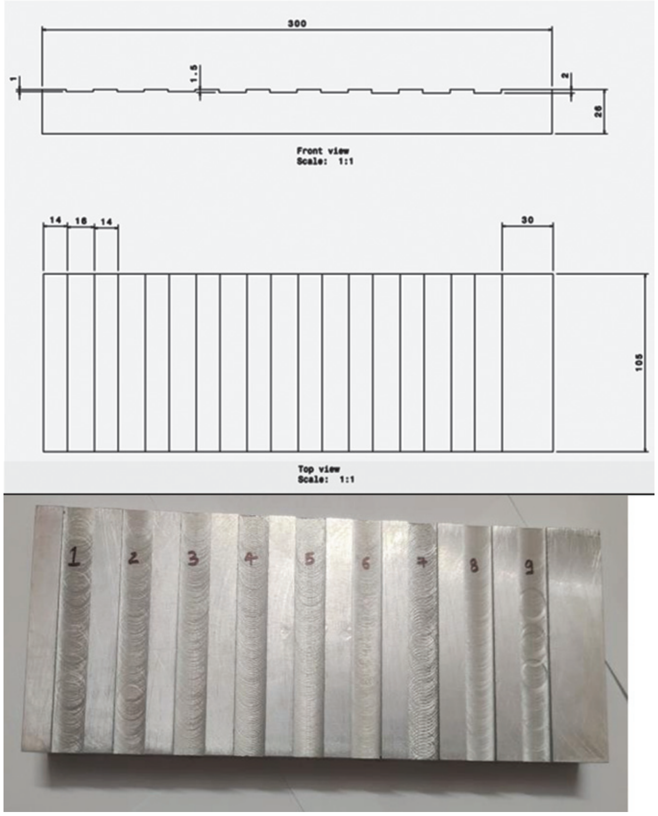

Figure 4: Nine slots milled at the top surface ofAl-Li work piece

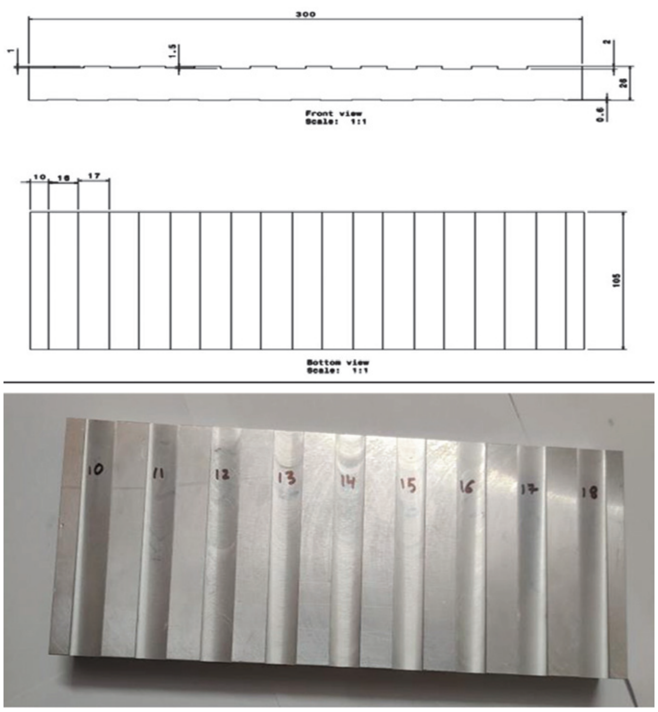

Figure 5: Nine slots milled at the bottom surface pfAl-Lislab

constant variables[18]. The cutting parameters of the 18 slots milled at the top and bottom surface of Al-Li slab are shown in Table 3.

2.2 Measurement of Surface Roughness

The surface roughness of the only nine slots which were machined using different machining parameters at the bottom surface of the slab was determined with the help of TIME 3200 surface roughness tester (TR200) as the surface roughness of the other nine slots at the top surface of the slab could not be determined due to high surface roughness and the tester could be damaged. Three readings of the surface roughness for each slot are measured at different positions in the slot.

The time 3200 model surface roughness tester (TR200), which is more affordable and more accurate, is used to measure surface roughness.

Figure 6: TIME 3200 surface roughness tester (TR200)

Table 3 The cutting parameters of the 18 slots milled at the top and bottom surface of Al-Li 3.

	Speed (rpm)	Feed (mm/min)	Depth of cut (mm)
Top Surface			
1	1000	500	0.5
2	2000	1000	0.5
3	3000	1500	0.5
4	1000	1000	0.75
5	2000	1500	0.75
6	3000	500	0.75
7	1000	1500	1
8	2000	500	1
9	3000	1000	1
Bottom surface			
10	10	4000	150
11	11	4000	300
12	12	4000	450
13	13	5000	150
14	14	5000	300
15	15	5000	450
16	16	6000	150
17	17	6000	300
18	18	6000	450

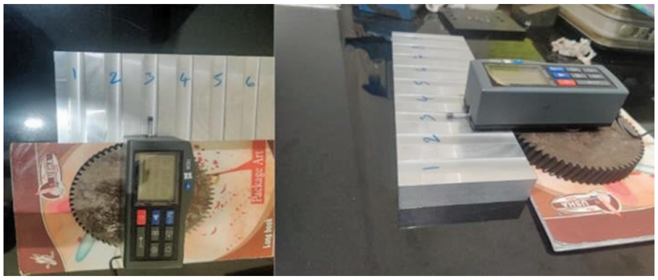

Figure 7: Surface roughness determined with the help of TIME3200 surface roughness tester (TR200)

3.0 Result and Discussion

Al-Li alloy 2099 was machined with the following settings: speed range of 3000-6000 rpm, feed rate 150-450 mm/min, depth of cut 0.1-0.2 mm, and Sol XL coolant (1:20 water based). Data for the milling of Al-Li alloy with different variables were recorded using the Taguchi method with the

Table 5: The result of surface roughness

Expt.No.	Speed (rpm)	Feed (mm/min)	Depth of cut (mm)	Mean Ra (µm)
1	4000	150	0.1	0.282
2	4000	300	0.15	0.471
3	4000	450	0.2	0.58
4	5000	150	0.15	0.476
5	5000	300	0.2	0.433
6	5000	450	0.1	0.536
7	6000	150	0.2	0.447
8	6000	300	0.1	0.473
9	6000	450	0.15	0.481

Signal-to-Noise (S/N) ratio[20,21,24] for process optimization on a Hartford Omins VMC 1270 CNC machine using a 16mm flat Widia ALUFLASH series 3AN9 solid carbide tool[9,10,12]. Minitab software has been used to study the primary influencing elements of surface roughness. The most effective parameters were determined using analysis of variance (ANOVA)[22].

The results of the surface roughness and signal-to-noise ratio of nine slots that were drilled in accordance with chosen parameters are shown in Table 5. Referring to Table 5, the graph illustrates that the minimal surface roughness was measured at 0.282 m with Level 1 spindle speed, Level 1 feed rate, and Level 1 depth of cut (0.1 mm). Level 1's 150 mm/min feed rate contributes to the greatest value of Mean Ra. The highest value indicated for spindle speed is level 1 (4000 RPM). The depth of cut graph indicates that level 1 has the highest value (0.1 mm). In other words, the experiment's ideal parameter is determined by the lowest value is by combination (4000RPM, 150mm/min, 0.1mm)[14,15,19].

The response tables for means and signal to noise ratio are shown in Tables 6 and 7. According to Table 6, feed rate holds the top spot, indicating that it is the crucial variable that most significantly influences surface roughness. The depth of cut and spindle speed come next. Table 7 however displays the response table for the signal to noise ratio. The outcomes are in line with the study from Table 6, where the feed rate has the biggest delta (2.644) and is ranked highest, followed by depth of cut and spindle speed. Similar to other processes for removing material, the performance of surface roughness in milling is highly correlated with the interplay between spindle speed and feed rate. When the cutting tool comes in contact with the work piece, the spindle's rapid rotation raises the temperature in that area, causing the material to thermally soften. In such circumstances, the thrust forces can be reduced, the machine can feed tools with less energy, and the surface finish may be improved[19,26]. The work piece could be deformed by the tool's thrust force if the feed rate was too high, which would impair the surface finish. The study of Table 7 shows that feed rate is the first-best component. Effect of changing the cutting speed in Figure 8 (a) shows that when the spindle speed is increased from 4000 rpm to 5000 rpm, the surface roughness increases. Surface roughness, however, somewhat decreased when the surface roughness increased from 5000 rpm to 6000 rpm[18,19].

The variation in surface roughness of the milled slots is shown in Figure 8 based on the factors looked at. The minimal surface finish was most significantly impacted by feed rate. Figure 8 (b) illustrates how adjusting the feed rate alters the surface roughness. Surface roughness increases when the feed rate increases from 150 mm/min to 450 mm/min.

Table 6: The response table for means

Level	Spindle speed (RPM)	Feed rate (mm/min)	DOC
1	0.4443	0.4017	0.4303
2	0.4817	0.4590	0.4760
3	0.4670	0.5323	0.4867
Delta	0.0373	0.1307	0.0563
Rank	3	1	2

Table 7: The Response Table for Signal to Noise Ratios (smaller is better)

Level	Spindle speed (RPM)	Feed rate (mm/min)	DOC
1	7.422	8.146	7.638
2	6.378	6.771	6.448
3	6.618	5.502	6.332
Delta	1.044	2.644	1.306
Rank	3	1	2

4.0 Conclusions

The paper has discussed the impact of slot milling and has given details on the machining settings used for wet milling Al-Li 2099 grade alloy. The surface roughness of an Al-Li alloy slab is measured using a slot milling operation using the Taguchi method[20], which identifies important variables and the ideal machining settings. Following the outcome, the following conclusions can be made:

- Based on the delta value and rank numbering by the analysis, the feed rate of the machine has the greatest impacton the surface roughness, followed by the depth of cut and spindle speed.

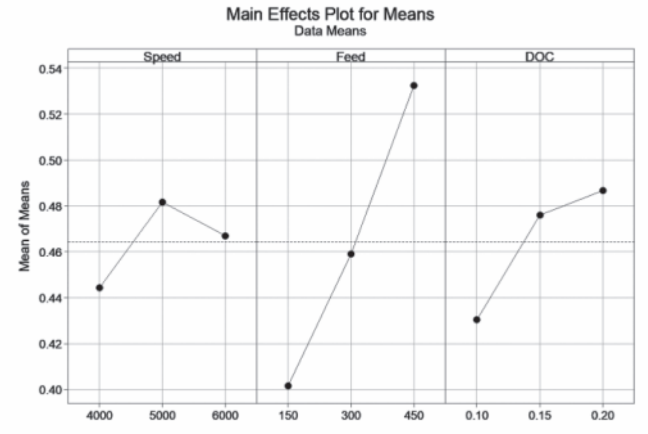

Figure 8: Main Effects Plot for Means, (a) Spindle speed,(b) Feed rate and (c) DOC

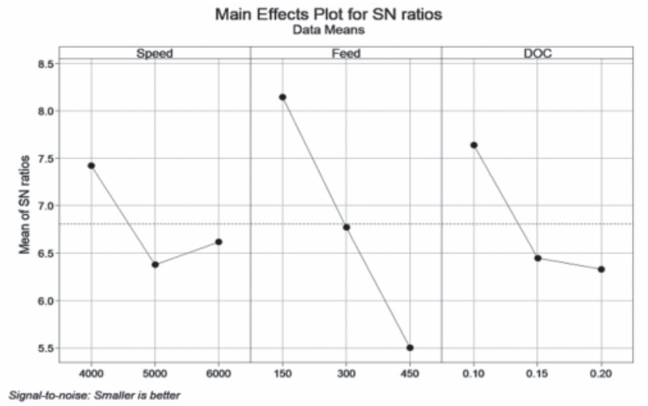

Figure 9: Main Effects Plot for SN ratios

- It has been found that the ideal parameters are a 4000 rpm spindle speed, a 300 mm/min feed rate, and a 0.15mm depth of cut.
- The lowest performance was produced by higher feed rates,which also resulted in a very poor surface finish.
- The feed rate and depth of cut regulate the milling machine's efficiency and produce a higher surface finish.

The majority of aluminum-lithium alloys have been used uptill now in military and spacecraft. To meet the operational needs of these vehicles, aluminum-lithium alloys' weight savings and performance enhancements were crucial in these applications. As an illustration, the conversion of the exterior tank of NASA's Space Shuttle to the lower density Al-Li alloy immediately led to payload increases that were crucial for the transport of big components to the International Space Station. The production concerns have been eliminated or much reduced by the current generation of aluminum-lithium alloys. Initial formability testing show that these novel alloys (2099 and 2050) perform as well as or better than existing conventional alloys. Al-Li alloys have a limited business case in earlier commercial usage. However, There has been a resurgence of interest in novel, sophisticated aluminium alloys in recent years, particularly Al-Li alloys. The difficulty of meeting the new military aircraft that are currently being developed is much greater performance specifications is what signifying this new interest.

Al-Li alloy has good corrosion resistance properties compared to the conventional aluminum alloys. This gives an immense advantage to use it in marine conditions. It is also seen that the 3rd generation Al-Li alloy's crack initiation and propagation is also considerably less compared to 1st and 2nd generation alloys when exposed to the salt/marine environment. Hence, the use of Al-Li not only helps in reducing the weight but also provides better corrosion resistance and higher damage tolerance. So, these alloys can be widely used in the naval applications. Apart from the landing gear which is made of steel and other minority metals like titanium etc., most of the aluminum alloys can be replaced by the Al-Li alloy which is 40% by weight. This can significantly reduce the weight of the aircraft therefore, have the feed rate as low as possible for better surface finish and with higher spindle speeds with low range of depth cuts and also using of Sol XL coolant has greater significance inproviding a smooth surface with no rings or war pages formed on the machined surfaces.

5.0 References

1. Alloying: Understanding the Basics, Davis, J.R., p.351-416, (2001): ASM International DOI:10.1361/autb2001 p351
2. Augustyn-Nadzieja, Joanna & Adrian, Henryk and Rzadkosz, S and Choroszyñski, M. (2013). Structure and Mechanical Properties of Al-Li Alloys as Cast. Archives of Foundry Engineering. 13. 10.2478/afe-2013-0027.
3. Bois-Brochu, Alexandre and Blais, Carl & Tchitembo Goma, Franck & Larouche, Daniel. (2016). Modelling of anisotropy for Al-Li 2099T83 extrusions and effect of precipitate density. *Materials Science and Engineering:* A.673.10.1016/j.msea.2016.07.081.
4. Cisko, Abby & Jordon, J. & Amaro, R. & Allison, Paul & Wlodarski, J. & McClelland, Z. & Garcia, L. & Rushing,T. (2020): A parametric investigationon friction stir welding of Al-Li 2099. Materials and Manufacturing Processes. 35.1-8.10.1080/10426914. 2020.1765249.
5. Bois-Brochu, Alexandre & Tchitembo Goma, Franck & Blais, Carl & Larouche, Daniel & Gauvin, Raynald & Boselli, Julien (2011): Al-LiAlloy 2099-T83 Extrusions: Static Mechanical Properties, Microstructure and Texture. *Advanced Materials Research.* 409. 29-34.10.4028/www.scientific.net/AMR.409.29.
6. Bois-Brochu, Alexandre & Blais, Carl & Tchitembo Goma, Franck & Larouche, Daniel & Boselli, Julien & Brochu, M.(2014): Characterization of Al–Li 2099 extrusions and the influence of fiber texture on the anisotropy of static

mechanical properties. *Materials Science and Engineering:* A.597.62–69.10.1016/j.msea.2013.12.060.

7. Improvements of Mechanical Properties in Aluminum-Lithium Alloys, Seth Schlatter , p1-16, 2001, College of Science, Engineering, and Technology.
8. Ali Abd El-Aty, Yong Xu, Xunzhong Guo, Shi-Hong Zhang,Yan Ma, Dayong Chen, Strengthening mechanisms, deformation behaviour, and anisotropic mechanical properties of Al-Li alloys: A review, *Journal of Advanced Research*,Vol.10, 2018, Pages 49-67, ISSN 2090-1232, https://doi.org/10.1016/j.jare.2017.12.004.
9. Arkadeep Bandyopadhyay, Anup Biswas, Shubha Saha, Shuvo Saha, Mihir Kumar Dey, Arkyadeep Dhar, Palash Biswas, (2021): Study of Surface Roughness in CNC Milling Operationon 6061 Graded Aluminum Alloy, *International Journal Of Engineering Research & Technology* (Ijert) Nceter 2021 (Vol.09, Issue 11),
10. Nathanhanapalan, G. Thanigaiyarasu and K.Vani, Prediction of surface roughness of 6061aluminium alloy end milling: a machine is ion approach, International *Journal of Machining and Machinability of Materials*. Vol.16, No. 3-4, pp.285-302 Feb. 5,2015
11. Tsao, C. (2007): Grey-Taguchi method to optimize the milling parameters of aluminum alloy. *International Journal of Advanced Manufacturing Technology.* 40.41-48. 10.1007/s 00170-007-1314-3.
12. Maiyar, Lohithaksha & Radhakrishnan, Ramanujam & Venkatesan, K. Venkatesan & Jayaraj, Jerald (2013): Optimization of Machining Parameters for End Millingof Inconel 718 Super Alloy Using Taguchi Based Grey-Relational Analysis. Procedia Engineering. 64. 1276-1282.10.1016/j.proeng.2013.09.208.
13. Mou, H., Huang, X., Zhang, X.,Ding, H.(2013): Experimental Study of Surface Integrity of Aluminum Lithium Alloy by Face Milling. In: Lee, J., Lee, M.C., Liu, H., Ryu, JH.(eds) Intelligent Robotics and Applications.ICIRA2013.Lecture Notes in Computer Science (), vol. 8103. Springer, Berlin, Heidelberg.https://doi.org/10.1007/978-3-642-40849-6_50.
14. Mário C. SantosJr & Alisson R. Machado & Wisley F. Sales & Marcos A. S. Barrozo & Emmanuel O. Ezugwu, “Machining of aluminum alloys: are view”, *International Journal of Advanced Manufacturing Technology*. February2016.
15. Azizur Rahman, M. & Bhuiyan, Md. Shahnewaz & Bibek, Sourav & Kamal, Mohammad & Imtiaz, M.M. & Alfaify, Abdullah & Nguyen, Trung-Thanh & Khanna, Navneet & Sharma, Shubham & Gupta, Munish & Anwar, Saqib & Mia, Mozammel. (2021): Influence of Feed Rate Response (FRR) on Chip Formation in Micro and Macro Machining of Al Alloy. Metals - *Open Access Metallurgy Journal*. 11. 10.3390/met11010159.
16. Bhushan, Rajesh. Kumar., Kumar,S. & Das, S. Effect of machining parameters on surface roughness and tool wear for 7075 Alalloy SiC composite. *Int J Adv Man uf Technol* 50, 459–469(2010).https://doi.org/10.1007/s00170-010-2529-2.
17. Sergey N. Grigoriev1, Sergey V. Fedorov1* and Khaled Hamdy 1,2, Materials, properties, manufacturing methods and cutting performance of innovative ceramic cutting tools – are view, *Manufacturing Rev.* 6,19(2019),https://doi.org/10.1051/mfreview/2019016.
18. Patel, Ravikumar & Bhavsar, Dr. Sanket. (2020): Optimization of Machining Parameters to Minimize Surface Roughness During End Milling of AISI D2Tool Steel Using Genetic Algorithm. 10.1007/978-981-15-1307-7_25.
19. Yue, Haitao & Guo, Chenguang & Li, Qiang & Zhao ,Lijuan & Hao, Guangbo (2020): Milling Parameters Optimization of Al-Li Alloy Thin-Wall Workpieces Using Response Surface Methodology and Particle Swarm Optimization. *Computer Modelling in Engineering & Sciences.* 124. 937-952.10.32604/cmes.2020.010565.
20. Sami Abbas Hammood, Optimization of Cutting Parameters for Milling Process of (4032) Al-Alloy using Taguchi-Based Grey Relational Analysis, *Al-Khwarizmi Engineering Journal.* Vol.17, No.3, Sptember, (2021): pp.1-12, https://doi.org/10.22153/kej.2021.06.00
21. B.M.Gopalsamy, B. Mondal, and S.Ghosh, “Taguchi method and anova: An approach for process parameters optimization of hard machining while machining hardened steel,” *J.Sci.Ind.Res.* (India).,vol.68,no. 8,pp.686–695, 2009.
22. M. Chahal, V. Singh, and R. Garg, “Optimum surface roughness evaluation of dies steel H-11 with CNC milling using RSM with desirability function,” *Int. J.Syst. Assur. Eng. Manag*., vol. 8, no. 2, pp. 432–444,2017,doi:10.1007/s13198-016-0446-y.
23. Goel, Pankul & Khan, Zahid &Siddiquee, Arshad & Kamaruddin, Shahrul & Gupta, Rajeev (2012): Influence of slab milling process parameters on surface integrity of HSLA: A multi-performance characteristics optimization. *International Journal of Advanced manufacturing Technology*. 61.859-871. 10.1007/s00170-011-3763-y.
24. Osman, M., Tamin, N., Ahmad, M., AB. Rahman, M.,Wahid, M., Maidin, N., Abu Bakar, M., & Azahar, A. (1). Effect of Cutting Parameters on Surface Roughness in Dry Drilling of AISID2 Tool Steel by Using Taguchi Method. *Journal of Advanced Manufacturing Technology (JAMT)*, 12(1(2), 535-546. Retrieved from https://jamt.utem.edu.my/jamt/article/view/4311
25. A. Srithar, K. Palanikumar and B. Durgaprased, “Experimental Investigation and Surface roughness Analysis on Hard turning of AISID2 Steel using Coated Carbide Insert”, Procedia Engineering, vol. 97,pp. 72-77, 2014.
26. Rahman, M. & Bhuiyan, Md. Shahnewaz & Bibek, Sourav & Kamal, Mohammad & Imtiaz, M.M. & Alfaify, Abdullah & Nguyen, Trung-Thanh & Khanna, Navneet & Sharma, Shubham & Gupta, Munish & Anwar, Saqib & Mia, Mozammel. (2021). Influence of Feed Rate Response (FRR) on Chip Formation in Micro and Macro Machining of Al Alloy. *Metals-Open Access Metallurgy Journal.* 11. 10.3390/met11010159.