Impact of process parameters on noise emission and microhardness during dry turning of squeeze cast Al 7075 alloy: a case study

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Abstract. The objective of the research is to investigate the machinability characteristics of squeeze cast Al 7085 through carbide insert using Taguchi design of experiment and obtain the parametric optimization of responses such as noise emission and vickers micro-hardness. Squeeze cast sample surface generates micro-hardness of 139.3-149.6 HV whereas emissions of noise during dry turning are in the range of 68.1dB-77.1dB respectively. Impact of process parameters on noise emission are increasing in trend with 52.94%, 32.33% and 14.69% contribution at 95% confidence level. The contribution of cutting speed and depth of cut on micro-hardness of specimen are significant with 69.39% and 29.39% respectively. Prediction models through multiple linear regressions are found to be fitted well as coefficient of regression approaches one. During desirability multi-response optimization approach, the optimal parameters are found to be vc: 127.255 m/min, f: 0.05 mm/rev and ap: 0.1 mm with minimum values of micro-hardness and noise emission are 141.752 HV and 71.5405dB respectively. The outcome of the research has shown improvements in terms of good machinability and may be adopted in industries for green and sustainable manufacturing process.

1 Introduction

Aluminum 7075 alloy is primarily high strength light weight zinc-based alloy with copper and magnesium suitable for aerospace and defense applications in structural components of aircraft, missile parts, spacecraft and satellite systems along with automobile components like gears, shaft, sports equipment etc. Due to its widespread applications in engineering, its machinability aspects is utmost essential for investigation as it is difficult-to-cut material. The appropriate machining parameters are essential for favorable machining of Al7075 alloy as it has high strength properties. Zinc rich in Al7075 alloy enhances hardness and machinability as lower shear force is required for shear deformation of the material and behaves like a solid lubricant because of its oxides [1]. Singh et al. [2] investigates the machinability behavior of Al7075-T6 with various cutting environments and optimized the machining parameters. Minimum quantity lubrication (MQL) environment called near dry

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machining induces better machinability in reduction of tool wear and improves the surface quality. Sequeiera et al. [3] optimized the milling parameters for better surface finish using Grey-Taguchi approach with influencing parameters as cutting speed and feed. Soni and Thomas [4] observed the improvement of machinability under MQL condition than dry environment during turning Al 7075 and hybrid nanocomposite produced through squeeze casting. Kannan et al. [5] studied comparative machinability assessment of squeeze cast hybrid nanocomposite and unreinforced Al7075 alloy for surface roughness, tool wear and cutting forces where MQL performed better performance. Magabe and Gupta [6] investigated the machinability studies of Al7075 alloy under dry environment using carbide cutting insert for tool wear and surface roughness as responses and obtained favourable machinability characteristics without failure of the cutting tool. Lakshmanan et al. [7] investigated the machining characteristics of Al7075 utilizing carbide insert under dry and wet cutting environments for surface quality and material removal rate and obtained the optimal cutting parameters through Grey relational analysis and analysis of variance. Significant parameters for both environments are observed to be feed, depth of cut and spindle speed. Ramakrishnan et al. [8] studied turning of Al7075 alloy with Al_2O_3 nano-cutting fluids to assess the surface roughness and material removal rate where 1% of Al_2O_3 nano-cutting fluid yields better results. Zhang et al. [9] explored micro hardness of Al7055 alloy at different aging temperature and discovered that hardness values primarily increased then decreased with increase of aging time. Aliyah and Anawati [10] experimented on the effect of heat treatment by varying temperatures of 300°C - 600°C for a duration of 1 hour in a vacuum furnace on hardness of AA7075-T651. Anahid et al. [11] studied influence of various machining cutting parameters and properties of the material along with coating on cutting tool on the frequency domain of acoustic emission signals on aluminum alloys. Vie et al. [12] studied the fatigue characteristics of Al7075-T6 alloy specimens with various coating systems, using acoustic emission revealing that AE based indicators can effectively differentiate damage mechanisms and identify characteristic times such as oxide layer cracking at 15% and substrate fracture at 70% of fatigue life, thus enabling early prediction of remaining useful lifetime. Pawel Sutowski et al. [13] analyzed surface characteristics of Al 5251 abrasive waterjet machining through acoustic emission signal. Bankar et al. [14] studied the turning performance of Al7075 where MQL induces the improved machinability for surface quality and cutting temperature than dry and wet environments. Muthuraman and Arunkumar [15] investigated machinability of Al7075 alloy where LN_2 cooling environment yielded better performance than conventional coolant for surface finish, cutting temperature and cutting force.

From above review, rare studies are noted on the development of squeeze cast Al7075 alloy and its machinability characteristics as squeeze cast induces fine homogeneous alloy without voids and pores. Again, consideration of both machinability indices such as evolution of noise and microhardness during machining is rarely being investigated for squeeze cast Al7075 alloy as it is the important consideration for environmental sustainability and health concern for operators. Thus, an attempt has been made to investigate the machinability (noise emission level and hardness) of the novel squeeze cast Al 7075 alloy using carbide cutting insert under dry environment and developed prediction models with optimisation of the process parameters through composite desirability method.

2 Materials and methods

The workpiece Al7075 alloy has been fabricated through squeeze casting process in a resistance furnace through stirring followed by squeeze casting to reduce the casting defects like pores and voids etc. A cylindrical workpiece of squeeze cast Al7075 alloy with 48 mm diameter and 100 mm cutting length has been utilized for dry turning process using cemented carbide cutting tool on CNC (Jyoti DX 200) lathe with FANUC controller. The experimental factors and levels are shown in Table 1 as input and noise emission and Vickers micro-hardness were considered as output parameters for the study. The selection of cutting parameters is made through manufacture recommendation and previous literatures [2, 4, 5, 6, 7, 8, 15]. The measurement of noise during machining has been performed through Fluke sound level meter which has been calibrated to maintain the accuracy and reproducibility. The repeatability experiment has been performed with three times before the final experiment and the errors are less than ± 2% for both NE and MH respectively. Noise meter has been kept within 1 meter from the machining zone with proper background noise control. The schematic turning operation setup have been illustrated in Figures 1 and 2.

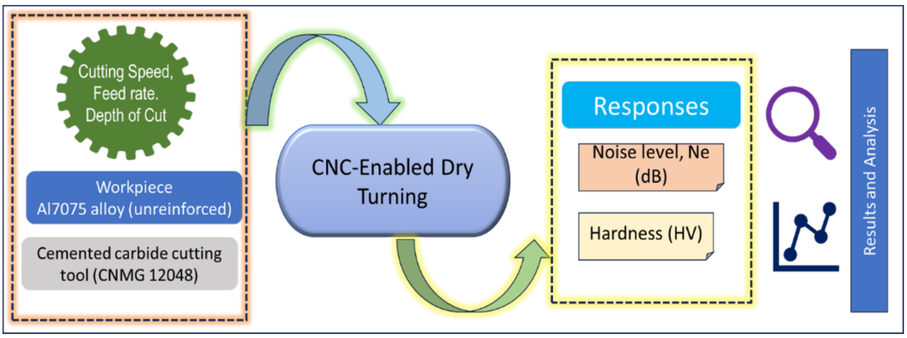

Fig. 1. Experimental scheme.

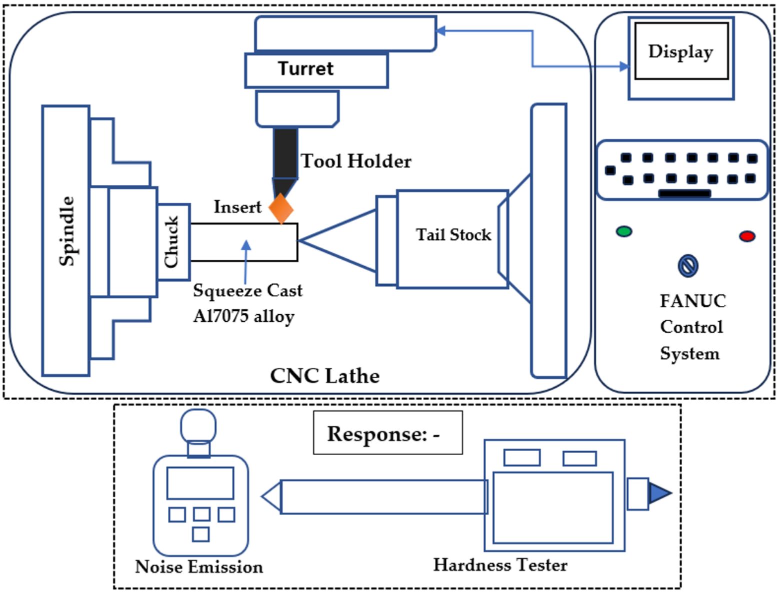

Fig. 2. Schematic turning operation layout for squeeze cast Al7075 alloy.

Table 1. Test conditions.

Experimental Scheme	Factors
CNC Lathe machine tool	Jyoti DX 200 with FANUC controller
Workpiece	Squeeze cast Al 7075 alloy (111-121 HV)
Cutting tool and tool holder	Cemented carbide tool (CNMG120408)-THM, WIDIA with PCLNR2525M12 tool holder
Experimental factors and level (Taguchi L_9 DoE)	• Cutting speed (vc, m/min): 60, 110 and 160 • Feed (f, mm/rev): 0.05, 0.1 and 0.15 • Depth of cut (ap, mm): 0.1, 0.2 and 0.3
Observed responses	Noise emission (NE), Vickers microhardness (MH)
Measuring instruments	• Fluke Model 945 Sound Level meter: Noise emission • Insize Portable Leeb Hardness Tester (Basic Type) HDT-L41: Micro-hardness measurement

3 Results and discussion

The results of noise emission and Vickers microhardness during dry turning of squeeze cast Al7075 alloy has been shown in Table 2 and trends of observations in Figure 3 and discussed as follows:

Table 2. Experimental matrix and measured responses.

Trial no.	Process parameters			Measured results	
	vc	f	ap	NE (dB)	MH (HV)
1	60	0.05	0.1	68.10	146.2
2	60	0.10	0.2	71.52	147.0
3	60	0.15	0.3	74.00	149.6
4	110	0.05	0.2	72.30	145.0
5	110	0.10	0.3	75.90	146.7
6	110	0.15	0.1	74.82	142.3
7	160	0.05	0.3	75.00	143.7
8	160	0.10	0.1	74.80	139.3
9	160	0.15	0.2	77.10	141.0

Noise emission and induced microhardness during turning play vital role in affecting machinability and thus needs to be controlled with appropriate process parameters and environments for sustainable manufacturing. The operator's health point of view and environmental consciousness poses attention in sustainability during machining particularly in shop floors as it affects hearing and hazards if exceeds the 85dB level of sound. Tool wear or vibration/chatter are the main source of cause of noise emission during machining as it increases additional noise, friction, cutting forces, instability of the machining process and irregular in chip formation, amplitude of sound particularly in the larger range of frequency thus yields rapid tool failure and thus needs to be controlled. Again, surface Vickers microhardness is affected during machining because of severe plastic deformation, strain hardening, recrystallization and grain growth and thus alters microstructure of the specimen and needs to be controlled by choosing optimal process parameters. The variation of machining variables affect the microhardness and noise emission during machining process. In most of the operation during dry turning, noise emission lies between 68.1-77.1dB which is below the acceptable limit and safe for the operator's health. The increasing trend of noise emission is observed at Run-5, 7 and 9 i.e. above 75dB at the combination of higher cutting speed-depth of cut condition as seen in Figure 3 (a). The decreasing trend of microhardness are seen at higher cutting speed ranges Run 7, 8 and 9 during machining shown in Figure **3** (b). The effects of machining parameters on noise emission and microhardness is shown as main effects plots Figure 4 (a-b). Higher emission of noise is observed as cutting speed increases (Figure 4a) because of the rise of power/energy requirements during machining. Also at higher cutting speed, material removal rate and chip formation are faster that leads to higher friction and thus induces more noise during turning operation. Similarly at higher feed and depth of cut, more chip removals in each revolution and induces vibration and noise (Figure 4a). The increasing trend of microhardness is observed when cutting depth of cut increases due to severe plastic deformation as more material is removed and thus induces intense strain hardening and surface microhardness (Figure 4b). However, the decreasing trend of microhardness is observed when cutting speed increases with negligible impact with feed rate. Rise of vc and f enhances the cutting temperature due to friction and plastic deformation that behaves like a tempering process and consequently softens the machined surface and decreases the surface microhardness. This higher temperature also changes microstructure with grain recrystallization that results in the decrease of microhardness. The material microhardness decreases during machining as cutting speed increases mainly due to the thermal softening whereas strain hardening is predominant particularly at lower cutting speed range as observed in the main effects plot where higher microhardness is observed. The similar observations are noticed for both NE and MH as seen from the surface plot Figure 5 (a-b). The significance effects of machining parameters on NE and MH are tested through analysis of variance (ANOVA) study with probability of $p<0.05$ at 95% CI and shown in Figure 6 (a-b). The percentage of contributions of vc, f and ap on noise emission are 52.947, 32.338 and 14.692 respectively. Similarly, the percentage of contributions of vc, f and ap on Vickers microhardness are 69.396, 0.996 and 29.396 respectively. Mathematical regression prediction models for both NE and MH are developed through multiple linear regressions as shown in Eq-1 and Eq-2 and are found to be fitted well as coefficient of regression (R^2) approaches one and p-value of the models are less than 0.05. The percentage of error between mathematical regression model and experimental findings for all nine runs are within 0.01-1.31 for NE and 0.04-0.44 for MH respectively with average error percentage of 0.58 for NE and 0.12 for MH that shows the model accuracy and significance.

$$\text{Noise emission (NE)} = 62.96 + 0.04427\,vc + 35.07\,f + 11.97\,ap \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$
$$R^2 = 96.12\ \%,\ R^2\ (adj) = 93.79\ \%,\ R^2\ (pred) = 86.5\ \%,\ p<0.05$$

$$\text{Vickers Microhardness (MH)} = 148.027 - 0.06267\,vc - 6.67\,f + 20.33\,ap \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$
$$R^2 = 99.27\ \%,\ R^2\ (adj) = 98.83\ \%,\ R^2\ (pred) = 97.93\ \%,\ p<0.05$$

During composite desirability multi-response optimization approach, the multiple responses are converted into single composite desirability function (D) to obtain the optimal parametric settings. By applying the approach, the optimal combinations are 127.255 m/min cutting speed, 0.05 mm/rev feed and 0.1 mm depth of cut with minimum values of microhardness and noise emission are 141.752 HV and 71.5405dB respectively with composite desirability D: 0.6861 as shown in Figure 7. The optimal results are verified through confirmation experiment where the microhardness and noise emission results are obtained as 141.5 HV and 71.8 dB respectively which accounts for 0.17% and 0.36% error only between experimental and optimal results that yields better reliability.

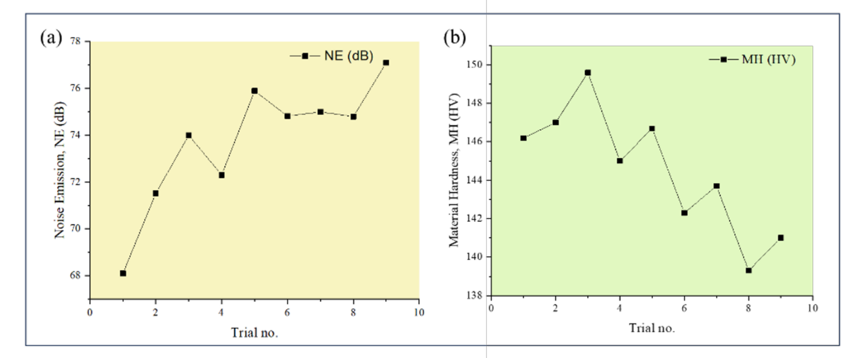

Fig. 3. Experimental run with (a) Noise emission, NE, and (b) Material microhardness, MH.

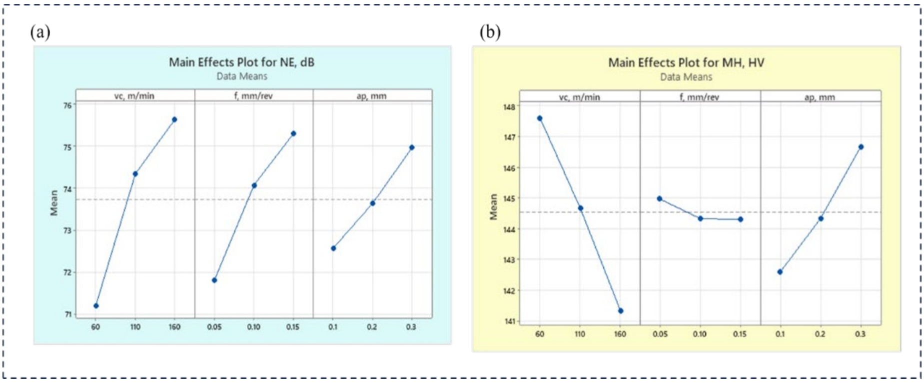

Fig. 4. Main effect plot for (a) Noise emission, NE, and (b) Material microhardness, MH.

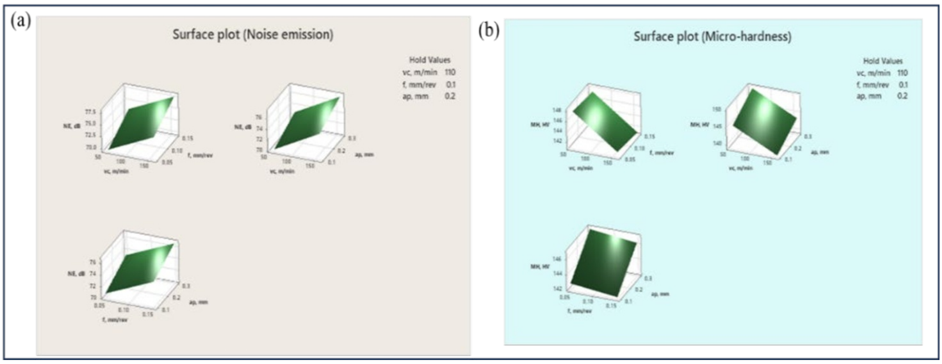

Fig. 5. Surface plot for (a) Noise emission, NE, and (b) Material microhardness, MH.

(a)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage of Contribution
vc, m/min	2	31.0859	15.5429	2428.58	0.000	52.947
f, mm/rev	2	18.9859	9.4929	1483.27	0.001	32.338
ap, mm	2	8.6259	4.3129	673.90	0.001	14.692
Error	2	0.0128	0.0064			
Total	8	58.7104				

(b)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage of Contribution
vc, m/min	2	58.9867	29.4933	327.70	0.003	69.396
f, mm/rev	2	0.8467	0.4233	4.70	0.175	0.996
ap, mm	2	24.9867	12.4933	138.81	0.007	29.396
Error	2	0.1800	0.0900			
Total	8	85.0000				

Fig. 6. ANOVA for (a) noise emission, NE, and (b) Material Hardness, MH.

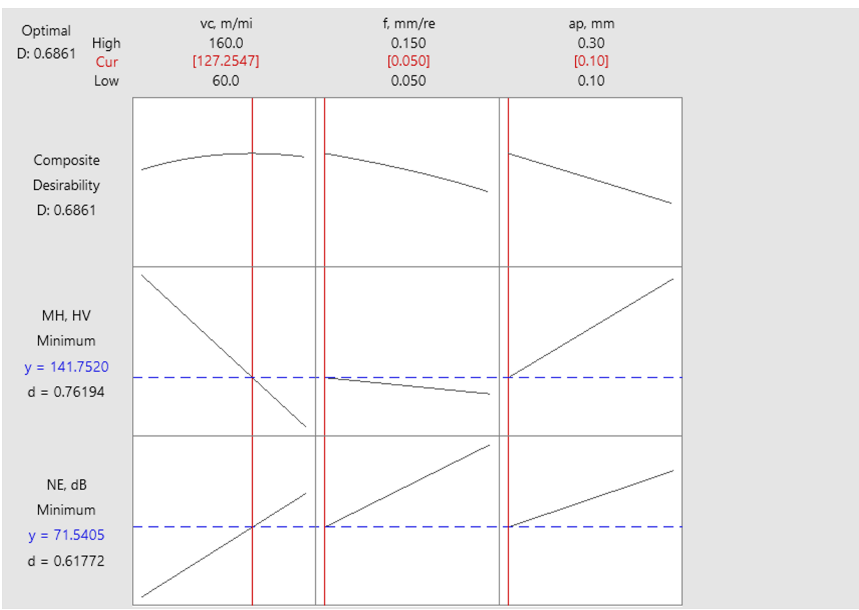

Fig. 7. Optimal parameters through composite desirability.

4 Conclusions

From dry turning, following findings are revealed from the study.

From machinability assessment, the evolution of emission of noise and Vickers micro-hardness during turning lie between 68.1dB-77.1dB (11.6 % reduction of noise emission) and 139.3-149.6 HV (6.8 % reduction of material microhardness) respectively. Impact of process parameters on noise emission are increasing in trend with 52.94%, 32.33% and 14.69% contribution at 95% confidence level from ANOVA study as $p<0.05$. The contribution of vc and ap on micro-hardness of specimen are significant with 69.39% and 29.39% respectively. Prediction models through multiple linear regressions are found to be fitted well as coefficient of regression approaches one. During desirability multi-response optimization approach, the optimal combinations are 127.255 m/min cutting speed, 0.05 mm/rev feed and 0.1 mm depth of cut with minimum values of micro-hardness and noise emission are 141.752 HV and 71.5405dB respectively. The microhardness and noise emission results are obtained as 141.5 HV and 71.8 dB respectively through confirmation experiment at optimal conditions which accounts for 0.17% and 0.36% error only for better reliability. The research signifies successful development of squeeze cast Al7075 alloy and has shown improvements in machinability characteristics. The study demonstrates its potential application where good machinability is required and can be recommended for further consideration in industries for a green and sustainable manufacturing process. The study may be further investigated considering various sustainable lubrication techniques and hybrid techniques for improvements in overall machinability and sustainability.

This research is funded by Science and Engineering Research Board (SERB) under core research grant (CRG) Project, DST, Govt of India, New Delhi (File No: CRG/2022/002399). Authors express their sincere thanks and gratitude for the financial support towards research.

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