Study of Mechanical Properties and Surface Roughness of As-cast and Heat Treated Al-7075 Alloy

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Abstract- Aluminium and its alloys are used in many fields, whether in daily life or industrially because of its inherent properties like low density, lightweight and high strength. Al alloys are widely used in Aerospace and Bio-medical applications etc. In this present work investigations are made to enhance the properties and to optimize the process parameters of Al-7075 alloy during turning operation in conventional lathe machine. Properties like ultimate tensile strength and hardness of the material are studied. The process parameters considered for this work are spindle speed, feed rate and depth of cut, surface roughness is taken as response variable. The experiment is carried out as per the Taguchi's experimental design and L9 orthogonal array is used to study the influence of various combinations of process parameters. MINITAB 17 software is used for the analysis and to optimize the process parameters. Analysis of variance (ANOVA) method is used to determine the significance of each process parameter on machining of the alloy. In this study experiments are carried for three cases, first the properties of the material is studied in the As-cast stage and then the material is subjected to heat treatment i.e solutionization and aging(T6 temper) is carried out at 460º for 2 hours and water quenched and followed by aging at 120º for 24 hours for enhancing the properties. Finally the Retrogression and Re-aging (RRA) is carried out retrogression at 200º for 50 min and water quenched and followed by re-aging at 120º for 24 hours. For all the three cases tensile, hardness and surface roughness tests are conducted and compared.

Index Terms- process parameters; heat treatment; ANOVA; Taguchi method; s/n ratio.

1. INTRODUCTION

Many of the applications in the world today require materials with unusual combinations of properties that cannot be met by the conventional monolithic materials. This is especially true for materials that are needed for high technology areas such as jet engines, airframes, space shuttles, hypersonic spacecrafts and deep-sea submersibles etc. Al-7075 is an aluminium alloy, with zinc as the primary alloying element. It is strong, with a strength compared to many steels, and has good fatigue strength and average machinability, but has less resistance to corrosion than many other Al alloys. Its relatively high cost limits its use to applications where cheaper alloys are not suitable [1].
The quality of a product is the main factor for showing growth of a company. The quality of the product mainly depends upon the material and process parameters. Optimization technique plays a vital role to increase the quality of the product. Hence, many authors have presented their works on the optimization of process parameters for various machining processes [3]. The surface finish is an important factor in evaluating the productivity of machine tools and machined parts. The surface roughness of machined parts is a significant design specification that is known to have considerable influence on properties such as wear resistance and fatigue strength. Surface roughness is one of the most important measures in finish cutting (turning, milling, drilling, etc.) operations. Consequently, it is important to achieve a consistent tolerance and surface finish. When surface finish becomes the main criteria in the quality control department, the productivity of the metal cutting operation is limited by the surface quality [3]. Recent investigations state that mechanical properties of the alloy increases with the less number of experimentations as compared to other factorial analysis and yields similar results.
Taguchi's method provides simple, systematic and efficient methodology for optimizing the process parameters.

DESIGN OF EXPERMENTS

The Design of Experiments is considered as one of the most comprehensive approach in product/process developments. It is a statistical approach that attempts to provide a predictive knowledge of a complex, multi-variable process with few trials. Following are the major approaches to DOE:

1.1. Full Factorial design

A full factorial experiment is an experiment whose design consists of two or more factors, each with a discrete possible level and whose experimental units take all possible combinations of all those levels across all such factors. Such an experiment allows studying the effect of each factor on the response variable, as well as on the effects of interactions between factors on the response variable. A common experimental design is the one with all input factors set at two levels each. If there are k factors each at 2 levels; a full factorial design has 2k runs. Thus for 6 factors at two levels it would take 64 trial runs.

1.2 Taguchi Method

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community he desired cutting parameters are determined based on experience or by hand book. Cutting parameters are reflected on surface roughness, surface texture and dimensional deviation turned product. In a manufacturing process it is very important to achieve a consistence tolerance and surface finish. Taguchi method is especially suitable for industrial use, but can also be used for scientific research.

1.3 Signal to Noise ratio

The term "signal" represents the desirable value and the "noise" represents the undesirable value. The formulae for signal-to-noise are designed such that the experimentalist can always select the larger factor level settings to optimize the quality characteristics of an experiment. Therefore, the method of calculating the signal-to-noise ratio depends on whether the quality characteristic has smaller-the-best, larger-the-better or nominal-the-better formulation is chosen. The signal-to-noise ratio measures how the response varies relative to the nominal or target value under different noise conditions. You can choose from different signal-to-noise ratios, depending on the goal of your experiment.

1.4 Analysis of Variance

ANOVA is a statistically based, objective decision-making tool for detecting any differences in the average performance of groups of items tested. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels. First, the total sum of squared deviations SST from the total mean S/N ratio nm can be calculated as

$$SS_T = \sum_{i=1}^{n}(n_i - n_m)^2$$

Where n is the number of experiments in the orthogonal array and ni is the mean S/N ratio for the ith experiment. The percentage contribution P can be calculated as:

P = SSd / SSt

Where SSd is the sum of the squared deviations.

Statistically, there is a tool called an F test, named after Fisher, to see which design parameters have a significant effect on the quality characteristic. In the analysis, the F-ratio is a ratio of the mean square error to the residual error, and is traditionally used to determine the significance of a factor.

2. SOFTWARE

All major statistical software packages, e.g. SAS System, Stata, Statistica and Minitab perform variance analysis correctly and in a user-friendly way. Simpler regression can be done in spreadsheets like MS Excel or OpenOffice.org Calc. Experts can run complex types of regression using special programming languages like Mathematical, R programming language or Matlab. There are a number of software programs that perform specialized forms of variance analysis. Minitab is statistical analysis software. It can be used for learning about statistics as well as statistical research. Statistical analysis computer applications have the advantage of being accurate, reliable, and generally faster than computing statistics and drawing graphs by hand

In this work MINITAB software is used to carry out analysis of variance and f-test, which relates cutting parameters (cutting speed, depth of cut, feed rate) to predict surface roughness.

3. HEAT TREATMENT

Heat treatment was done in 2 stages

1. Solution heat treatment and age hardening(T6)

2. Retrogression and Re-aging (RRA)

Solution heat treatment and aging is a type of heat treatment used in metallurgy to strengthen metal alloys. It is also called precipitation hardening, as it strengthens the metal by creating solid impurities or precipitates.[4].Retrogression heat treatment is a heat treatment process that rapidly heat treats age-hardenable aluminum alloys. Re-aging is a process of repeated aging which significantly improves the strength of the alloy.

4. EXPERIMENTAL DETAILS

In the present work experiments were carried out for As-cast, T6 temper and RRA heat treated samples.

Mechanical properties like tensile strength and hardness are studied and compared. Surface roughness studies are done by selecting the parameters like speed, feed rate and depth of cut. Factors affecting the surface finish are studied and optimum parameters are recommended for each case using Taguchi's experimental design and L9 orthogonal array in MINITAB software. The test specimens were prepared by die casting method and machined using lathe as per the ASTM standards.

4.1 Hardness testing

Hardness test was made using Brinell hardness tester 500 kg load and 10 mm ball indenter was used for the test. Brinell microscope was used to find the diameter if indentation and Brinell hardness value is calculated using the formula.

$$HB = \frac{2P}{\pi D[D - (\sqrt{D^2 - d^2})]}$$

D=Ball diameter, d = impression diameter, P = load, HB = Brinell hardness value.

4.2 Tensile strength

Tensile strength is the maximum stress that a material can withstand while being stretched or pulled. Tensile test was conducted using electronic Horizontal Tensometer for As-cast, T6 temper and RRA heat treated test samples.

4.3 Surface roughness

Cylindrical samples of 22 mm diameter and 110 mm length were machined by HSS tool in hmt lathe. The experiment was conducted as per Taguchi's experimental design and L9 orthogonal array. Cutting parameters like speed, feed rate and depth of cut are considered and surface roughness is determined for As-cast, T6 temper and RRA heat treated samples and compared.

5. RESULTS AND DISCUSSION

Table 1: Chemical composition

Zn	Mg	Cr	Cu	Si	Fe	Mn	Ti
5.9	2.41	0.2	1.42	0.05	0.08	0.05	0.05

The test specimens were prepared by die casting method and machined using lathe as per the ASTM standards.

Table 2: Output of hardness test

Sample	Hardness value(HB)
As-cast	53.43
T6 temper	96.28
RRA heat treated	107.08

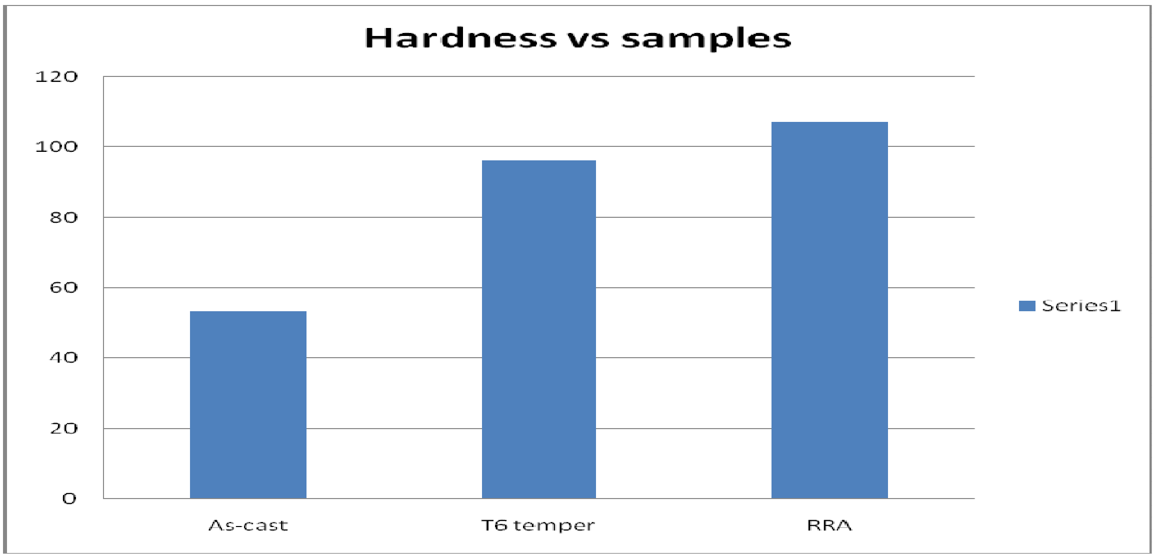

Fig 1 plot of hardness vs samples

From the above graph it is clear that hardness of the material increases with the Heat treatment.

Table 3: Output of tensile strength test

SL. No.	Sample	Engineering Ultimate Tensile Strength (N/mm2)	Break load (N)
1	As-cast	102.8	3255.90
2	T6 temper	141.2	4471.80
3	RRA	155.4	4921.52

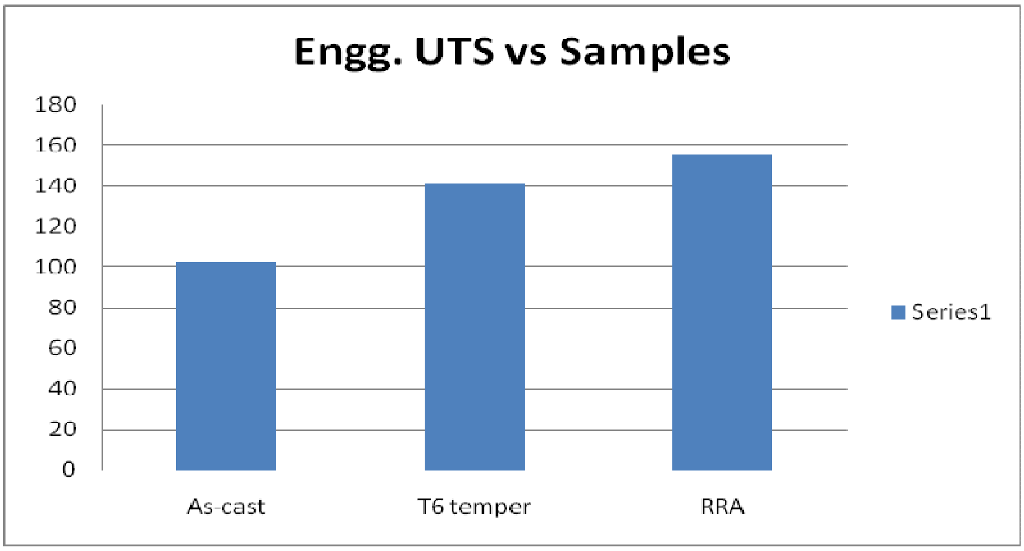

Fig 2: Graph of Engg. UTS values for different samples**.**

From the above graph it is clear that Tensile strength of the material increases with the Heat treatment.

Table 4: Cutting parameters

Symbol	Cutting parameter	Level 1	Level 2	Level 3
A	Speed (rpm)	420	710	1200
B	Feed rate (mm/rev)	0.050	0.11	0.22
C	Depth of cut (mm)	0.25	0.50	0.75

Case 1: Influence of cutting parameters on As-cast sample

Table 5: Cutting conditions and response for As-cast

Run	Cutting speed	Feed rate	Depth of cut	Surface roughness RA (µm)
1	420	0.05	0.25	3.28

2	420	0.11	0.50	2.36
3	420	0.22	0.75	6.18
4	710	0.05	0.50	1.83
5	710	0.11	0.75	3.06
6	710	0.22	0.25	5.08
7	1200	0.05	0.75	3.62
8	1200	0.11	0.25	2.54
9	1200	0.22	0.50	5.10

ANOVA analysis considering cutting parameters as input and surface roughness as output for As-cast samples reveals the influence of various cutting parameter on surface roughness.

Table 6 ANOVA table for surface roughness of As-cast sample

Source	Degrees of freedom	Sum of squares	Mean square	F value	P value	% C
Speed	2	0.6000	0.30001	4.51	0.181	3.48
Feed rate	2	14.3744	7.18721	108.11	0.009	83.38
Depth of cut	2	2.1310	1.06548	16.03	0.059	12.36
Error	2	0.1330	0.06648			0.77
Total	8	17.2384				100

The analysis carried out by using MINITAB software indicates the influence of cutting parameters on surface roughness. From the above ANOVA table we can see that for As-cast sample feed rate influencing the surface roughness than other parameters
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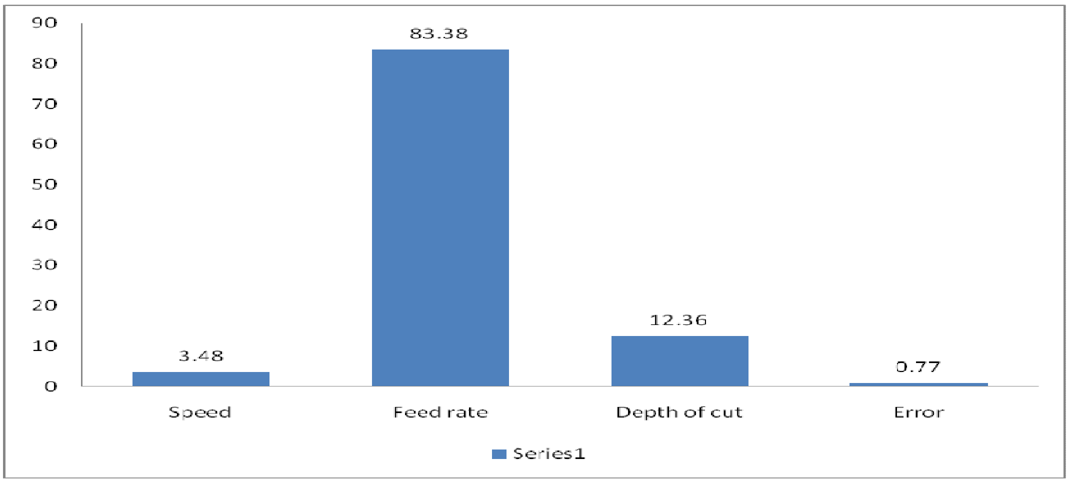

Fig 3 effect of each parameter on surface roughness of As-cast sample (%)

Fig. 3 shows the percentage effect of each parameter on the surface roughness of As-cast sample. It is illustrated that feed rate has the most significant effect on the output response (surface roughness). Other significant parameters are in turn depth of cut and cutting speed These results can be used to optimally determine the best set of machining parameters as well as tool geometry specification in order to achieve the best possible surface finish.

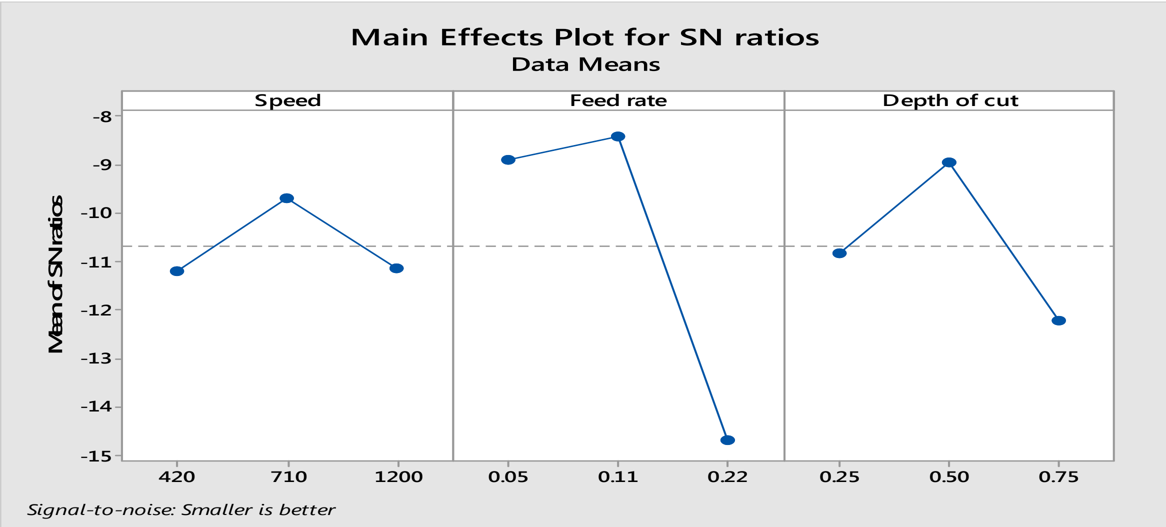

Fig 4 graph representing the influence of cutting parameters on As-cast sample

From fig 4 it also indicates the signal to noise ratio is more in case of feed rate and hence confirming the influence of cutting speed on surface roughness

Optimum cutting parameters for As-cast sample

Parameter	**Optimum value**
Speed	710
Feed rate	0.11
Depth of cut	0.50

Case 2: Influence of cutting parameters on T6 temper sample

Table 7 Cutting conditions and response for T6 temper

Run	**Cutting speed**	**Feed rate**	**Depth of cut**	**Surface roughness Ra (μm)**
1	420	0.05	0.25	2.63
2	420	0.11	0.50	4.07
3	420	0.22	0.75	6.85
4	710	0.05	0.50	3.05
5	710	0.11	0.75	5.41
6	710	0.22	0.25	8.46
7	1200	0.05	0.75	3.49
8	1200	0.11	0.25	3.35
9	1200	0.22	0.50	5.87

ANOVA analysis considering cutting parameters as input and surface roughness as output for T6 temper samples reveals the influence of various cutting parameter on surface roughness.

Table 8 ANOVA table for surface roughness of T6 temper

Source	**Degrees of freedom**	**Sum of squares**	**Mean square**	**F value**	**P value**	**% C**
Speed	2	3.310	1.6548	2.37	0.297	10.59
Feed rate	2	25.262	12.6310	18.10	0.052	80.86
Depth of cut	2	1.271	0.6353	0.91	0.523	4.08
Error	2	1.396	0.6978			4.46
Total	8	31.238				100

The analysis carried out by using MINITAB software indicates the influence of cutting parameters on surface roughness. From the above ANOVA table we can see that T6 temper sample feed rate influencing the surface roughness than other parameters.

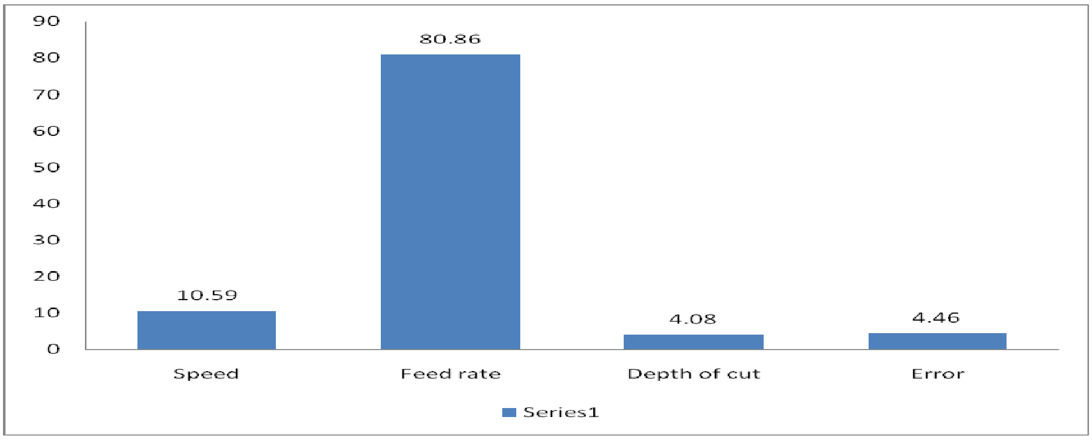

Fig 5 effect of each parameter on surface roughness of T6 temper sample (%)

Fig. 5 shows the percentage effect of each parameter on the surface roughness of T6 temper sample. It is illustrated that feed rate has the most significant effect on the output response (surface roughness). Other significant parameters are in turn cutting speed and depth of cut. These results can be used to optimally determine the best set of machining parameters as well as tool geometry specification in order to achieve the best possible surface finish.

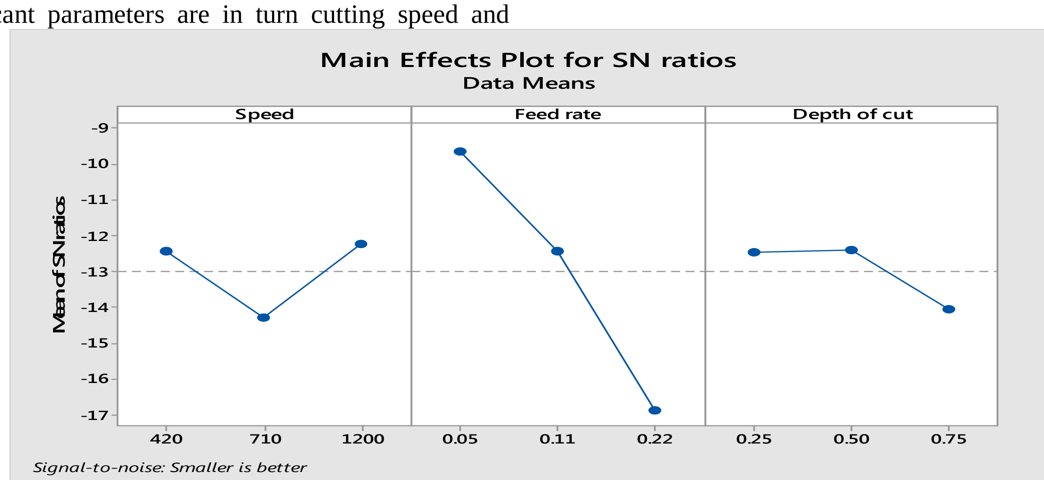

Fig 6 graph representing the influence of cutting parameters on T6 temper sample

From fig 6 it also indicates the signal to noise ratio is more in case of feed rate and hence confirming the influence of cutting speed on surface roughness
From the fig 6 optimum parameter conditions to minimize surface roughness are as follows

Table 9 Optimum cutting parameters

Parameter	**Optimum value**
Speed	1200
Feed rate	0.05
Depth of cut	0.50

Case 3: Influence of cutting parameters on RRA heat treated samples

Table 10 Cutting conditions and response for RRA

Run	**Cutting speed**	**Feed rate**	**Depth of cut**	**Surface roughness Ra (μm)**
1	420	0.05	0.25	3.43
2	420	0.11	0.50	4.25
3	420	0.22	0.75	7.54
4	710	0.05	0.50	3.28
5	710	0.11	0.75	5.09
6	710	0.22	0.25	3.26
7	1200	0.05	0.75	2.30
8	1200	0.11	0.25	2.46
9	1200	0.22	0.50	8.52

ANOVA analysis considering cutting parameters as input and surface roughness as output for RRA heat treated samples reveals the influence of various cutting parameter on surface roughness.

Table 11 ANOVA table for surface roughness of RRA samples

Source	**Degrees of freedom**	**Sum of squares**	**Mean square**	**F value**	**P value**	**% C**
Speed	2	2.153	1.076	0.25	0.802	5.52
Feed rate	2	18.959	9.479	2.17	0.315	48.65
Depth of cut	2	9.141	4.571	1.05	0.488	23.45
Error	2	8.717	4.358			22.36
Total	8	38.970				100

The analysis carried out by using MINITAB software indicates the influence of cutting parameters on surface roughness. From the above ANOVA table we can see that RRA heat treated samples feed rate influencing the surface roughness than other parameters.

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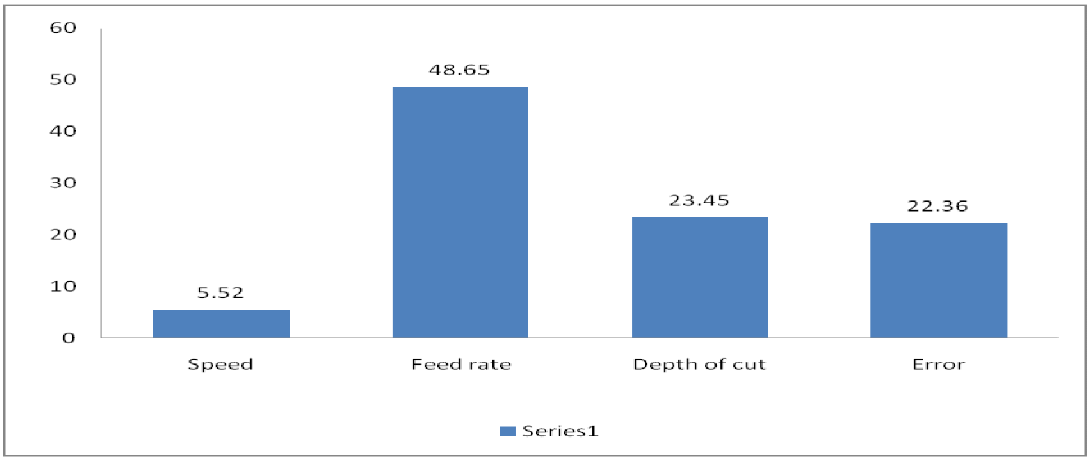

Fig 7 effect of each parameter on surface roughness of RRA sample (%)

Fig. 7 shows the percentage effect of each parameter on the surface roughness of RRA sample. It is illustrated that feed rate has the most significant effect on the output response (surface roughness). Other significant parameters are in turn depth of cut and cutting speed. These results can be used to optimally determine the best set of machining parameters as well as tool geometry specification in order to achieve the best possible surface finish

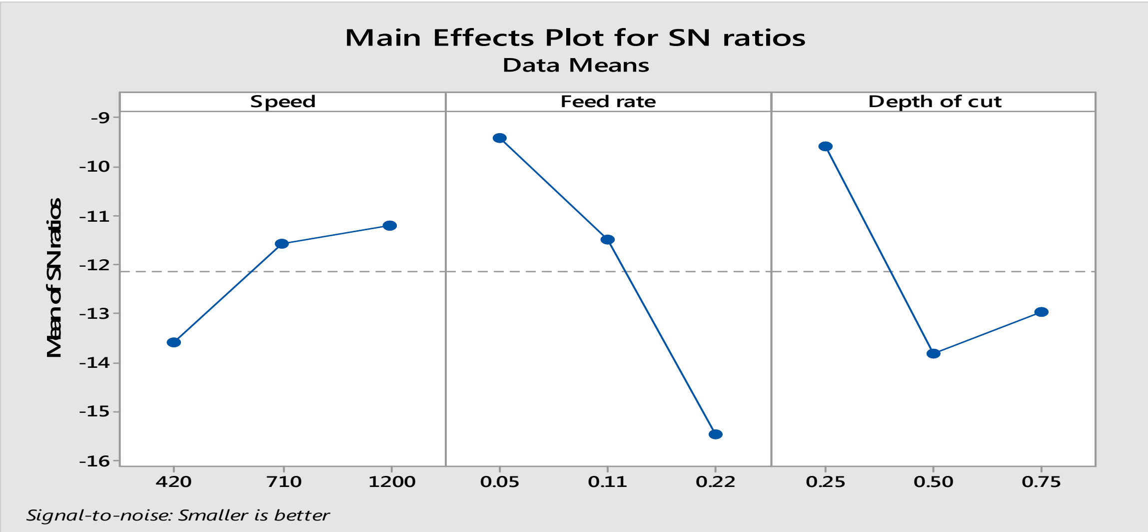

Fig 8 graph representing the influence of cutting parameters on RRA sample

From fig 8 it also indicates the signal to noise ratio is more in case of feed rate and hence confirming the influence of cutting speed on surface roughness

From the fig 8 optimum parameter conditions to minimize surface roughness are as follows

Table 12 Optimum cutting parameters for RRA

Parameter	Optimum value
Speed	1200
Feed rate	0.05
Depth of cut	0.25

6. CONCLUSIONS

In this course of study, experiment were conducted on Lathe machine with set of cutting parameters such as cutting speed, feed rate, depth of cut operation based on Taguchi orthogonal array technique for Aluminium 7075 alloy with and without heat treatment. Surface roughness as output characteristic relation between input and output was established using analysis of variance (ANOVA) tool. Tensile and harness properties of the alloy are studied before and after heat treatment. Based on the study the following conclusion is drawn

1. Hardness of the material increased after heat treatment.
2. Hardness for the As-cast sample is 53.43 HB, for T6 temper sample is 96.28 HB and for RRA heat treated sample is 107.28 HB
3. Ultimate tensile strength of the alloy increased after heat treatment.
4. Ultimate tensile strength for As-cast sample is 102.8 Mpa, for T6 temper is 141.2 Mpa and for RRA heat treated sample is155.4 Mpa.
5. Taguchi's experimental design can be performed with less number of experimentations as compared to other factorial analysis and yields similar results.
6. Taguchi's method provides simple, systematic and efficient methodology for optimizing the process parameters.
7. Surface roughness is affected by feed rate in all the three cases.

REFERECES

[1] ASM specialty hand book of Aluminum and Aluminum alloys by Joseph R. Davis.

[2] Janardhana K, D. N. Drakshayani. "Evaluation of mechanical properties of retrogression and reaged al 7075 alloy reinforced with sicp composite material". International Journal of Research in Engineering and Technology (IJRET)-Vol-03 Issue-11-Nov-2014. eISSN: 2319-1163 | pISSN: 2321-7308.

[3] Raghuraman S, Thiruppathi K, Panneerselvam T, Santosh S. "Optimization Of EDM Parameters Using Taguchi Method And Grey Relational Analysis For Mild Steel Is 2026" International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET)- Vol. 2, Issue 7, July 2013, ISSN: 2319-8753.

[4] Farhad Kolahan, Mohsen manoochehri, Abbas Hosseini. "Application of Taguchi Method and ANOVA Analysis for Simultaneous Optimization of Machining Parameters and Tool Geometry in Turning". World Academy of Science, Engineering and Technology (WASET)- 74-2011.

[5] Adeyemi Dayo Isadarea, Bolaji Aremob, Mosobalaje Oyebamiji Adeoyec, " Effect of Heat Treatment on Some Mechanical Properties of 7075 Aluminium Alloy". Materials Research. 2013; 16(1): 190-194.

[6] Vinod Kumar Vankantia, Venkateswarlu Gantab, "Optimization of process parameters in drilling of GFRP composite using Taguchi method" Journal of Material Research and technology (JMRT)- 2013.

[7] Vladimir Aleksandrovich Rogov, Ghorbani Siamak. "Optimization of Surface Roughness and Vibration in Turning of Aluminum Alloy AA2024 Using Taguchi Technique" International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering (IJMAIME)- Vol:7, No:11, 2013.

[8] Material Science by Prof. Satish V. Kailas-Associate Professor Dept. of Mechanical Engineering, Indian Institute of Science, Bangalore – 560012.

[9] Aluminium: Physical Properties, Characteristics and Alloys by Ron Cobden, Alcan, Banbury.

[10] Aluminium Alloys: Introduction to Aluminium and its alloys by Aalco. (Aalco is a registered trademark of Aalco Metals Ltd)- 07 November 2013.

[11] Shairulafizan Bin Muhammad Shamsuddin "Heat treatment process of aluminium alloys to minimize the presipitate free zones and it effect to wear resistence.

[12] P.L. Srinivasamurthy, B.N.Sarada, Karthik.B.S, Shamanth.S.Holla. "Effect of Retrogression and Reaging Heat Treatment on Microstructure and Corrosion Properties of Al-7075" International Journal of Innovative Research in Science, Engineering and Technology (IJIRSC)-Vol. 2, Issue 11, November 2013. ISSN: 2319-8753.