MULTI OBJECTIVE OPTIMIZATION OF PROCESS PARAMETERS IN DRILLING OF AL 6061-T6 AND BRASS C360 ALLOYS BY WASPAS METHOD

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Abstract: *In the present work, the drilling experiments are performed on Aluminum 6061-T6 and Brass C360 alloy block of 8mm thickness using HSS Twist drills by means of universal drilling machine. Cutting parameters drill diameter, speed and feed rate are varied at 3 different levels. A number of drilling experiments are conducted using the L_9 orthogonal array according to Taguchi design of experiment (DOE) on both materials separately. The output performances viz. MRR, surface roughness, torque and cutting forces are recorded for each run. Multi objective optimization technique WASPAS (weighted aggregated sum product assessment) method is used for determining the optimal drilling parameters resulting in minimum Surface roughness, Torque, cutting force and Maximum MRR. The measured responses were analyzed and the Influence of drill parameters on output responses such as metal removal rate and surface roughness, cutting force, torque is studied. After nine experimental trials, responses are compared for Al 6061-T6 and Brass C360 alloys.*

Keywords: *Drilling, Taguchi Design of Experiment (DOE), Al 6061-T6 and Brass C360 alloys, WASPAS method.*

1. INTRODUCTION

Drilling operation is widely used in many areas such as aerospace, automotive, marine and electrical industries etc. although modern metal cutting methods have improved in the manufacturing industries, but conventional drilling still remains one of the most common machining. It is used as a preliminary step for many operations, such as reaming, tapping and boring and most of assembly work is done through bolts and nuts, rivets etc. so components need drilling of holes for assembly. The important goal in the modern industries is to manufacture the products with lower cost and with high quality in short span of time. There are two main practical problems that engineers face in a manufacturing process. The first is to determine the values of process parameters that will yield the desired product quality (meet technical specifications) and the second is to maximize manufacturing system performance (productivity) using the available resources. It is therefore, essential to optimize quality and productivity simultaneously. The output characteristics like Material Removal Rate (MRR), surface roughness, torque, cutting force etc. are greatly influenced by the input cutting parameters like speed, feed rate, drill size etc. Therefore, selection of cutting parameter plays an important role for a sound production. The industries have to concern about a number of performance characteristics simultaneously because focus on a single objective may appear as loss for rest of the objectives and hence, multi-objective optimization techniques may be suitable.

2. LITERATURE REVIEW

A. Prabukarth et.al [1] conducted the drilling experiments on Titanium alloy to improve the hole characteristics such as hole diameter, circularity and exit burr of currently available processes. The hole quality (hole diameter and circularity), thrust force, torque and exit burr were evaluated at various spindle speeds, feed rates combinations. The optimized parameter is chosen using the multi-objective weighted sum optimization technique. The optimized spindle speed and feed rate for drilling titanium are found to be 1000 rpm and 0.13 mm/rev respectively. M.A. Amran et.al [2] conducted experiment on effects of drilling parameter such as spindle speed, feed rate and drill diameter on the surface roughness and surface texture of drilled hole using response surface method (RSM) and concluded that the appropriate combination of spindle speed, feed rate and drill diameter is very important for drilling process and also found that the parameters that affects surface roughness is spindle speed, followed by drill diameter and feed rate. Nisha Tamta et.al [3] analyzed the effect of spindle speed, feed rate, drilling depth on drilling Aluminum alloy 6082 with the help of CNC machine. Taguchi L9 orthogonal array was used to perform the experiment. Signal to noise ratio, ANOVA were used to analyze the effects drilling parameters on surface roughness. It has been found that spindle speed 3000 rpm, feed rate 15 mm/min, drilling depth 9 mm were the optimum value. According to the paper drilling depth was the most significant factor for surface roughness followed by spindle speed. B. Shivapragash et.al [4]studied optimization of the process parameters spindle speed, feed rate, depth of cut to investigate their influence in drilling of composite Al-TiBr2.Taguchi method with grey relational analysis were used to optimize the factors. L_9 orthogonal array has been used and optimal settings found for better surface finish were spindle speed (1000 rpm), feed rate (1.5 mm/rev), Depth of cut 6 mm. Madic M et.al [5] focused on multi-criteria economic analysis of various machining processes by applying recently developed MCDM method i.e. weighted aggregated sum product assessment (WASPAS) method. By using available data from literature MCDM model consisting of eight different machining processes and five economical criteria was defined. In order to determine relative significance of considered criteria a pairwise comparison matrix was applied. The obtained results from multi-criteria economic analysis suggested that AJM is the best alternative, followed by PAM and LBM. ECM obtained lowest rankings due to very high investments cost as well as low removal efficiency. Hari Singh, et.al [6] attempted to optimize the drilling process parameters considering weighted output response characteristics using grey relational analysis. The output response characteristics considered are surface roughness, burr height and hole diameter error under the experimental conditions of cutting speed, feed rate, step angle and cutting environment. The drilling experiments were conducted using L27 orthogonal array. The results reveal that combination of Taguchi design of experiment and grey relational analysis improves surface quality of drilled hole.

3. DESIGN OF EXPERIMENTS

The experiments were planned using Taguchi's L_9orthogonal array which help in reducing the number of experiments.In present work the process parameters considered are drill diameter, speed and feed each with 3 levels. The investigation carried out by varying three control factors drill diameter, Speed, Feed rate during machining. The selected range of input parameters is shown in Table 1.

Table 1: Process Parameters and their Levels

Symbol	Process parameters	Units	Levels		
			1	2	3
A	Drill diameter	mm	15	17	19
B	Spindle speed	rpm	450	560	710
C	Feed	mm/rev	0.15	0.20	0.30

4. EXPERIMENTAL DETAILS

4.1 Work Piece and Tool Materials

In present work Al 6061-T6 and Brass C360 alloys are considered as work material samples with 8mm thickness for drilling operation. Al 6061-T6 alloy is one of the most widely used heat treatable alloy that has following characteristics such as high strength to weight ratio, light weight and good machinability, high resistance to corrosion, high thermal conductivity, Toughness and good formability. Aluminum alloy 6061-T6 is widely used in many areas such as aerospace, automobiles and marine industries due to above characteristics.

Table 2: Composition of Al 6061-T6 alloy

Element Name	% by weight
Aluminum	95.86 – 98.56 %
Chromium	0.04 – 0.35 %
Copper	0.15 – 0.40 %
Iron	0.7 % max
Manganese	0.15 % max
Magnesium	0.8 – 1.2 %
Silicon	0.40 – 0.80 %
Zinc	0.25 % max
Titanium	0.15 % max
Trace Elements	0.15 % max

Brass C360 alloy is high-strength and corrosion-resistant alloy. It is different from conventional grade of brass because it composition includes 2-3.7%of lead which provides self-lubricating property and makes it easily machinable. Its machinability rating of 100 is standard against which all other copper alloys are rated. 360 brass is ideally suited for applications where strength, good corrosion resistance, electrical conductivity characteristics are important.

Table 3: Composition of Brass C360 Alloy

Element	Cu	Zn	Pb	Fe
%Weight	60-63	32-37.5	2.5-3.7	Max0.35

It has a wide range of applications such as screw machine parts nuts, bolts, gears and pinions, couplings, bushings, heat exchangers, plumbing ware fittings, door lockers, radiators in automobiles.

High Speed Steel (HSS) is a form of tool steel; HSS bits are hard and much more resistant to heat than high-carbon steel. Standard high speed steel twist drill bits of 3 different diameters (15mm, 17mm and 19mm) are used in present work.

Table 4: Chemical Composition of HSS Twist Drill

Element	W	Mo	Cr	V	C	Fe
Weight (%)	6	5	4	2	0.95	Rest

4.2 Experimental Setup

Drilling experiments are conducted on Aluminum Alloy 6061-T6 and Brass C360 alloy block of 8mm thickness as per the experimental design using Universal drilling machine.

Fig 1. Experimental Setup of Drilling Machine

4.3 Drilling Response Measurement

4.3.1 Surface Roughness

After drilling operation surface roughness of holes are measured by using a Talysurf (SJ-201 P) portable surface roughness tester (figure 2)

Fig 2. Talysurf Surface Roughness Tester

4.3.2 Material Removal Rate

Material removal rate (MRR) in drilling is the volume of material removed from work piece by the drill per unit time. Metal Removal Rate is calculated by using below formula.

MRR $= \pi/4 \times d^2 \times f \times N$ (mm3/min)

Where d = actual diameter of hole (mm)

f = feed (mm/rev)

N = drill speed (rpm).

The Diameter of holes is measured with help of digital vernier calipers.

4.3.3 Torque

Torque produced during drilling experiments is measured using drill tool dynamometer.

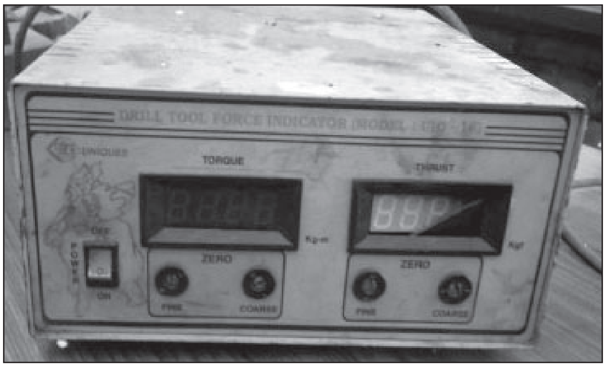

Fig 3. Drill Tool Dynamometer

4.3.4 Cutting Force

Cutting force refers to the contact force generated by the tool tip against the surface of work piece. It is perpendicular to thrust force and measured indirectly by torque determination. Cutting Force is calculated by using below formula.

Torque (T) = Cutting force (F) × radius of drill bit (N-m)

Cutting force (F) = T×2/D

Where F = Cutting Force (N)

T = Torque (N-m)

D = Diameter of Drill Bit (m)

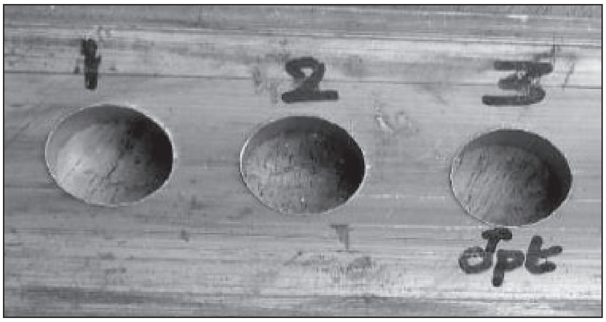

Fig 4. Brass Alloy Specimen After Drilling

Fig 5. Al Alloy Specimen after Drilling

5. WASPAS OPTIMIZATION METHOD

Weighted aggregated sum product assessment (WASPAS) method for solving MCDM. The procedural steps being involved in solving multi objective optimization problems is presented below

Step 1. Set the initial decision matrix

Step 2. Normalization of the decision matrix by using the following equations

$$\bar{X}_{ij} = \frac{X_{ij}}{max_i X_{ij}} \quad (5.1)$$

$$\bar{X}_{ij} = \frac{min_i X_{ij}}{X_{ij}} \quad (5.2)$$

Where xij is the assessment value of the i^{th} alternative with respect to the j^{th} criterion, and equations 1 and 2 are used for maximization and minimization criteria, respectively.

5.1 Entropy Approach for Weight Determination

Entropy method is one of the well-known and widely used methods to calculate the criteria of decision weights. Decision weights increases the importance of criteria and is usually categorized into two types. One is subjective weight which is determined by the knowledge and experience of experts or individuals, and the other is objective weight which is determined mathematically by analyzing the collected data. Here, it is an objective weighting method.

w_j is the weight of the jth criterion

$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}}$; X_{ij} = is normalized matrix

Entropy value e_j

$$e_j = -k \sum_{i=1}^{m} P_{ij} \ln(P_{ij})$$

Where K= $\frac{1}{\ln(m)}$; m = 9 (no.of experiments)

$$W_j = \frac{(1 - e_j)}{\sum_{j=1}^{n}(1 - e_j)}$$

Step 3. The total relative importance of the i^{th} alternative, based on weighted sum method

Table 5: Experimental Responses

Expt. No	On Al 6061-T6					On Brass C360				
	Torque (N-m)	Cutting Force (N)	Hole Diameter (mm)	MRR (cm^3/min)	SR (µm)	Torque (N-m)	Cutting Force (N)	Hole Diameter (mm)	MRR (cm^3/min)	SR (µm)
1	5.886	784.80	15.105	12.0958	0.423	6.867	915.60	15.01	11.9441	0.443
2	6.867	915.60	15.06	19.9507	0.617	7.848	1046.40	15.015	19.8316	0.640
3	8.829	1177.20	15.075	38.0175	0.723	8.829	1177.20	15.04	37.8412	0.710
4	9.810	1154.12	17.21	20.9360	0.457	11.772	1384.94	17.005	20.4402	0.483
5	11.720	1384.94	17.29	39.4447	0.567	15.696	1846.58	17.01	38.1775	0.597
6	8.829	1038.70	17.41	25.3534	0.533	10.791	1269.52	17.015	24.2161	0.730
7	14.715	1548.94	19.07	38.5589	0.683	17.658	1858.73	19.04	38.4175	0.840
8	8.829	929.36	19.10	24.0677	0.560	9.810	1032.63	19.07	23.9796	0.770
9	10.791	1135.89	19.07	40.5583	0.643	12.753	1342.42	19..11	40.6647	0.823
Avg.	9.586	1118.83		28.77	0.578	11.336	1319.3		28.39	0.67

Table 6: Normalized Values of Output Responses for Al 6061-T6

Normalized values Xij				
Exp. No	**Surface roughness**	**MRR**	**Torque**	**Cutting force**
1	1	0.298232	1	1
2	0.685575	0.491902	0.857143	0.857143
3	0.585062	0.937354	0.666667	0.666667
4	0.925602	0.516195	0.6	0.679999
5	0.746032	0.972543	0.502218	0.566667
6	0.793621	0.62511	0.666667	0.75556
7	0.619327	0.950703	0.4	0.506669
8	0.755357	0.59341	0.666667	0.844452
9	0.657854	1	0.545455	0.690912

(WSM), is calculated as follows:

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{X}_{ij}.W_j \quad (5.3)$$

Step 4. The total relative importance of the i^th alternative, based on weighted product method (WPM), is calculated as follows

$$Q_i^{(2)} = \prod_{j=1}^{n} \overline{X_{ij}}^{W_j} \quad (5.4)$$

Step 5. A joint generalized criterion of weighted aggregation of additive and multiplicative methods is then proposed as follows

$$Q_i = 0.5.\,Q_i^{(1)} + 0.5.\,Q_i^{(2)} \quad (5.5)$$

In order to have increased ranking accuracy and effectiveness of the decision making process, in the WASPAS method, a more generalized equation for determining the total relative importance of alternatives is developed as below:

$$Q_i = \lambda.\,Q_i^{(1)} + (1-\lambda).\,Q_i^{(2)} \quad (5.6)$$

Where λ = 0, 0.1, 0.2,…….1.

Table 7: Normalized Values of Output Responses for Brass C360

Normalized values Xij				
Exp. No	Surface roughness	MRR	Torque	Cutting force
1	1	0.293722	1	1
2	0.692188	0.487686	0.875	0.875
3	0.623944	0.930566	0.777778	0.777778
4	0.917184	0.502652	0.583333	0.661112
5	0.742044	0.938836	0.4375	0.495836
6	0.606849	0.595507	0.636364	0.721217
7	0.527381	0.944738	0.388889	0.492594
8	0.575325	0.589691	0.7	0.886668
9	0.538275	1	0.538462	0.682052

Table 8: Total Relative Importance and Ranking of Alternatives using WASPAS Method

Exp. No	A	B	C	On Al 6061-T6 alloy				On Brass C360 alloy			
				WSM Values $Q_i^{(1)}$	WPM Values $Q_i^{(2)}$	Q	Rank	WSM Values $Q_i^{(1)}$	WPM Values $Q_i^{(2)}$	Q	Rank
1	1	1	1	0.661016	0.557426	0.609221	8	0.708601	0.603224	0.655913	6
2	1	1	2	0.661509	0.639288	0.650399	7	0.685948	0.662185	0.674066	4
3	1	1	3	0.788285	0.774549	0.781417	2	0.8162	0.808495	0.812348	**1**
4	1	2	1	0.607948	0.59677	0.602359	9	0.616139	0.601935	0.609037	9
5	1	2	2	0.766351	0.735573	0.750962	3	0.702579	0.665837	0.684208	3
6	1	2	3	0.674117	0.671463	0.67279	5	0.628609	0.627151	0.62788	8
7	1	3	1	0.70654	0.661158	0.683849	4	0.657281	0.612023	0.634652	7
8	1	3	2	0.667833	0.662119	0.664976	6	0.664952	0.656851	0.660902	5
9	1	3	3	0.799385	0.773391	0.786388	1	0.75225	0.722401	0.737325	2

Table 9: Response Table for WASPAS Index

Process Parameter	Average WASPAS Index (for Al 6061-T6)				Rank	Average WASPAS Index (for Brass C360 alloy)				Rank
	Level 1	Level 2	Level 3	Max-min		Level 1	Level 2	Level 3	Max-min	
Drill diameter	0.680346	0.67537	**0.711738**	0.036367	3	**0.714109**	0.640375	0.677626	0.073734	2
Speed	0.63181	0.688779	**0.746865**	0.115055	**1**	0.6332	0.673059	**0.725851**	0.092651	**1**
Feed	0.648996	0.679715	**0.738743**	0.089747	2	0.648231	0.673476	**0.710403**	0.062171	3

Table 10 : Experimental Results at Optimal Parameter Combination

Work material	Optimum combination of parameter (Drill diameter, speed, feed)	Surface roughness (μm)	MRR (cm^3/min)	Torque (N-m)	Cutting force (N)
Al 6061-T6 alloy	19 , 710 , 0.3	0.673	62.443	11.77	1238.9
Brass C360 alloy	15, 710 , 0.3	0.710	37.841	8.829	1177.20

6. RESULTS AND DISCUSSIONS

6.1 Experimental Responses Obtained on Drilling of Al 6061-T6 and Brass C360 Alloy is Presented in Table 5

6.2 Optimization by WASPAS method

For each response the normalized values are calculated using equation 5.1 and 5.2 for maximization and minimization of responses respectively which is shown in table 7 and table 8 for both materials. From the equations 5.3, 5.4, 5.5 the relative importance in WSM, relative importance in WPM and total relative importance are calculated respectively shown in table 8.

The WASPAS index values for each level of process

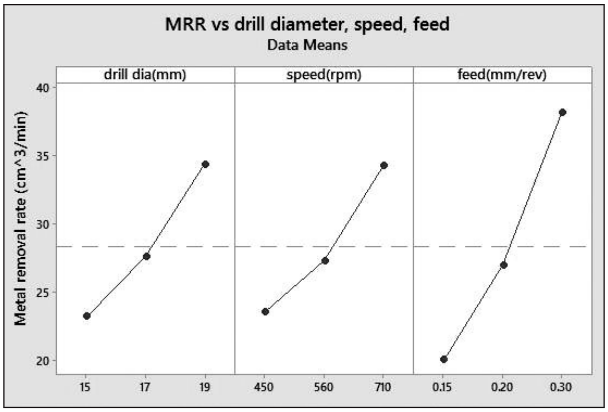

Fig 6. Effect of Drill Parameter on Metal Removal Rate

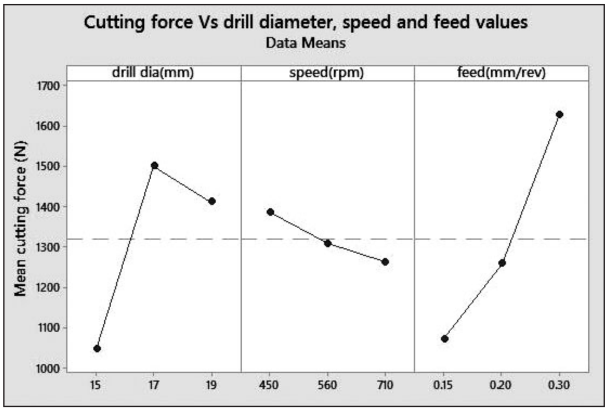

Fig 9. Effect of Drill Parameter on Cutting Force

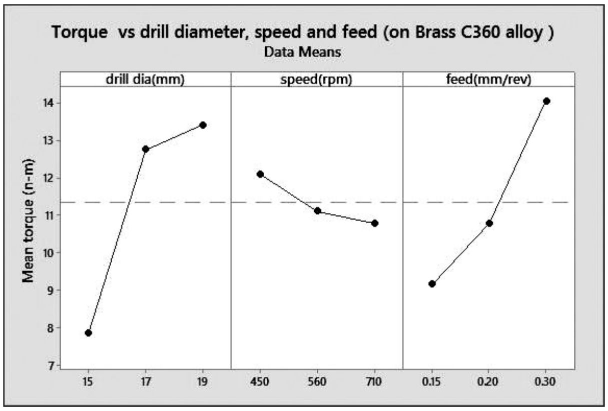

Fig 7. Effect of Drill Parameter on Torque

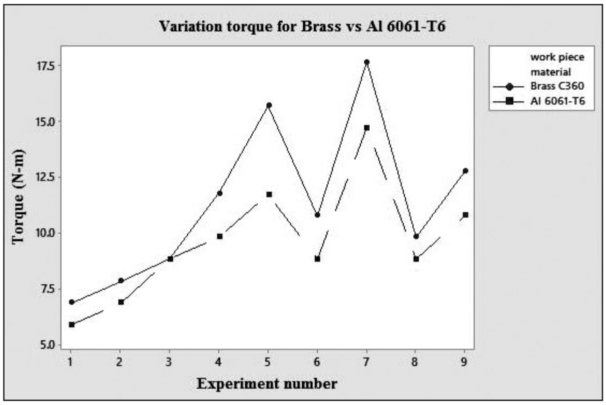

Fig 10. Variation of Torque

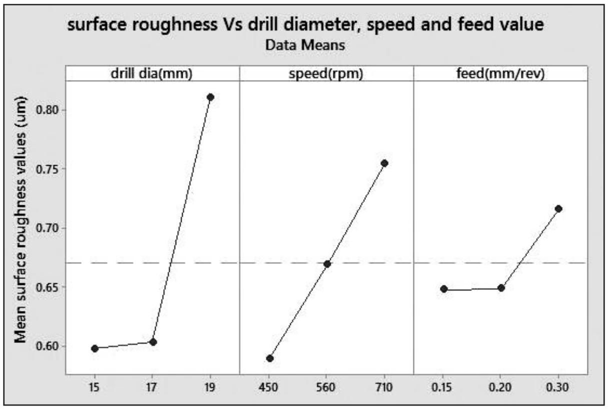

Fig 8. Effect of Drill Parameter on Surface Roughness

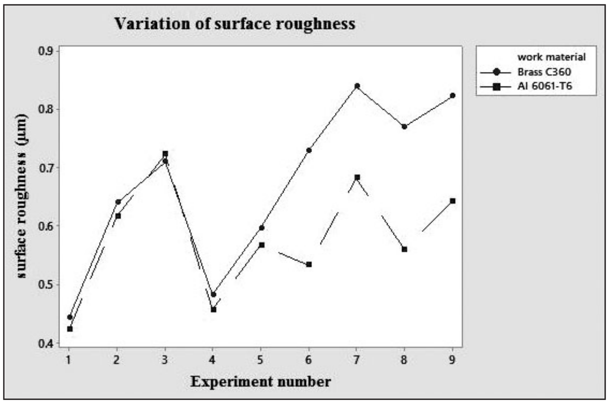

Fig 11. Variation of Surface Roughness

parameters are shown in Table 10. Regardless of the category of performance characteristics, a higher WASPAS index value corresponds to better performance. Therefore, the optimal level of the machining parameters was the level with the highest WASPAS index value. Finally conformation of experiment is done at optimum combination of drill parameters and the responses obtained at optimal combination of parameter is given in table 10.

6.3 Influence of Drill Parameters on Responses Obtained On Brass C360 Alloy

The below graphs shows the main effect of drill diameter, speed and feed levels on their mean responses such as MRR, surface roughness, torque and cutting force obtained on drilling of brass C360 alloy.

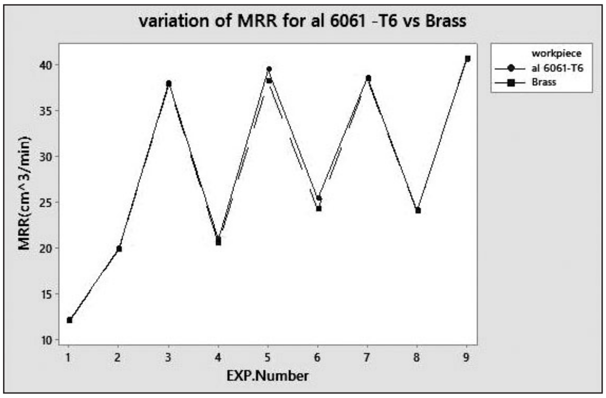

Fig 12. Variation of Metal Removal Rate

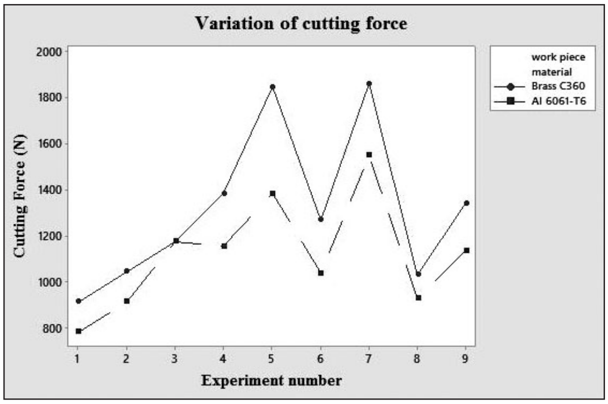

Fig 13. Variation of Cutting Force

From figure 6 metal removal rate increases with increase in drill diameter, speed and feed levels. This is due to the fact that the volume of material removal is to proportional to πD2/4*f*N, where D is the diameter of drill bit and f is the feed rate and N is drill speed.

From figure 7 Torque increases with increases in drill diameter and feed rate but as speed increases this results in reduction in heat generated at chip tool interface, and decreases the torque. Chip thickness increases with increase in feed rate. These thick chips need high amount of shear force, which directly increases the torque. From figure 8 main effects plot reveals that as increase in feed, speed and dill diameter increases the surface roughness.This is due to vibration and chatters produced at high speed and feed rates. From figure 9 reveals that cutting force increases with increase in feed rate and as speed increases the cutting force decreases. Similarly on Al alloy is studied.

6.4 Comparison of Experimental Responses

Experimental responses obtained by drilling on Al 6061-T6 and Brass C360 alloys under similar input conditions are compared and their plots are given below

From figure 10 it is observed from comparison, average torque obtained for 9 experiments on Al 6061-T6 is 9.586 N-m and on Brass C360 alloy is 11.336 N-m (i.e. 18.25% more than Al 6061-T6 alloy). Minimum torque is obtained for both material at experiment 1 but torque is more for brass alloy due to high strength. From figure 11 Average surface roughness obtained for 9 experiments on Al 6061-T6 is 0.578µm and on Brass C360 alloy is 0.67µm (i.e. 15.91% more compared Al 6061-T6 alloy). From figure 12 Average metal removal rate obtained on Al 6061-T6 is 28.77cm3/min and on Brass C360 alloy is 28.39cm3/min (i.e. 1.32% less compared to Al 6061-T6). The maximum metal removal rate is obtained at experiment 9 for both materials but MRR obtained on brass alloy is less because brass alloy is harder than Al 6061-T6 alloy. From figure 13 Average cutting force obtained on Al 6061-T6 is 1118.83 N and on Brass C360 alloy is 1319.3 N (i.e. 17.91% more compared to on Al 6061-T6).

7. CONCLUSIONS

From the research of present work, the following conclusions are drawn.

1. In the presents work, drilling parameters are optimized for obtaining higher MRR, lower surface roughness, cutting force and torque values on Al 6061-T6 and Brass C360 alloys having same thickness under similar input conditions using WASPAS method.
2. The optimal process parameter setting on Al 6061-T6 alloy lies at drill diameter 19mm, spindle speed 710 rpm and feed 0.3mm/rev.
3. The optimal process parameter setting on Brass C360 alloy lies at drill diameter 15mm, spindle speed 710 rpm and feed 0.3mm/rev.
4. Influence of variation in drill parameters on responses is studied.
5. Output responses are successfully compared between Al 6061-T6 and Brass C360 alloys for 9 experiments. It has been identified that torque, cutting forces, surface roughness are greater for Brass C360 alloy than Al 6061-T6 alloy and Metal removal rate obtained on Al 6061-T6 alloy is more compared to Brass C 360 alloy.

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