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Prediction of Process Parameters That Affecting on Surface Roughness in Multi-Point Forming Process Using ANOVA Algorithm

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Abstract

Multipoint forming process is an engineering concept which means that the working surface of the punch and die is produced as hemispherical ends of individual active elements (called pins), where each pin can be independently, vertically displaced using a geometrically reconfigurable die. Several different products can be made without changing tools saved precious production time. Also, the manufacturing of very expensive rigid dies is reduced, and a lot of expenses are saved. But the most important aspects of using such types of equipment are the flexibility of the tooling. This paper presents an experimental investigation of the effect of three main parameters which are blank holder, rubber thickness and forming speed that affect the surface integrity for brass (Cu Zn 65-35) with 0.71 mm thickness.

This paper focuses on the development of prediction models for estimation of the product quality. Using Analysis of Variance (ANOVA), surface roughness has been modeled. In the development of this predictive model, blank holder, rubber thickness and forming speed have been considered as model parameters. The mean surface roughness (Ra) is used as response parameter to predict the surface roughness of multipoint forming parts. The data required has been generated, compared and evaluated to the proposed models obtained from experiments.

Taguchi algorithm was used to predict the forming parameters (blank holder, rubber thickness and forming speed) on product roughness in forming process of Brass (Cu Zn 65-35) based on orthogonal array of L9 and finally ANOVA was used to find the optimum parameters that have effect on the product quality.

Keywords: *Analysis of variance (ANOVA), Forming Parameters, Multipoint forming process (MPF, Surface Roughness.*

1. Introduction

Multipoint forming (MPF) is a modern manufacturing technology for three-dimensional sheet metal forming process. The idea of forming die of various shapes has been always attractive as a means of reduction costs of die design, since it would permit design iterations to be rapid and nearly cost Free [1].

The effecting method for manufacturing sheet metal product of 3D complex shapes is sheet metal forming process. This traditional process use a matched solid die set that forms a cavity into which the sheet is displaced. Sometimes, several sets may be needed to form a sheet metal parts. In this process, to produce different shaped of parts that must be required different dies. The design and manufacturing of punch and dies is a costly work and must rely on the experience of designers and workers. The idea of die forming of variable shape has always been attractive as a means of reducing die design costs [2].

A schematic of a multipoint forming process with a blank-holder is shown in figure (1).

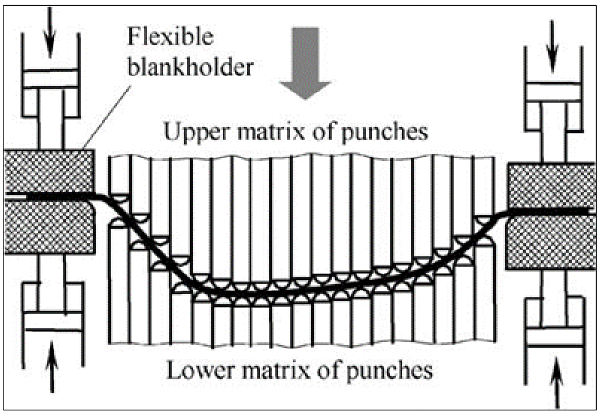


Fig. 1. Principle of multi point forming process [1].

A series of experiment have been carried out in design of experiments to investigate the effect of forming parameters such as blank Holder, rubber thickness and forming speed on surface roughness. Linfa Peng et al (2006) [3] design the contact surface between the workpiece and the surfaces of the blank holder. Two designs were developed to transition surface one is a bridge surface extension, and the flexible surface extension. These two approaches that used continuity type (G2) to transition the design surface with both reliable and effective. In this transition design surface, the Applications gave manufactured the forming product with high-quality products in (MPF). Yajie Liu et al (2016) [4] designed an original rigid flexible blank holder (FBH) device. Models of Finite element analysis (FBH) are established without used of blank holder (NBH); the simulation is applying with different BHF in forming spherical surface parts and then acquired the optimal BHF. The results indicate that FBH forming process can be release effectively wrinkling defects, thickness distribution is more reasonable, sheet metal flow is more uniform, and distribute uniformly and the stress and strain are minimum. Babak Beglarzadeh (2017) [5] investigate a flexible method for forming a metal, multi-point forming is used to form initial size of 300 × 300 mm using aluminum alloy sheet 2024. Finite elements were simulated through ABAQUS/EXPLICIT 6.14.1. Through, increasing of elastic layer (cushion) hardness, the minimum required a thickness of elastic layer proliferates. Furthermore, (BHF) increment has a direct relation with the enhancement in hardness of polyurethane layer. The multipoint forming process of aluminum sheet are performed, and the comparisons of a forming process between simulation functions and experimental parts are applied, which establish that the aluminum products have the best shape accuracy and surface accuracy.

A.A. Tolipov et al (2017) [6] investigated the effect of process variable such as the force of blank holder, elastic cushion thickness, radius of curvature and coefficient of friction on the performance of forming parts in a flexible multi-point process the research was carried out a multipoint forming process using a blank holder in order to study the effects of the, dimpling, wrinkling forming force and reduction of thickness to determine the optimum value of these variables are performed to simulate the multipoint forming of hemispherical shapes using finite element modeling. The effects of process variables on maximum deviation from thickness reduction, the target shape and wrinkling were estimate using the response surface methodology.

Tahseen Fadhel Abaas et al (2018) [7] investigated the achievement of a multipoint die with tools in square matrix and suitable blank holder. Each pin in the punch holder can be a significant moved according to the die high and at different load that applied with spring with respect to spring stiffness. The results shows the reduction in setting time with respect to traditional single point incremental forming process that lead to (90%). and also show during the forming process, the deformation of the interpolator formed work-piece can induce a shape error and the blank holder can eliminate or reduce dimples in the work-piece.

They predict the optimum value of some process variable that effect on surface roughness and estimate the empirical equation that present the response value with respect to process variables.

2. Experimental Work

2.1. Material and Process

Samples of brass alloy (Cu Zn 65-35) with thickness (0.7 mm) were used to perform the experiments (9-samples). The geometry of forming tool that used in this work is shown in figure (2). While the geometry of final product illustrated in figure (3).

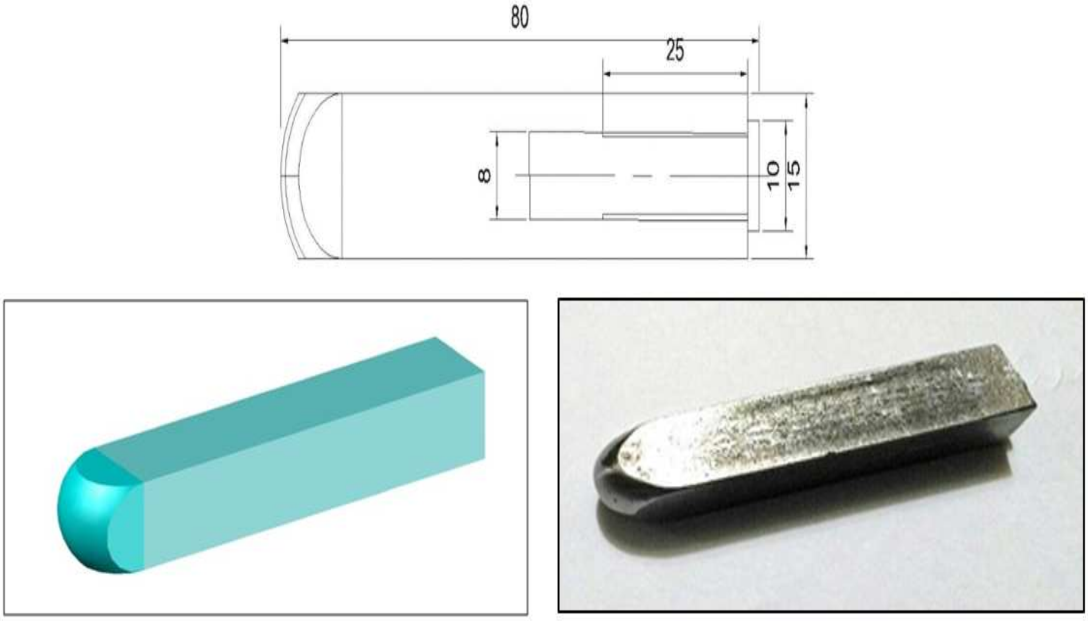
The experimental work was applied using oil lubricant on a C-tek three-axis (KM-80D) CNC machine with rotational speed of (6000 rpm), feed of (10 m/min) to manufacturing the hem-spherical shape used as the a half-die. The mechanical properties and chemical composition of brass (65-35) is illustrated in tables (1 & 2). The shape of forming tools that used in this work is square tool steel (15x15x80 mm) while the tip of tool is hem-spherical shape. Three types of blank holder was with different size and shape that illustrated in Figure (4) while multi-point forming die and the final nine products are illustrated in figure (5).

Table 1,
Mechanical properties for Brass sheet (Iso- Cu Zn 65-35 426/1).

Material		**Tensile Strength MPa**	**Modulus of Elasticity GPa**	**Poissons Ratio**	**Elongation % on 50 mm G.L.**	**Vickers Hardness HV**	**Iso**
65/35 Brass	Exp.	230	-	0.375	31.5	≤ 100	Cu Zn 35
’O’	Iso	230	110	0.33	56	≤ 90	426/1

Table 2,
Chemical composition of Brass sheet (Iso- Cu Zn 65-35 426/1).

Material		**Zn%**	**Pb%**	**Sn%**	**P%**	**Mn%**	**Fe%**	**Ni%**	**Si%**	**Al%**	**Cu%**
Brass	Exp.	35.23	0.007	0.001	0.007	0.000	0.021	0.001	0.001	0.002	64.7
	Iso	35.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.0



Forming Tool

Fig. 2. Geometry of the forming tool (all dimension in (mm)).

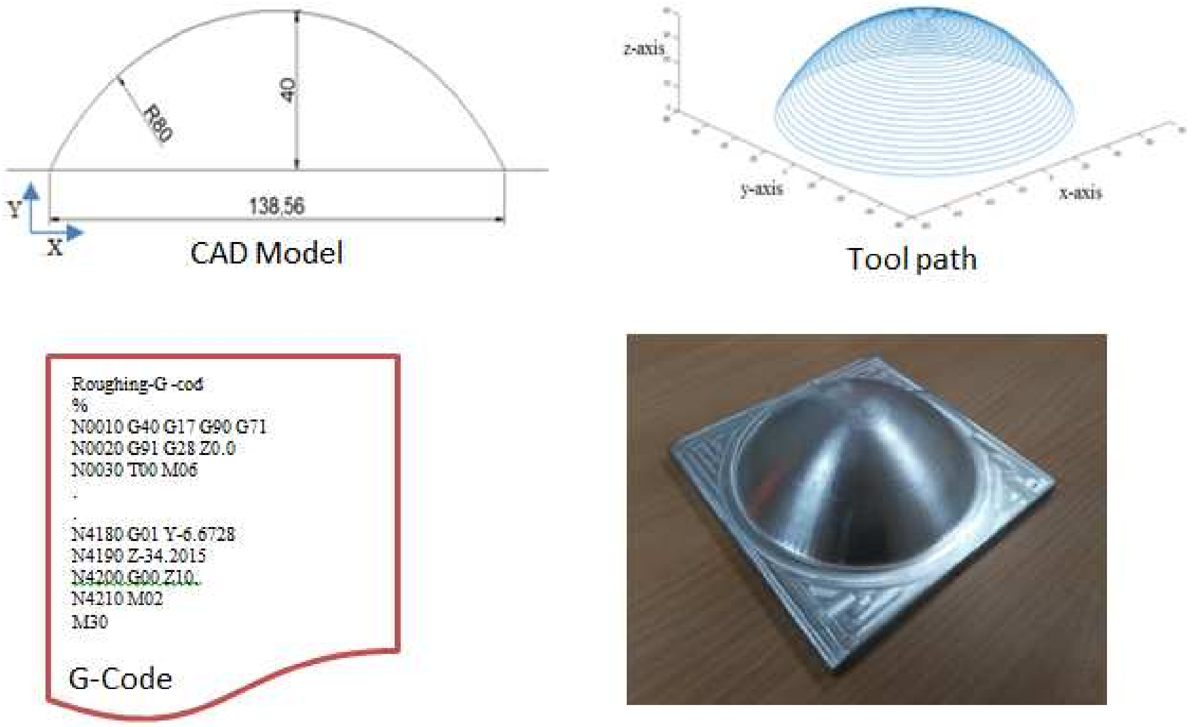
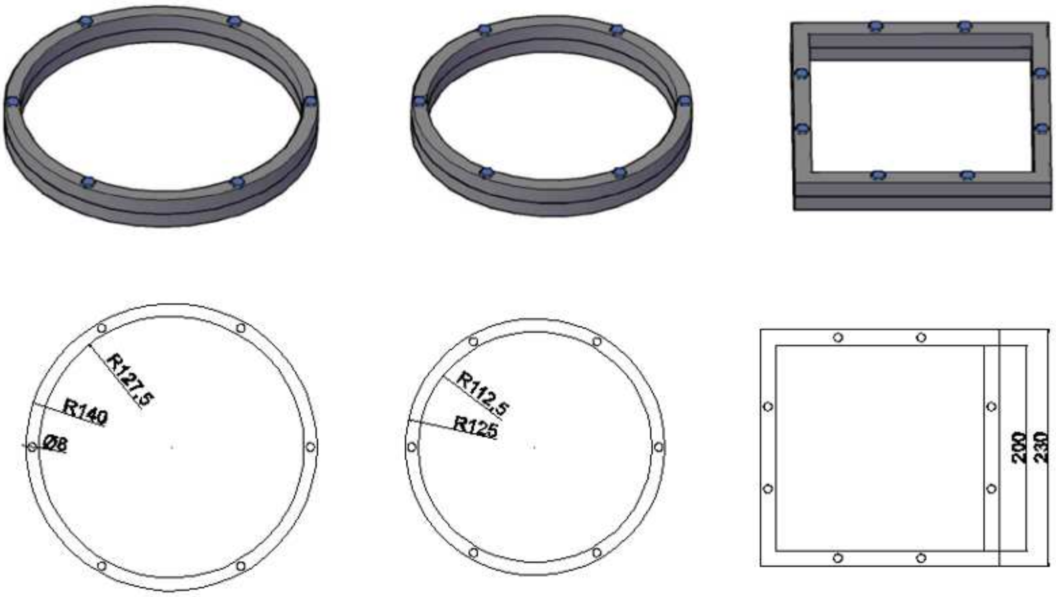


Fig. 3. Geometry of part and CNC-part program. (all dimension in (mm)).



(a) **(b)** **(c)**

Fig. 4. Types of blank holder that used in this work.

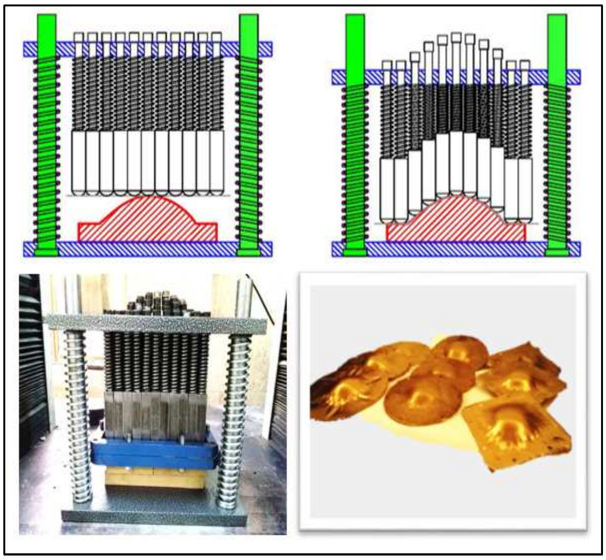


Fig. 5. The experimental setup and nine-samples.

The measurement device that used in this work is surf tester (Mahr pocket surf test) device, figure (6). This device was used to measure the surface roughness of the formed surface, the forming surface was measured after cut off to simplest the measurement procedures at three different positions and Arithmetic mean surface roughness (Ra) are used as output parameters to evaluate the surface quality of multipoint forming product**.**

Fig. 6. Surface roughness measurement device.

2.2. Plan of Experiments

An important stage in response surface model generation by ANOVA is the planning of experiments. The parameters which has a significant influence on surface quality was identified they by blank holder types, cushion thickness and forming speed in multi-point forming process. Figure (7) present the problem solving and the analysis of data.

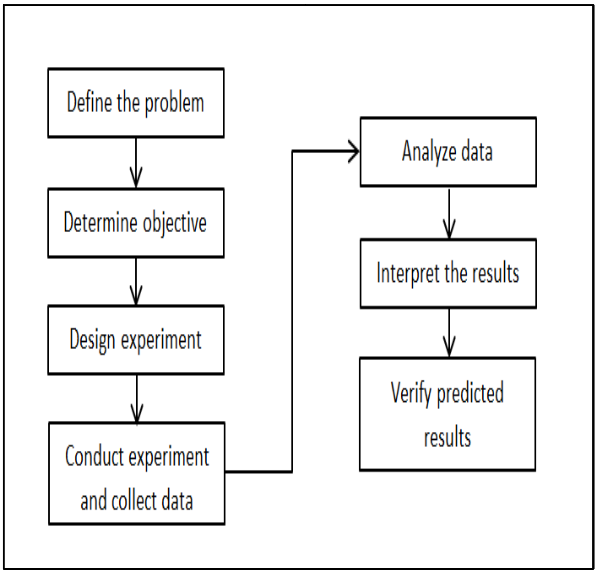


Fig. 7. define the research problem and their analysis.

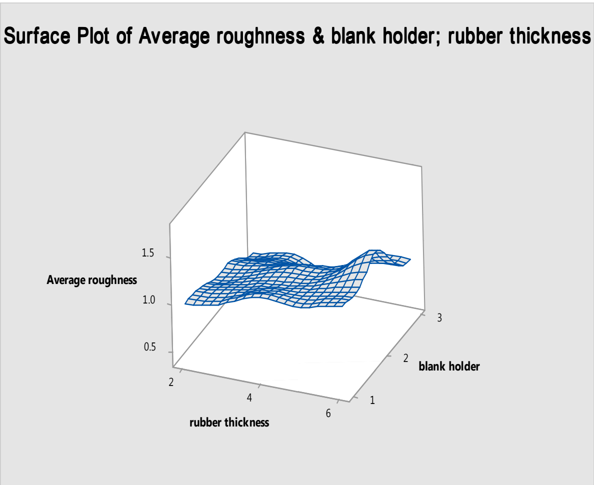
Uses a special design of orthogonal arrays with a small number of experiments Taguchi method to study the entire parameter space. The methodology of Taguchi for three factors (blank holder, elastic cushion thickness and forming speed) at three levels for each is used to applied the experiments. To define the nine trial conditions, is used the degrees of freedom required for the study is six and Taguchi's (L9) orthogonal array. The levels and process parameters are illustrated in table (3). The average response and Replicated twice values for each of the process designs of nine trials are used. Table (4) illustrated the present work and the test results, and figures (8, 9 and 10) represent the relationship between experimental data.

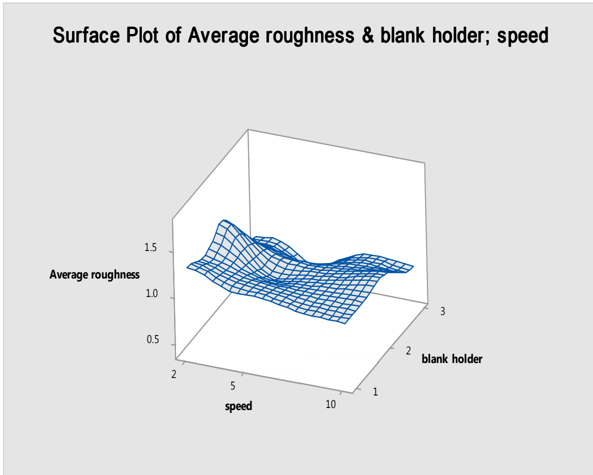
Table 3,
levels and parameters

Parameters	**Unit**	**Lev.1**	**Lev.2**	**Lev. 3**
Blank holder type (B)	-	1	2	3
Rubber thickness(R)	mm	2	4	6
Speed (S)	mm/min	2	5	10

Table 4,
Taguchi's L9 orthogonal array and response value

	Parameters			Response value			
Exp. No	**blank holder type**	**Rubber thickness mm**	**Speed mm/min**	**Surface roughness μm**			
				R_{a1}	R_{a2}	R_{a3}	R_{av}
1	1	1	1	1.11	1.13	1.15	1.13
2	1	2	2	1.30	1.27	1.27	1.28
3	1	3	3	1.02	1.09	1.06	1.0567
4	2	1	2	0.50	0.58	0.57	0.55
5	2	2	3	0.99	1.01	1.01	1.0033
6	2	3	1	1.80	1.71	1.82	1.7767
7	3	1	3	0.80	0.84	0.79	0.81
8	3	2	1	0.55	0.54	0.54	0.5433
9	3	3	2	0.81	0.74	0.77	0.7733





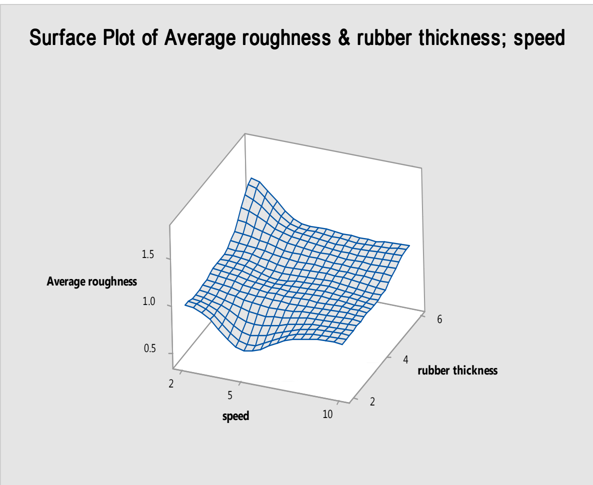


Fig. 8. The relationship of average roughness with respect to process parameters.

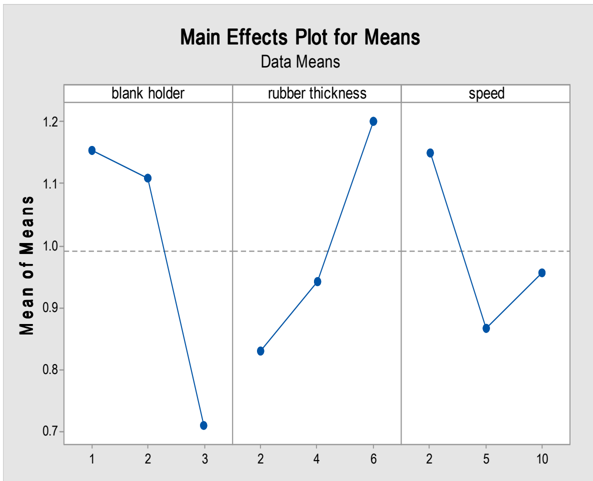


Fig. 9. The relationship of mean of mean for each process variable.

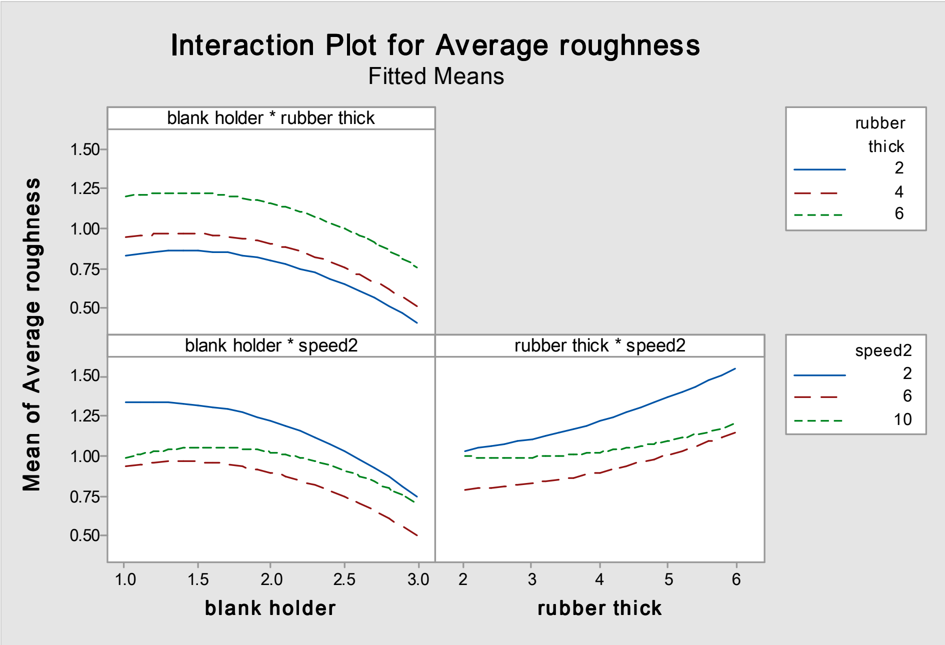


Fig. 10. The relationship of response value with respect to process variables.

3. Prediction of Process Parameters

Using Taguchi's algorithm to predict the effect of each parameters on the response value and to estimate the empirical equation contribute between each process parameter in second order as illustrated in equation (1) to optimize the present work with present of confidence (R=86.53%), From the given data (blank holder (B), rubber thickness (R) and forming speed (S)) with respect to surface roughness. Table (5) represents the final prediction value using Taguchi's algorithm, while table (6) represent the analysis of variance using ANOVA algorithm.

$$R_{av} = 0.5617 + 0.2034B + 0.7165R - 0.4155\ S - 0.1778\ B^2 - 0.03105\ R^2 + 0.0081S^2 - 0.116BR + 0.1321BS \quad \dots (1)$$

Table 5,
prediction of process parameters with respect to response value using empirical equation

	Process Parameters			**Average Response**
Exp. No.	**blank holder type**	**Rubber thickness mm**	**Speed mm/min**	**Surface roughness µm R_{av}**
1	1	2	5	0.87037
2	1	2	10	0.95925
3	1	4	2	1.26481
4	1	4	10	1.07148
5	1	6	2	1.52481
6	1	6	5	1.24259
7	2	2	2	1.10704
8	2	2	10	0.91370
9	2	4	2	1.21926
10	2	4	5	0.93703
11	2	6	5	1.19704
12	2	6	10	1.28593
13	3	2	2	0.70592
14	3	2	5	0.42370
15	3	4	5	0.53592
16	3	4	10	0.624815
17	3	6	2	1.07815
18	3	6	10	0.884815

Table 6,
analysis of variance using ANOVA algorithm

Analysis of Variance					
source	Df	Adj ss	F-Value	P-Value	F_t
blank holder	1	0.84043	40.61	0.000	✓
rubber	1	0.57484	27.78	0.000	✓
speed	1	0.16820	8.13	0.011	✓
Second order					
blank h*blank h	1	0.18963	9.16	0.008	✓
rubber*rubber	1	0.03276	1.58	0.225	×
speed*speed	1	0.25852	12.49	0.003	✓
2-Way Interaction					
blank h*rubber	1	0.00038	0.02	0.893	×
blank h*speed	1	0.06678	3.23	0.090	×
rubber*speed	1	0.07449	3.60	0.075	×
Error	17	1.5834			
Total	26	2.61191			

Level of confidence (F-value) =95% =0.95
Level of significance (P-value) =5% = 0.05
1- P-value
P < 0.05 → Significant
P > 0.05 → Non- Significant
2- Fisher value (F-value)
F > FT (from table) Critical tabulated
FT=4.4513

$$\text{Percent of contribution \%} = \frac{\text{Adj ss}}{\text{Total Adj ss}} * 100\ \% \quad \dots (2)$$

Percent of contribution %
Blank holder =53.075 %
Rubber thickness =36.301 %
Speed of forming =10.622 %

4. Results and Discussion

The results of this work is to investigate the effect of various forming parameters (blank holder (B), rubber thickness (cushion) (R) and forming speed (S)) with respect to surface roughness that occurs on the forming parts of Brass (Cu Zn 65-35) using multi-point forming process. The figures were result from the experimental work using ANOVA algorithm that illustrated in Figures (7and 8). The effects of two input parameters represents in each curve in otherwise the parameter was kept constant.
The effect of blank holder on the minimum surface roughness at the different cushion thickness and forming speed were used. In this work, with respect to the range of forming parameters used, explain that at the rubber thickness (R=2mm) and using blank holder type (3) and forming speed of (S=2mm/min) that gives minimum surface roughness (R_a=0.42370), as shown in Figures (9) and table (5). While Figure (10) presents the variance of average roughness value with respect to three process parameters. The final result is estimate the empirical model of each forming parameters with respect to average surface roughness using Taguchi's algorithm. Percentage effect of blank holder types, rubber thickness and forming speed with respect to minimum surface roughness was (53.075, 36.301 and 10.622) % respectively as shown in Figure (11).

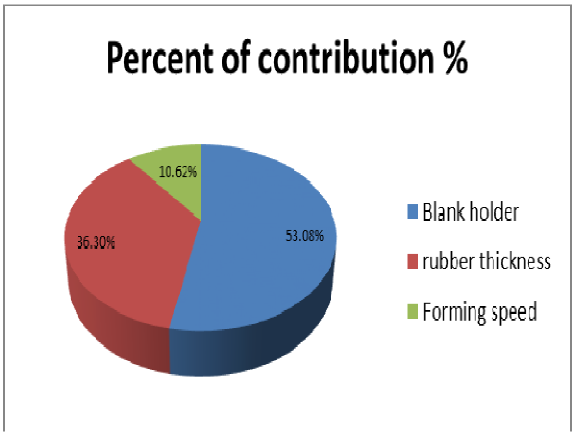


Fig. 11. The contribution of process parameters that effect on surface roughness.

5. Conclusion

The current research reviewed some important aspects related with surface roughness on forming of materials with special emphasis in brass-alloy. Based on the results of the present work of surface roughness in multi-point forming process using ANOVA algorithm, the following conclusions can be drawn:

1. In multipoint forming process, the process parameters (blank holder types, rubber thickness and forming speed) is the main factors that effect on surface roughness.
2. The results of ANOVA Algorithm and the effectiveness experiments data that the developed empirical models for the output responses provide the predicted values and shows an excellent fit of these surface roughness factors that are close to the experimental values, at (R=86.53%)% confidence level.
3. The optimum value of roughness that result from this work using ANOVA is equal to (Ra=0.42370) when using blank holder type (3) and cushion thickness (R=2mm) and at forming speed of (S=5mm/min).
4. medium forming speed gave the best surface roughness, because it give enough time for the metal to reorganize the atoms and thus reduce the strength of the metal resistance to the forming force, the effectiveness range up to (10.622%).
5. Low cushion thickness takes the best surface roughness because the contact area between forming tool and blank is minimum that occurs best result, the effectiveness range up to (36.301%)
6. The blank holder type (3) gave the best surface roughness up to (53.075%).

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تخمين متغيرات عملية التشكيل متعدد النقاط التي تؤثر على خشونة السطح باستخدام خوارزمية تحليل التباين

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الخلاصة

التشكيل متعدد النقاط هو مفهوم هندسي يعني بتشكيل السطح باستخدام قالب علوي وسفلي متكون من عدد كروية صغيرة مستقلة في فعاليتها تدعى (مسمار) والتي يكون فيها كل عدة تشكيل مستقرة وموضوع بشكل ملائم نسبة للسطح المراد تشكيله، عدد متنوع من النماذج ممكن تصنيعه عن طريق تغير موقع العدة مما يؤدي الى تقليل زمن الانتاج والتي تعد من العمليات واطئة الكلفة والسريعة لإمكان انتاج منتجات متعددة للقالب نفسه، والتي تزيد من مرونة المعدات المستخدمة في عملية التشكيل. في هذا البحث سيتم تحقيق تأثير ثلاثة متغيرات رئيسة في عملية التشكيل (نوع مثبت المنتج، سمك طبقة المطاط وسرعة عملية التشكيل) على جودة السطح الناتج لسبيكة البراص بسمك (٠.٧١ملم).

في هذا البحث تم التركيز على تطوير موديل تخميني لتطوير جودة السطح. وباستخدام خوارزمية تحليل التباين تم تكوين الموديل الرياضي لجودة السطح بالنسبة لنوع المثبت وسمك طبقة المطاط وسرعة عملية التشكيل حيث تم اختبار البيانات المطلوبة ومقارنتها مع النتائج العملية وحساب مقدار التطابق وتاثير كل متغير للعملية. تم استخدام خوارزمية تاكوشي لتخمين متغيرات العملية (مثبت الصفيحة، سمك طبقة المطاط وسرعة عملية التشكيل) على الخشونة السطحية لتشكيل صفيحة براص (٦٥-٣٥) باستخدام مصفوفة (L9) وايجاد اكثر متغير له تاثير على مخرجات العملية.