Optimization Of Hardness In Barreled Cylindrical Billets - A Taguchi Approach

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Abstract

The present work focuses on the application of 'Taguchi Approach'. In the cold forging process at the die/billet interface plays a significant role. were as deciding the billet material, lubrication ,and number of stages to make products .in this work, the influence of varied friction conditions on the hardness is studied. The friction factors of these lubricants molybdenum disulphide(m=0.29), Teflon grease(m=0.37)and silicon grease(m=0.44) were obtained from ring compression test(RCT). The whole configuration assumed to be axi-symmetric and the AA2014 solid cylindrical billets compressed between the dies. At each and every incremental level of deformation process, the following results were noted down. From the simulation study mainly hardness depends upon three major factors as friction effect, aspect ratios, and temperature effect. By using these parameters were optimized to get much uniform distribution of hardness in the billet, to reduce the deformation load and barrelling effect.

***Keywords**— Ring compression test(RCT);Ageing; Machining; forging.*

1. Introduction

1.1 Factors Effecting hardness:

The parameters which influence the hardness are ductility of the material, friction, rate of deformation, heat treatment process such as annealing, ageing etc and height to the diameter ratios of the billets. Out of these parameters, the aging time will improve the ductility of the material. Less friction at the billet interface allows the free flow of material in the radial direction in simple upsetting process and high friction makes the die to stick to the billet and constraining the material to flow in the radial direction. This inability of flow of material reduces the plastic strain and thereby decreasing the hardness. More height to the diameter ratios makes the material to fail at lower strain and bulge more at the equator. This makes loosening of the material near the equator of the billet and hardness inside the billet is not uniform.

1.2 Investigation plan : Taguchi approach will be followed to optimize the hardness which requires a minimum of 3 parameters.

(i) Friction at the die/billet interface**:** Friction coefficient varies with the lubricant applied which was evaluated from the Ring Compression test.

(ii) Height to the diameter ratios of the billet **:** AA2014 cylindrical billets of diameter 24mm were machined to different height to the diameter ratios of h/d=1, h/d=0.75 and h/d=0.5.

(iii) Heat Treatment process: The billets were heat treated in a furnace at a temperature of 502 ^{0}c and then water quenched. The solutionized samples were aged at 160^{0}c for different times of 2hrs, 4hrs and 6hrs to improve the ductility of the material.

After performing the above steps the samples need to be deformed by applying the necessary conditions for the optimization approach.

The objective of the present work is to optimize the process parameters involved in billet expansion process by using Taguchi and ANOVA methods. The settings of process parameters were determined by using Taguchi's experimental design method. Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, the analysis of variance (ANOVA), and regression analyses are employed to find the optimal levels and to analyze the effect of the process parameters on experimental values. The parameters that affect the process were determined using Taguchi method, and the most significant process parameters and their percentage contribution were determined by using ANOVA technique. Confirmation test with the optimal levels of process parameters was carried out in order to illustrate the effectiveness of Taguchi's optimization method.

2. Dissimilar Materials

AA2014 is the material used for the current investigation. The major constituents of this alloying material are Al-0.8Si-4.4Cu-0.8Mn-0.4Mg. This is one of the most widely used wrought aluminum-copper alloys. This is a heat-treatable alloy and has the behavior of corrosion resistance. AA2014 has the ultimate tensile strength of 483 MPa, yield strength of 414 MPa, Rockwell hardness (RHN-B) of 82 and percentage elongation of 13%. This alloy is used for heavy-duty forgings, air craft fittings and truck frames..

3. Ring Compression test

A series of ring compression tests were conducted by UTM (universal testing machine) on Aluminium 6 ring specimen For each condition of lubrication, 6 ring samples were compressed to different heights within different loads. In the present study, the friction calibration curves were constructed and the deformation behavior of the geometry of the ring specimen was examined. This method has the advantage of determining friction coefficient based on the dimensional changes of the geometry of ring specimen. They obtained the calibration curves for estimating friction by plotting the decrease or increase of hole diameter versus percentage change in height reduction of the ring specimen. Problems such as barreling of ring specimen, mushrooming of the hole were analyzed by employing the lubricants such teflon grease, silicon grease , molibdunm disulphate at the die billet interface.

After the experimental process is done friction was defined at each different lubricants, and the material changes will taken place at inner dia, height.

Fig 1: RCT Equipment

Table. 1 Processing Conditions for the Ring Compression test

Ring specimen size (OD: ID:H=6:3:2)	24:12:8
Total No of ring samples required for each and all lubrication conditions	(6 + 6 + 6 = 18- total)
Compression testing machine	Capacity of 1000 ton
Two Dies	Rigid (H-13 steel)
Measurement of geometry parameters	Digital Vernier calipers
Temperature	Cold working (under room temperature)

This indicates good lubrication condition. After noting down all the results at each and every incremental % reduction in height, the above parameters will be noted down and the friction calibration curves will be plotted. The mean value of the change in the hole diameter to the height reduction of all the 6 specimens gives the value of the friction coefficient 'm'.

Fig of MoS_2

Fig Teflon grease

Fig of Silicon grease

Fig 2: Deformed ring samples for different lubricants

After upsetting six ring specimens to different height reductions as illustrated in Fig. 2, the change in the hole diameter was noted down. The mean value of the change in the hole diameter to the height reduction of all the 6 specimens gives the value of the friction coefficient 'm'. For the condition of no friction between the die/billet interface the friction coefficient m=0 and m=1 for sticking Low friction causes expansion of the hole and high friction causes bulging of the internal hole of the ring (Fig. 2). For molybdenum disulphide, teflon grease and white grease,the values of m are 0.24, 0.33 and 0.44 respectively

4. Experimental Procedure

A. Upsetting Procedure

Solid cylindrical test specimens of different aspect ratios were compressed between two rigid flat dies to different strain levels. As the material undergoes plastic deformation a bulge near the equatorial region can be observed. When this plastic deformation becomes severe, the material damages and a crack will appear on the surface of the cylindrical specimen. The non-uniform deformation of the cylinder is because of the high friction between the contact surfaces of the billet and the dies. By applying proper lubrication, the cylindrical billets can be deforming without failure and utilizing the material and processing conditions effectively

Table:2 Processing conditions for conducting experiments

Material used	AA2014
Aspect ratio	h/d=1, h/d=0.75, h/d=0.5
Condition of Lubrication Grease/ on the top/bottom faces	Grease/Molybdenum disulphide,
Die	Rigid
Billet	Plastic
Mode	Axi-symmetric configuration

A series of Aluminium solid cylinders will be compressed between the rigid cylindrical dies for the lubricant conditions using a 3000 ton capacity UTM. At each and every stage of the deformation process the following parameters will be noted using digital vernier calipers. For each and every lubricant condition, to find the ductility property for 3 different categories,in 9 different pieces, by applied on the faces of the billet and were reduced to 30% in height. Thereby the geometry parameters will be compared for all the conditions of the lubrication as mentioned.

Table3. Factors and levels for the Upsetting process

Factors	Factor description	Level 1	Level 2	Level 3
Aspect ratio (h/d)	A	0.5	0.75	1
Aging time in hrs (t)	B	2	4	6
Friction coefficient (m)	C	0.24	0.33	0.4

h height of the cylinder before upsetting

d diameter of the cylinder before upsetting

H_f Height after deformation

D_b Central bulging after deformation

R_b Bulged radius at the center of the billet

D_c Contact diameter at the die/billet interface

R_a barrel radius after deformation

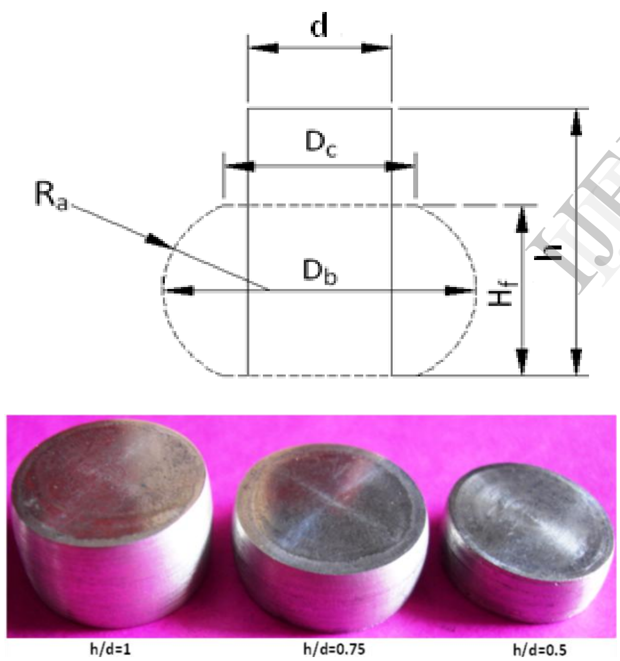


Fig. 3. Geometry profile of the billet after upsetting.

B. Hardness

After conducting all the 9 experiments, the results were noted down in Table. 2. The response 'R1' indicates the difference in the Rockwell hardness- B at the center of the billet and at the equator is indicated by 'Δ RHN-B'.

C. Barrel radius

The barrel radius after deformation was also calculated for all the experiments using the equation proposed by Narayanasamy et al. [17]. Where h_f is the height after deformation of the billet, D_b is the bulged diameter, D_c is the contact diameter and R_a is the barrel radius

$$R_a = \frac{h_f^2}{4(D_b - D_c)}$$

Table 4: Response charecterstic measured table

Experiment No	Factor A	Factor B	Factor C	$(RHN\text{-}B)_c$	$(RHN\text{-}B)_e$	Response Δ RHN-B (R1)	Barrel radius (R2)	Load (R3)
1	0.5	2	0.24	91.5	86.8	4.7	29.86	464
2	0.5	4	0.33	92.5	86	6.5	22.25	441
3	0.5	6	0.4	93	86	7	18.17	422
4	0.75	2	0.33	93.5	86.5	7	31.509	458
5	0.75	4	0.4	94	86.5	7.5	26.92	427
6	0.75	6	0.24	92.5	87	5.5	43.89	390
7	1	2	0.4	96	86.7	9.3	33.83	445
8	1	4	0.24	94	87	7	52.07	404
9	1	6	0.33	94.5	87	7.5	43.08	382

5. Results and Discussions:

A. Taguchi Analysis

(i) Minimum deviation in hardness distribution, S/N ratio 'smaller the better':

Table 5: Response table for signal to noise ratio (S/N) and Means

Response(R1)for signal to noise ratio				Response (R1) for means			
Level	A	B	C	Level	A	B	C
1	-15.53	-16.4	-15.05	1	6.06	7.00	5.73
2	-16.4	-16.57	-16.89	2	6.66	7.00	7.00
3	-17.92	-16.89	-17.92	3	7.93	6.66	7.93
Δ	2.39	0.48	2.87	Δ	1.86	0.33	2.2
Rank	2	3	1	Rank	2	3	1

To obtain the results of minimum deviation in hardness distribution, the response (R1) 'smaller the better' has been chosen for which the S/N ratio is as follows.

$$\text{S/N ratio} = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} Y_i^2 \right] \quad (2)$$

Where Y_i is the measured value of the response characteristic and 'n' is the no. repetitions for the experimental condition. Signal to noise ratio (S/N) values for different levels and different factors are calculated from the above formula and given in Table 5.

(ii) Maximum barrel radius, S/N ratio'larger the better':

To obtain the results of maximum barrel radius, the response "larger the better" has been chosen for which the S/N ratio is as follows.

$$\text{S/N ratio} = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} \frac{1}{Y_i^2} \right] \quad (3)$$

Table 6:Response table for signal to noise ratio (S/N) and Means

Response for signal to noise ratio				Response for Means			
Level	A	B	C	Level	A	B	C
1	27.21	30.02	32.34	1	23.43	31.73	42.61
2	30.47	30.07	29.87	2	34.11	34.41	32.28
3	32.64	30.24	28.12	3	43.66	35.05	26.31
Δ	5.43	0.22	4.21	Δ	20.23	3.31	16.3
Rank	1	3	2	Rank	1	3	2

(iii) Minimum load absorption, S/N ratio 'smaller the better':

Table 7: Response (R3) Table for Signal to Noise ratio and Means

Response for singal to noise ratio (S/N)				Response for Means			
Level	A	B	C	Level	A	B	C
1	-52.91	-53.17	-52.43	1	442.3	455.7	419.3
2	-52.55	-52.54	-52.58	2	425	424	427
3	-52.25	-51.99	-52.69	3	410.3	398	431.3
Δ	0.69	1.18	0.27	Δ	32	57.7	12
Rank	2	1	3	Rank	2	1	3

Reduces the load absorption capacity of the billet. Shorter billets absorb more load than the longer billets, the response (R3) 'smaller the better' has been chosen for which the S/N ratio is as follows.

$$\text{S/N ratio} = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} Y_i^2 \right] \quad (2)$$

B. Analysis of variance (ANOVA)

ANOVA is a decision making tool which aids in evaluating the most significant factor among all the process parameters. The output quality characteristic is judged based on the variance, F-ratio and percentage contribution ratio and the results are tabulated in Table 4. Using 95% confidence level, the results obtained from ANOVA are tabulated in Table 4. The F-ratio and percentage contributions reveal that friction has contributed 54.31% while the aging time contributed 1.64% and the size of the billet has contributed to 40.45%.

Table 8 : Analysis of variance for Means(R1)

Source	Degree of Freedom	Sum of squares	variance	F-ratio	Contribution ratio (%) (R1)
A	2	5.4489	2.7244	11.30	40.45
B	2	0.222	0.111	0.46	1.64
C	2	7.3156	3.6578	15.17	54.31
% Error	2	0.4822	0.2411		3.58
Total	8	13.468			100

Table 9: Analysis of variance for Means (R2)

Source	Degree of Freedom	Sum of squares	variance	F-ratio	Contribution ratio (%) (R2)
A	2	614.72	307.358	188.07	58.84
B	2	18.57	9.283	5.68	1.77
C	2	408.01	204.007	124.83	39.06
%	2	3.27	1.634		0.31
Total	8	1044.56			100

Using 95% confidence level, the results obtained from ANOVA are tabulated in Table 6. The F-ratio and percentage contributions confirm that size of the billet has contributed 58.84% while the aging time contributed 1.77% and the friction at the die/billet interface has contributed to 39.06%.

Table 10: Analysis of variance for Means (R3)

Source	Degree of Freedom	Sum of squares	variance	F-ratio	Contribution ratio (%) (R3)
A	2	1539.6	769.78	71.42	22.68
B	2	5004.22	2502.11	232.15	73.73
C	2	221.56	110.78	10.28	3.26
% Error	2	21.56	10.78		0.31
Total	8	6786.89			100

A similar procedure has been adopted for investigating the effect of process parameters on deformation load as in the case of studying hardness variation and barrel radius. Using 95% confidence level, the results obtained from ANOVA are tabulated in Table 8. The F-ratio and percentage contributions explain that aging time has contributed 73.73% while the size of the billet has contributed 22.68% and the friction at the die/billet interface contributes to 3.26%.

C. Prediction of Optimum value for R1, R2 and R3

From the results of S/N ratio and the mean values, the optimum control factors and levels have been chosen as A1, B3 and C1 for R1; A3, B3 and C1 for R2 and R3. The mean optimum values (M_{R1}, M_{R2} and M_{R3}) for the responses can be determined as below.

$$M_{R1} = \overline{Y} + (\overline{A1} - \overline{Y}) + (\overline{B3} - \overline{Y}) + (\overline{C1} - \overline{Y}) \quad (4)$$

$$M_{R2} = \overline{Y} + (\overline{A3} - \overline{Y}) + (\overline{B3} - \overline{Y}) + (\overline{C1} - \overline{Y}) \quad (5)$$

$$M_{R3} = \overline{Y} + (\overline{A3} - \overline{Y}) + (\overline{B3} - \overline{Y}) + (\overline{C1} - \overline{Y}) \quad (6)$$

Where; $\overline{Y}$ is the average expansion of all the 9 experiments in the Taguchi orthogonal array, A1, B3 and C1; A3, B3 and C1 are the response values of the mean with process parameters at optimum levels.

D. Confirmation run

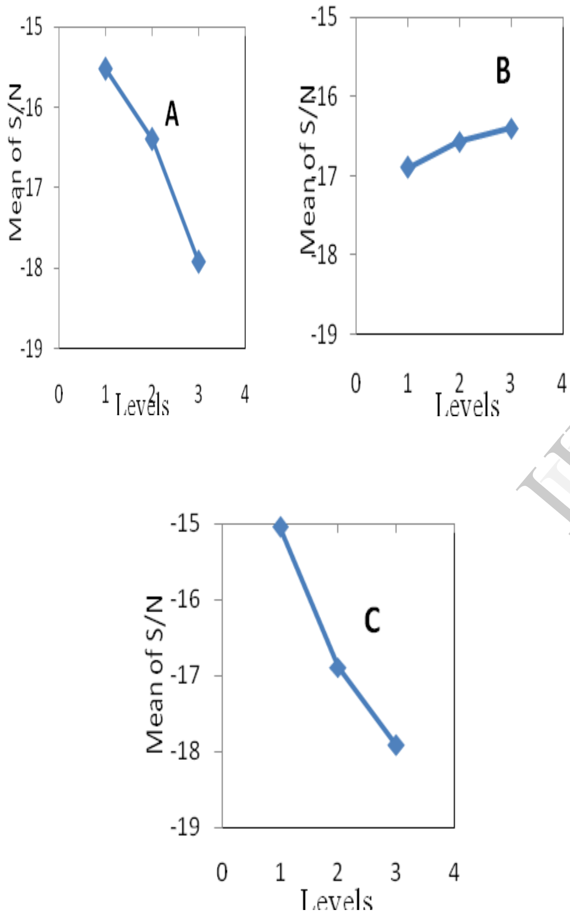
The confirmation tests were conducted to evaluate the results predicted from Taguchi technique. The predicted results and the experimental results are tabulated in Table 9. It can be examined that the results obtained are within the span of predicted 95%

confidence level and the predicted values are in close agreement with the experimental results.

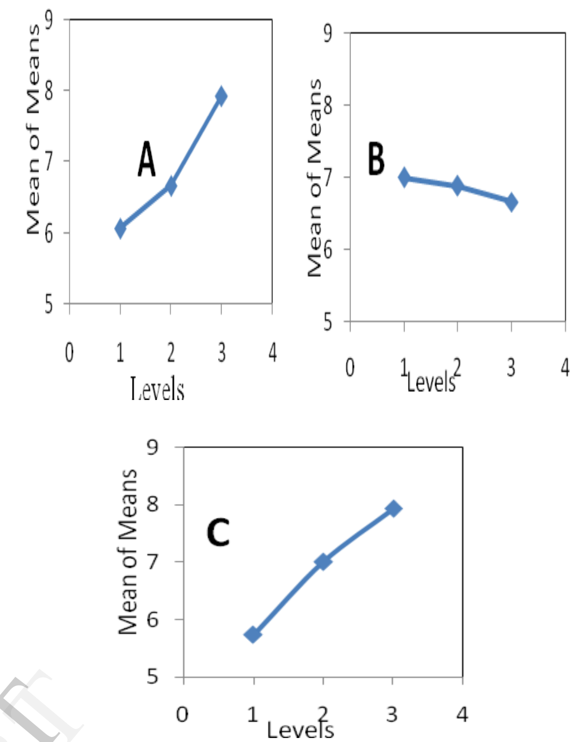
Table 11: Test data confirmation run

Responses	Optimum	Predicted	Experimental	%Error
R1	A1, B3,	4.67	4.46	4.49
R2	A3, B3,	54.07	56.12	3.79
R3	A3, B3,	375.84	385	2.44

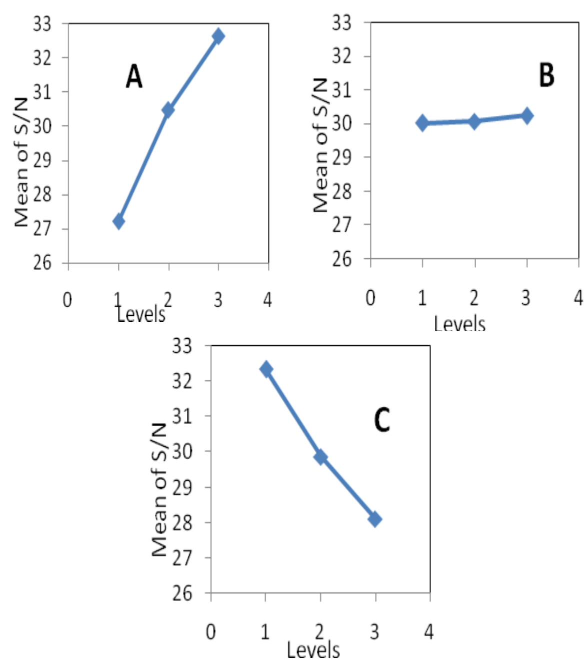
6. Graphs



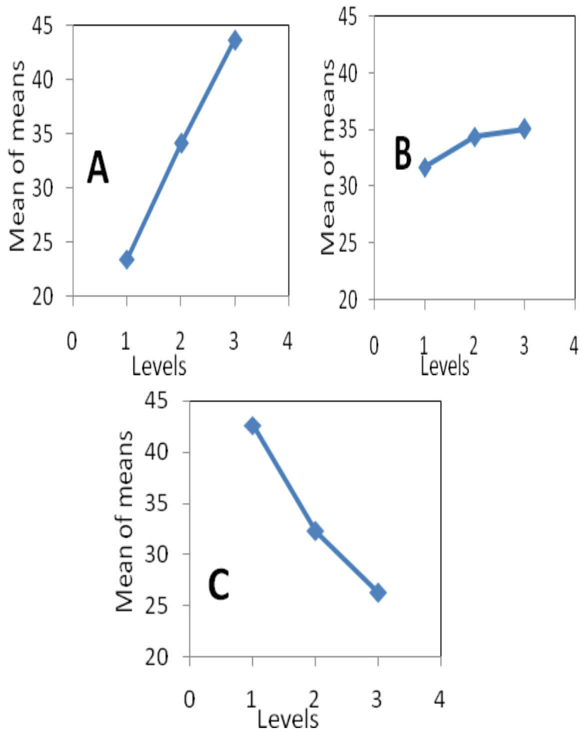
Graph 1: Main effects plot for S/N ratio to investigate hardness distribution.



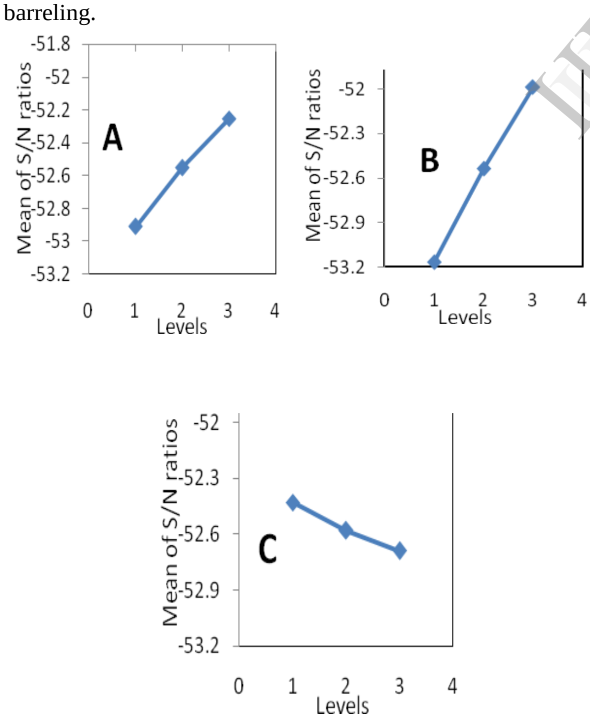
Graph 2: Main effects plot for Means to investigate hardness distribution.



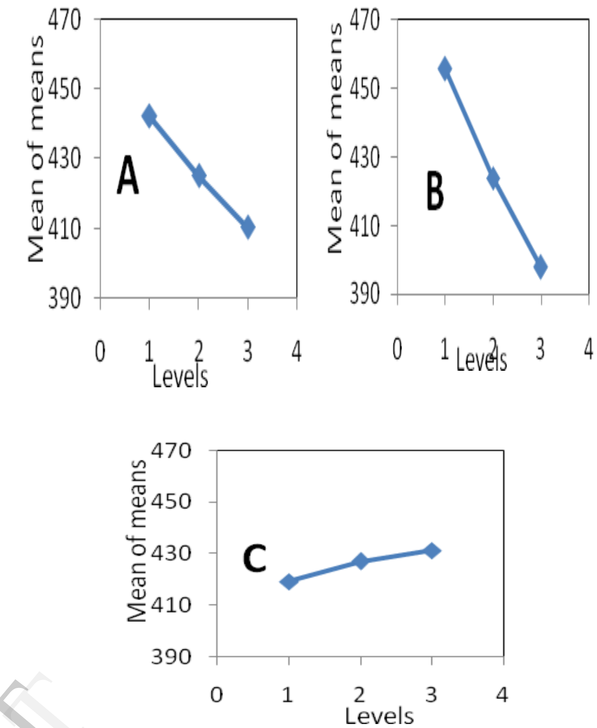
Graph 3: Main effects plot for S/N ratio to investigate barreling.



Graph 4: Main effects plot for Means to investigate barreling.



Graph 5: Main effects plot for S/N ratio to investigate deformation load



Graph 6: Main effects plot for Means to investigate deformation load.

7. Conclusions

The following conclusions can be drawn from the present work:-

(i) The significant factor responsible for the indifference hardness distributions throughout the billet is friction which contributes 54.31% among the total value.
(ii) The major parameter affecting the barreling behavior is size of the billets which contributes 58.84% and the ageing condition contributes 73.73% on the deformation load.
(iii) The optimum factors to control the deviation in hardness distribution are A1, B3 and C1; A3, B3 and C1 for barreling behavior and minimum deformation load.
(iv) The optimum value obtained from the Taguchi method is 4.67 for hardness distribution, 54.07 for barreling behavior and 375.84 for deformation load.
(v) The values obtained from the optimum condition of Taguchi method are in good agreement with the confirmation experiments of hardness distribution, barreling behavior and deformation load.

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