International Journal of Modern Manufacturing Technologies
ISSN 2067–3604, Vol. X, No. 1 / 2018

ANALYSIS OF FLOW FORMING PROCESS USING GRA

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Abstract: The flow forming is a rotary assistance shape transformation procedure, eternally used to manufacture highly precisied seamless products for aerospace and defence industries like missile casing, rocket cases, rocket launcher casing etc. Besides, seamless gas bottles and small pressure equipments are also being manufactured by this process now days. During the process, a blank/workpiece (deformable) is set over rotating mandrel then rotating roller(s) plasticize beneath the contact. Further, the knowledge of power consumption as well as the formability during the process can be essentially used to improve process yield with lesser energy. The process required to be optimized in such fashion that the power consumption is minimum but at the same time formability has to be increased to promote energy conservation aspects. Also, process capabilities needs to be improved along with energy saving. Hence, an attempt is made to investigate the effect of process variables considering Taguchi L_9 design. Three levels of three variables (i.e. rotational speed, axial feed and percentage reduction) have been taken for present study. The speed was found to be most eminent factor influencing the power consumption. It has been discerned that all of these parameters are significantly affecting percentage elongation (formability). Further, the Grey Relation Analysis (GRA) conducted for multiple characteristics optimization i.e. power consumption and formability. The results are confirmed with the necessary confirmation experiments.

Key words: Flow Forming, Experiments, Power Consumption, Formability, Grey Relational Analysis

1. INTRODUCTION

Flow forming is the sub module of the conventional spinning. The process consists of a workpiece (generally tubular) which is placed on the mandrel (rigid body) afterwards the deformation of tube takes place by menas of roller(s) in deformation region/contact zone. Forward and backward/reverse are the two different approaches which are being employed normally during execution. The forward approach has the direction of feed and material deformations are similar (Figure 1(a)). While, the reverse approach has the direction of feed and material deformations are dissimilar (Figure 1(b)).

There are several applications of flow forming such as seamless tubes for heat exchangers and pressure equipments, gas bottles, automobile rims etc., but it is mainly used in aerospace, aviation and defence sectors to produce missile casing, cartridge case, rocket launcher case etc. Wong et al. (2005) employed two different rollers shapes i.e. flat and with approach angle during single roller flow forming process on NC lathe machine. It was reported that, a radial flange was produced by the flat faced roller. Also, shallow crater was observed by the researchers during the operation with both the rollers. Razani et al. (2014) carried out experiments using DOE technique of RSM (Box-Behnken) for AISI 321 steel tube. The parameters were studied as rotation of mandrel, axial feed, and reduction of wall thickness. The hardness after flow forming was taken as response function. It was reported that as the speed and forming depth increases, hardness increases. The hardness decreases with decrease in feed rate.

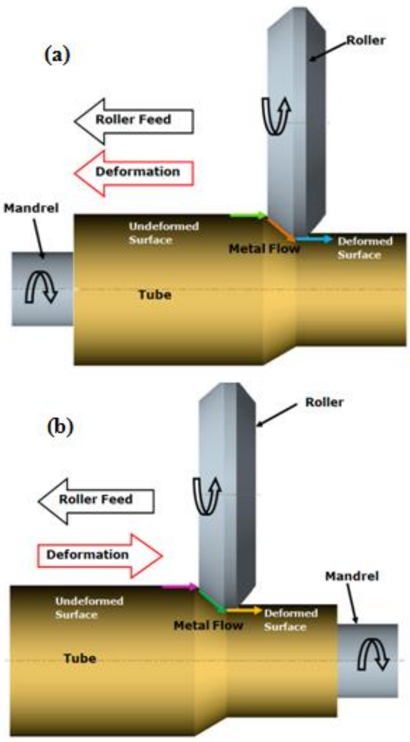

Fig. 1. Mechanism of flow forming process (a) forward (b) reverse (Bhatt and Raval, 2017)

Zhao et al. (2017) studied unveen plastic deformation using experiments and simulation during multi pass hot backward power spinning (MHPBS). It was commented that the unevenness of equivalent stress distribution increases with increase in the tube thickness. The temperature distribution during the process was also uneven. Preheating temperature decreases significantly in contact area of the roller and tube (i.e. outer surface) compared to inner surface of tube. Abedini et al. (2014) implemented Taguchi L_{27} design to investigate surface roughness. Six parameters at three levels were used. The parameters include thickness reduction, axial feed, speed of rotation, leading/attack angle, tip/nose radius and smooth/trailing angle. It was reported that the relative significance of the factors were roller nose radius, reduction rate, axial feed, speed of rotation, leading angle, and trailing angle, respectively. D'Annibale et al. (2017) investigated the friction condition between workpiece and roller during single roller flow forming process for AA6060. Also, finite element model was developed to study the effect of interaction of roller and workpiece on the forces, strains and temperature distribution.

However, the power consumption and energy conservation aspects were untouched. Therefore, in present study the power consumption is investigated along with formability (in terms of elongation percentage). It is desirable to have maximum percentage elongation during process with minimum power consumption. The experiments were conducted by employing Taguchi L_9 design and the results are examined using analysis of variance (ANOVA). Three levels of three operating parameters (speed, feed and reduction percentage) are taken during analysis. It was found that speed is most significantly affecting the power consumption. Also, all three factors are prominent for the elongation percentage. Moreover, multi characteristic optimization is carried out using Grey Relation Analysis (GRA).

2. EXPERIMENTAL PLAN & PROCEDURE

Flow forming is affected by many variables like operating, geometrical and workpiece material. Here, three operating parameters are selected for present study. These are 1) speed: it is the rotation of workpiece, 2) feed: it is the linear motion of roller during deformation 3) reduction percentage: it is the amount of depth given to the roller. The main reason behind these parameters selection is; these can be varied at operator will. Further, the values are taken based on literature survey and the capacity of the available machine tool. In present case, reverse forming strategy used as it does not require any special clamping. Moreover, commercial aluminum alloy (AA6061) is taken as work material because it serves advantages like excellent corrosion resistant, more ductile, easily available, re-cyclability, cost effective and widely used in aerospace & defense sectors. The mechanical properties of aluminum alloy 6061 used during study are: density (ρ) = 2700 kg/m^3, YS (yield strength) = 55.2MPa, elastic modulus = 68.9GPa, US (ultimate strength) = 124MPa, poisson's ratio = 0.33. Further, proposed methodology can also be used for pure copper, brass, bronze etc. materials.

The Taguchi et al. (2005) L_9 design used to reduce the experimentations. The parameters along with their levels and experimental plan are shown in Table 1 and Table 2 respectively.

Table 1. Parameters and their values

Factor	Notations	Level 1 (L)	Level 2 (M)	Level 3 (H)
Speed (RPM)	A	250	420	710
Feed (mm/rev)	B	0.05	0.10	0.15
Reduction (%)	C	30	40	50

Table 2. Layout of analysis (L_9 design)

Exp. No.	Speed [rpm]	Feed [mm/rev]	Reduction [%]
1	250	0.05	30
2	250	0.1	40
3	250	0.15	50
4	420	0.05	40
5	420	0.1	50
6	420	0.15	30
7	710	0.05	50
8	710	0.1	30
9	710	0.15	40

Fig. 2. Annealing procedure

The conventional engine lathe machine of HMT (Model: LTM 20/1500) used during the experiments. The material is annealed before operation at 416° C (Davidson et al., 2008). A furnace (model: electroheat) was used for the annealing as shown in Figure 2. The experimental set up is given in Figure 3. It consists of tool (roller), mandrel, blank/workpiece and ejector ring. The roller and its housing are made up of die steel (D2) of 66 HRC hardness. Also, the mandrel and ejector ring are made up of EN8 (AISI 1040) of 46 HRC hardness. The exploded view of the tool and holder is shown in Figure 4. It comprises of roller housing, two taper roller bearings (make: SKF), check nut and washer.

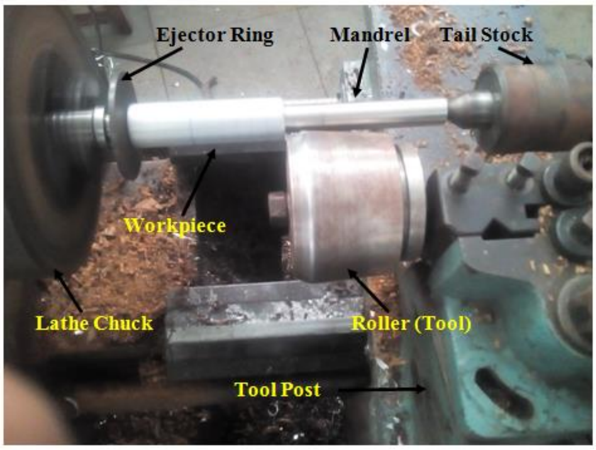

Fig. 3. Experimental Setup

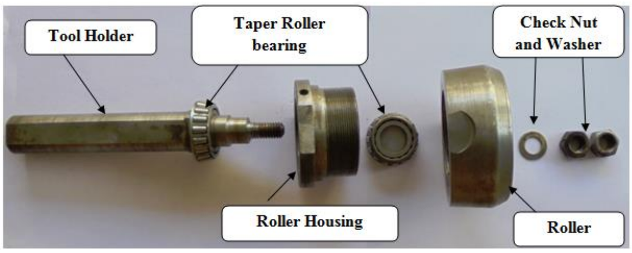

Fig. 4. Exploded view of tooling

3. RESULTS AND ANALYSIS

The power measurement mechanism is provided in Figure 5. It illustrates that, the power meter is connected between the main supply and the machine tool. To determine net power consumption, idle power was measured without operation (for predefined forming length) i.e. no load condition. Later, highest power during operation was measured & recorded for the same length i.e. loads condition. The measured power is subtracted from the idle power to obtain net power consumption. Now, the elongation percentage was determined by subtracting the initial length from final length of workpiece as per equation 1 (see Figure 7). Power was measured using power meter (Make: Multispan, resolution = 0.01 kW) as shown in Figure 6. The elongation was measured using Mitutoyo digital vernier caliper (Model: Digimatic, least count = 0.01 mm) as shown in Figure 8.

Taguchi et al. (2005) depicted three types of classification such as smaller is better, nominal is better and larger is better. Hence, power was analyzed based on smaller is better quality criteria while percentage elongation is analyzed based on larger is better criteria. Also, it was illustrated that superior performance is the outcome of higher S/N ratio. The graphs of S/N ratio for power consumed and percentage elongation are given in Figure 9 and Figure 10 respectively.

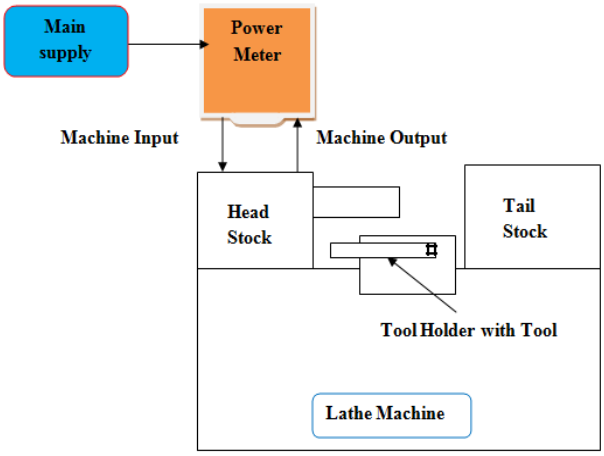

Fig. 5. Illustration of Power consumption measurement

Fig. 6. Power measurement

$$\text{Elongation } \% = l_1 - l_0/l_0 \quad (1)$$

where, l_0 and l_1 are initial and final length of workpiece respectively.

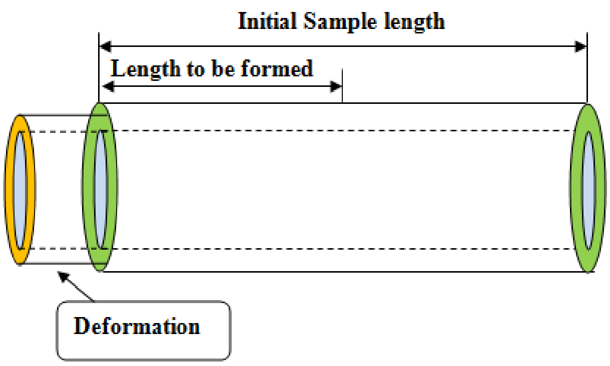

Fig. 7. Illustration of measurement of change in length

It can be seen from Figure 9 that A1-B1-C1 furnish optimal representation for consumption of power. Whereas, optimal performance for the elongation percentage can be achieved at A3-B3-C3 (Figure 10). It is obvious that lower power can be obtained at smaller values of parameters. Also, more elongation can be obtained at higher values of factors.

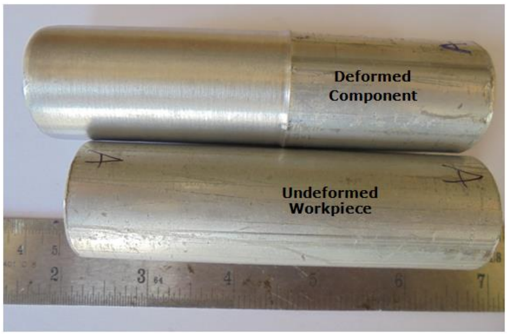

Fig. 8. Deformed samples

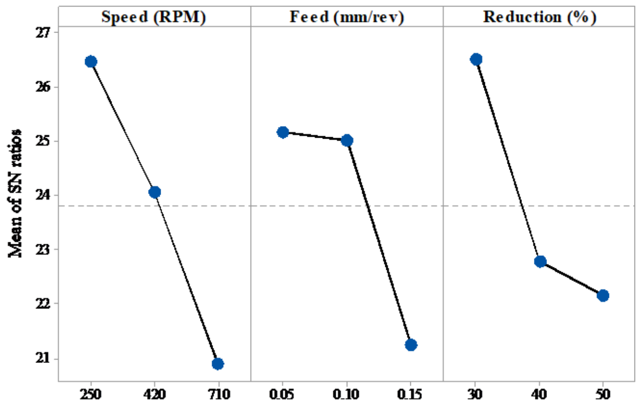

Fig. 9. Graph of S/N ratio for power consumed

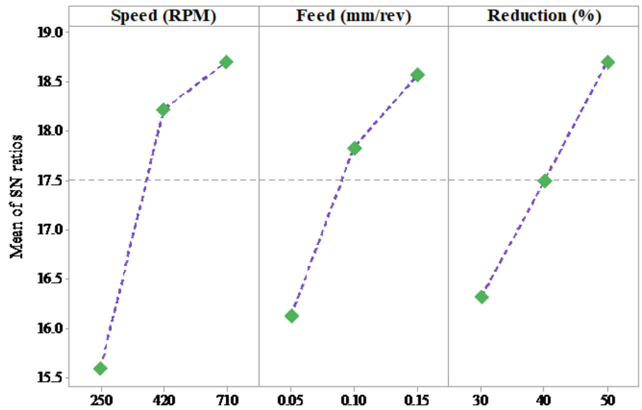

Fig. 10. Graph of S/N ratio for elongation

The ANOVA (analysis of variance) is applied to identify significant factor during the study. The confidence level was selected as 95% therefore p-values should be less than 0.05 for the significance of the factor. Table 3 shows the ANOVA of the power. It is observed that speed is having p-value less than 0.05. Hence, based on p-value it can be said that speed is statistically significant for the power consumption. It is because of as the spindle speed increases; it requires more power during operation. Moreover, all the factors are having significant effect on the percentage elongation (Table 4). The net power consumed during the forming operation can be classified as the summation of power consumed by machine modules and specific energy (which is depending on forming rate) required for forming. This is correlated with the relation reported by Nur et al., (2014) for power consumption during cutting operation.

It can be said that to optimize the power; speed is required to be set in such fashion that formability also improved with the set value of speed. Because; speed is the only governing factor affecting the power whereas formability is regulated by all operating factors. Further, feed and reduction can be set in such way that lesser value of speed can also improves formability and it also reduces power consumption.

Table 3. ANOVA of Power Consumed

Factor	DOF	SS	MS	F	P-value	%
Speed (RPM)	2	0.61654	0.30827	21.29	0.045	41.80
Feed (mm/rev)	2	0.39156	0.19578	13.52	0.069	26.55
Reduction (%)	2	0.43793	0.21896	15.12	0.062	29.69
Error	2	0.02896	0.01448	-	-	1.96
Total	8	1.47499	-	-	-	100
R-sq = 98.04%						

Table 4. ANOVA of Formability

Factor	DOF	SS	MS	F	P-value	%
Speed (RPM)	2	0.000391	0.000195	51.42	0.019	41.69
Feed (mm/rev)	2	0.000206	0.000103	27.09	0.036	26.14
Reduction (%)	2	0.000184	0.000092	24.21	0.040	23.35
Error	2	0.000008	0.000004	-	-	1.01
Total	8	0.000788	-	-	-	100
R-sq = 97.54%						

Note: % indicates percentage contribution of the factors

4. GREY RELATIONAL ANALYSIS

The DOE/Taguchi technique has limitation of optimizing single factor at a time. During last decade, several multiple characteristics optimization procedures acquire attention among the researchers. Out of various techniques Grey Relation Analysis (GRA) found more suitable for optimization of process parameters. The technique was effectively utilized in optimization of laser welding

(Shanmugarajan et al., 2016), drilling process (Haung and Liao, 2003; Sheth and George, 2016), friction stir welding process (Sahu and Pal, 2015), micro turning process (Kibria et al., 2013), grinding process (Patil P. J. and Patil C. R., 2016), electro discharge machining process (EDM) (Kao et al., 2010), turning process (Lin C. L., 2004) and many more.

Deng (1989) was reported multiple response optimization using GRA. The grade value can be determined using two sequences. The GRA procedure was proposed by Deng (1989). In present work, the concentration is emphesized the grey relation analysis. The steps to be followed to perform GRA are as mentioned below and briefly discussed in the coming sections (Deng, 1989).

- The response and input parameters should be identified;
- Perform the trials as per the fractional design matrix;
- Normalize the data of response factors;
- Execute the grey relation generation and evaluate the GRC (Grey Relation Coefficient);
- The grey relational grade can be calculated by average out the GRC;
- Use grey grade to analyze the results and find optimal levels of parameters;
- Perform confirmation test to validate the results.

The data is processed using the guidelines of standard literatures, relying on the attributes of the initial sequence (Lin C. L., 2004; Deng J. L., 1989). As formability has characteristic as larger-the-better, normalization of data is carried out using equation (2) (Lin C. L., 2004; Deng J. L., 1989).

$$x_i^*(k) = \frac{x_i^0(k) - \min x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \quad (2)$$

Similarly, power consumption has the quality criteria as smaller the better, therefore normali-zation of data is carried out by equation (3) (Lin C. L., 2004; Deng J. L., 1989).

$$x_i^*(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \quad (3)$$

where, $x_i^0(k)$ is the original value of the results, $x_i^*(k)$ is normalized value of results, $\max x_i^0(k)$ is the largest value of $x_i^0(k)$ and $\min x_i^0(k)$ is the smallest value of $x_i^0(k)$.

The GRC and GRG are evaluated by the method proposed by Lin C. L., (2004) and Deng J. L., (1989). The GRC $\xi_i(k)$ is calculated for the k^{th} performance characteristics in the i^{th} trial from equation (4).

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{0i}(k) + \zeta\Delta_{\max}} \quad (4)$$

$$0 < \xi\left(x_i^0(k), x_i^*(k)\right) \le 1$$

where,

$$\Delta_{0i}(k) = \left|x_i^0(k) - x_i^*(k)\right|$$

$$\Delta_{\max} = \max\left|x_i^0(k) - x_i^*(k)\right|$$

$$\Delta_{\min} = \min\left|x_i^0(k) - x_i^*(k)\right|$$

After calculating the GRC the GRG (γ_i) can be calculated using equation (5).

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad (5)$$

where, n = number of response functions

It was reported that, the trial run which has highest grey relation grade can be considered as best choice for the set of combination of variables (Lin C. L., 2004; Deng J. L., 1989). In present case, the results of the formability and power consumption are normalized as per the equations (2) and (3) respectively. Table 5 shows the normalized values as well as the GRC and GRG for the group of results. The highest GRG (i.e. 0.7778) is observed for the 9th experiment thus it can be said that the parameters of 9th experiment (710rpm speed, 0.15mm/rev feed and 40% reduction) gives optimum results for all the response functions.

Such way, an investigation is carried out in order to reduce power consumption and increase formability. It has been observed that rotational speed is the most contributing factor affecting the power consumption. Further, formability is mainly governed by speed, feed and reduction percentage. The grey relation analysis is carried out to optimize multiple responses.

5. CONCLUSIONS

From the experimental study on power consumption and formability following conclusions can be drawn.

- Speed is the most significant factors affecting the power consumption. Because the main drives of the speed is directly connected with the power supply. Hence, as the speed changes; power consumption changes.
- Formability (elongation) is mainly affected by speed, feed and reduction percentage. Thus it can be said that any of the operating variables varies; the formability changes significantly.
- The grey relation analysis demonstrates that the parameters of 9th experiment (710 rpm speed, 0.15 mm/rev feed and 40% reduction) gives optimized results for all three response functions.

Table 5. GRC and GRG calculations for experimental trials

Exp. No.	Normalized Reference Sequence		Deviation in Sequence		Grey Relation Coefficient (GRC)		Grey Relational Grade (GRG)
	Power Consumed [kW]	Elongation [%]	Power Consumed [kW]	Elongation [%]	Power Consumed [kW]	Elongation [%]	
1	0.0000	1.0000	1.0000	0.0000	0.3333	1.0000	0.5634
2	0.1086	0.8576	0.8914	0.1424	0.3593	0.7784	0.5177
3	0.4480	0.5712	0.5520	0.4288	0.4753	0.5383	0.5438
4	0.2896	0.7144	0.7104	0.2856	0.4131	0.6365	0.4610
5	0.3394	0.0000	0.6606	1.0000	0.4308	0.3333	0.4343
6	0.2353	0.5720	0.7647	0.4280	0.3953	0.5388	0.5300
7	0.4977	0.5069	0.5023	0.4931	0.4989	0.5035	0.4878
8	0.2624	0.5720	0.7376	0.4280	0.4040	0.5388	0.4619
9	1.0000	0.0000	0.0000	1.0000	1.0000	0.3333	0.7778

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Received: January 15, 2018 / Accepted: June 15, 2018 / Paper available online: June 20, 2018