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Optimization of Shear Spinning Parameters for Production of Seamless Rocket Motor Tube by Taguchi Method

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Abstract: *The thin walled seamless, high precision tubes are produced by progressive, continuous localized deformation (shear spinning).. The present experimental work, "Optimization of Shear Spinning Parameters and Production of Seamless Rocket Motor Tube by Taguchi Method", is performed at B D L, Hyderabad, on flow forming machine. Rocket motor tube is used as a pressure vessel in various missiles. It encases propellant and plays a vital role in missile thrust technology. The tube is supposed to withstand high temperature and pressure and should have high mechanical properties. The aim of present research is to establish optimum process parameters like roller radius, stagger, hardness and feed to produce precise mean diameter in reverse shear spinning rocket motor tube for pressure vessel application in aerospace engineering and missile technology with minimum cost of experimentation by Taguchi method. The material chosen for study is SAE 4130 Steel. Ovality of the tubes, mean diameter, surface finish and thickness variation were also studied and it is found that feed rate is 50mm/min for the final pass to flow from the SAE 4130 Steel for obtaining better geometry, thickness and mean diameter.*

Keywords: *Shear spinning, Taguchi method, Seamless Rocket Motor Tube, Flow forming, pressure vessel, etc.*

I. Introduction:

Flow forming technology has emerged as the most advanced metal forming technique due to its manifold advantages over conventional metal forming techniques such as extrusion and tube drawing. Flow forming, an advanced form of metal spinning, has been used for over 40 years in the military and aerospace industries. The process has found an increasing demand in commercial applications in the aviation, electronics and defense industries where the following features are needed: hollow symmetrical shapes with relatively close tolerance control, variable wall thickness and profile, improved tensile strength and superior surface finishes. Flow forming has spread widely since 1950; initially thick based sauce pans were produced to be used on electric cookers. The experience gathered showed that this technique could also be applied for different branches throughout industry. For some time it had been kept in the background due to the difficulties in recruiting labour. Since muscle power needed to carry out the process and hence was confined for long time to the processing of soft materials, such as non-ferrous metals. However, it soon developed again with the introduction of hydraulic machine with copying attachments, which can be operated by unskilled labour. For certain deformation metal spinning is superior to all other possible methods irrespective of the quantities involved. Modern spinning machines provide high forming forces. These machines helped in processing of stronger materials such as steels, light, medium, and even heavy gauge material and cast, forged or machined preforms. Mechanization of the spinning process has led to the evaluation of flow turning and flow forming. This chip less metal forming technique has gained increasing importance especially over the past two decades.

This forming technique offers significant advantages in comparison with conventional production techniques. Such as spinning, deep drawing, rounding circular bodies with subsequent welding etc. These advantages are particularly pronounced when components are to be produced in small or medium size batches due to relatively lower tooling costs that other process such as deep drawing, the other advantages are:

- Low production cost. Highly Precise, seamless construction to net shapes
- Improved mechanical properties, Tubular, conical & contoured geometry Uniform axially-directional, and stable grain micro structure.
- Very high diameter-to-length ratio, Repeatable accuracy part-to-part & lot-to-lot
- Very little wastage of material, excellent surface finishes, accurate components.
- Improved strength properties, Easy cold forming of high tensile strength alloys.

- Production of high precision, thin walled seamless component.

Fast and economical production rates inclined to other methods various applications are listed Tubular-type components i.e., Missile casings, flight and launch motor housings, Rockets and cartridge case. Rocket nose cones, rocket motor cases, gas turbine components and dish antennas in the aero-space Industry. Power trained components and wheels in the Automobile Industry, and gas bottles and containers for storage applications. The manufacturing of thin walled tubes and closed and cylinders for the chemical, nuclear, food, pharmaceutical, cryogenic, beverage, filtration and printing Industries.

II. Flow Forming Benefits:

METAL PROPERTIES:
Flow forming is a cold working process which, through its strain hardening of the base metal substantially increases Yield and Tensile Strengths of the formed material.

SEAMLESS:
One major benefit offered by flow forming is its seamless construction.Flow forming can produce a seamless component with varying contours and wall thicknesses, resulting in parts with no or few welds, thus reducing welding and related testing costs and the need to maintain inventories of different components. Even if there is a welded joint in the preform, once flow forming has been done, the weld is virtually indistinguishable in the final component.

Metallurgical Benefits:
GRAIN STRUCTURE: As a result of the cold work (strain hardening) that occurs during the process cycle, a flow formed component will have considerably higher mechanical properties than the ones of the starting material. Typically, the preforms material is plastically deformed with wall reductions in excess of 75% of the starting wall thickness, causing a substantial refinement of the grain structure and a total realignment of the grains' microstructure in a very uniform, axial direction. The greater the wall reduction, the finer the grain's microstructure of the finished component. If necessary, the grain structure can be recrystallized by a post forming annealing cycle.

Crystallographic Texture:
During the flow forming cycle, all the crystals that form the starting grain structure will be displaced and realigned. The overall orientation of these crystals is known as "texture". Nearly all mechanical properties are influenced by the metal's texture. In a flow formed component, the overall texture is always uniformly oriented. For example, in the case of Hexagonal Closed Packed (HCP) materials such as Titanium and Zirconium, their flow formed crystals will have radically oriented basal planes. This condition increases the biaxial strength of the metal, effectively increasing the circumferential strength. The flow formed crystallographic texture can be further intensified by a post flow forming annealing cycle. On a micro level, the annealing will recrystallize the grain structure while on an atomic level, the texturing effect will be magnified.

PRECISION:
The all-around dimensional controls for diameters and walls offered by precision flow forming will reduce or eliminate your need for secondary turning, grinding and honing operations.

- The very fine surface finishes generated by flow forming on the inner and outer diameters will, in most cases, also void your requirement for honing and/or polishing.

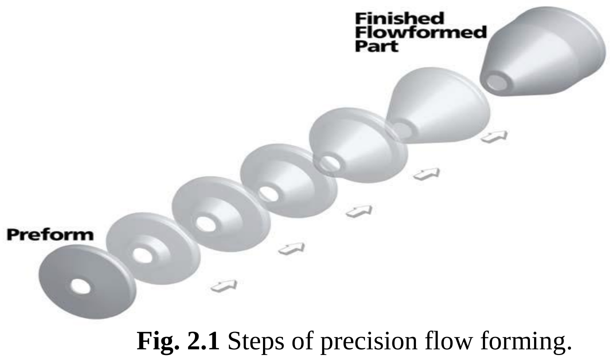


Fig. 2.1 Steps of precision flow forming.

THIN WALLS:

Precision flow forming can generate economically and without difficulty your very thin and precise wall thicknesses regardless of the diameter size of the component. If you have had to contend with the difficulties and costs of managing the deflection of a thin metal body under turning or grinding operations, you will come to greatly appreciate our precision flow forming process.

VARIED WALLS:

Unlike any other type of forming process (i.e. extruding, forging, impact extruding, deep drawing, pilgering, drawn over mandrel, etc.), flow forming can vary the wall thickness of a component at any place and as many times as desired along the length of the flow formed component without additional cost.

HARDENED METALS:

Flow forming offers you the unique possibility of forming to size a pre-hardened work piece, thus eliminating the difficulties and high costs associated with final machining, grinding and honing of a hardened and distorted hollow component.

Flow forming, an extension of shear forming for producing of axis-symmetric hollow cylindrical parts is one of the recent development in production technique for manufacturing of high precision, thin walled seamless component. In the process the material is processed by means of progressive continuous localized deformation.

III. Mechanism Of Plastic Flow:

The above experimental studies have indicated the following important aspects of the process.

- The deformation occurs mainly on the outer layer of the reduced section, and the depth deformation increases with the increase in thickness reduction.
- The total effective strain E is three times the approximate value of the absolute deformation.
- The value of the total effective strain E increase from the mandrel side to the spun side across the thickness and from the bottom of the specimen to its free end in the axial direction.

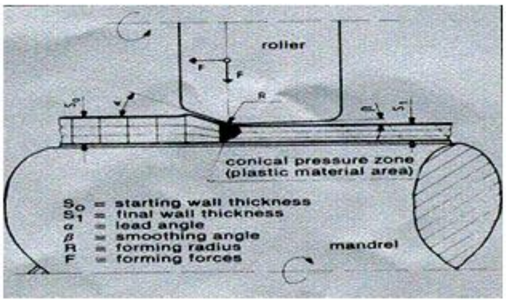


Fig. 3.1: Mechanism of plastic flow

IV. Types Of Flow Forming:

The flow forming process is classified into two types:

(a) forward flow forming and (b) backward or reverse flow forming process,

Depending on the direction of flow of material:-. In forward flow forming, the material flows in the same direction as that of rollers, whereas the material flows in opposite direction to the roller feed in case of backward flow forming. The principle of flow forming is shown in the Fig. 3.2.

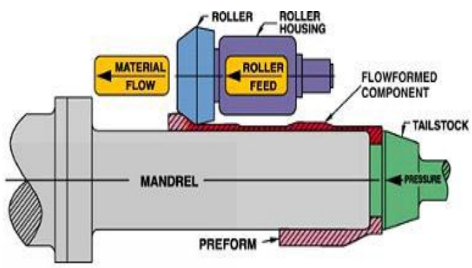


Fig. 4.1: Forward flow forming

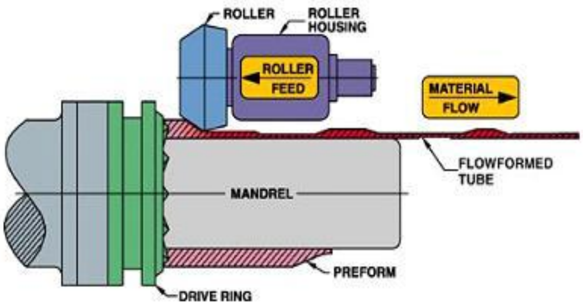


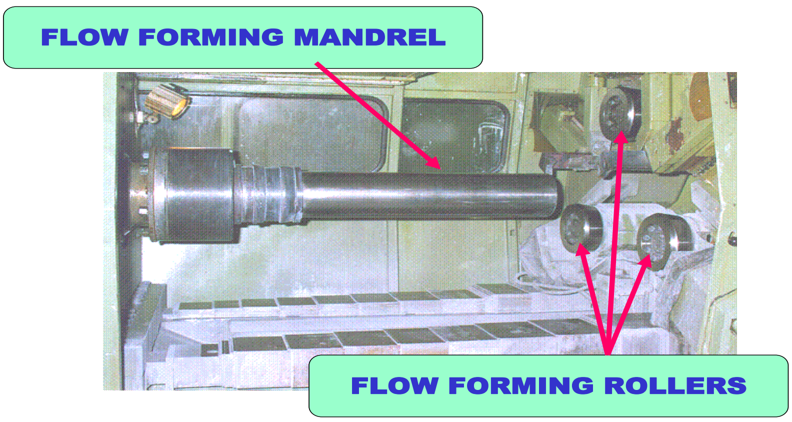
Fig. 4.2: Backward or reverse flow forming process

V. Lubricants And Coolants:

The effects of water, kerosene, water based coolants (20:1) and vector light oil on the process are studied. Water leaves the body very cool after working, hence the handling the product is very easy. The finish however is not acceptable as it gives raise to galling and rollers get damaged as it is not good lubricant but kerosene give a very good finish, the product is extremely hot and produces fumes and is a health hazard. Water based coolants which are used as coolant oil in normal cutting operations is a soapy solution when mixed with water. This gives a good surface finish. Product will be cool and easy to handle. As this is sculpture based oil it reacts with aluminum leaving a dark surface. However this can be removed chemically leaving the material bright. The cooling effect with light (for nonferrous) cutting oil is not much when compared to water based coolant, but the product will be bright with a good finish.

VI. Experimental Details:

Experimental investigations have been carried out with the object of establishing process parameters related to SAE 4130 Steel. The experiments have been carried out on Leifeild, West Germany make, three roller flow forming machine .The mandrel rotates at a speed, S rpm. The roller travels parallel to the axis of the mandrel with a feed rate, F mm/min and decreases the wall thickness of pre-form when a thickness reduction t (%) is given by radial feed. The thickness reduction is effected by maintaining gap between the mandrel and the roller less than the thickness of the pre-form. The axial and radial feeds are maintained by hydraulic power pack through servo motors. The preform is reduced to a final wall thickness by elongating it without change in the inside diameter of the tube. Due to volume constancy, this reduction in thickness of the pre-form leads to an increase in length of the tube.



Description Of Equipment:

It is a three roller CNC flow forming machine, Model ST 56-90, Leifeild make of West Germany.The specifications of the machine are as follows.

1. Machine model : ST 56-90 CNC
2. Length of bed : 8150 mm.
3. Min. flow forming dia : 30 mm
4. Max. Flow forming dia : 660 mm
5. Max. flow forming length (Forward) : 2000 mm
6. Stroke of Tail stock cylinder: 2400 mm

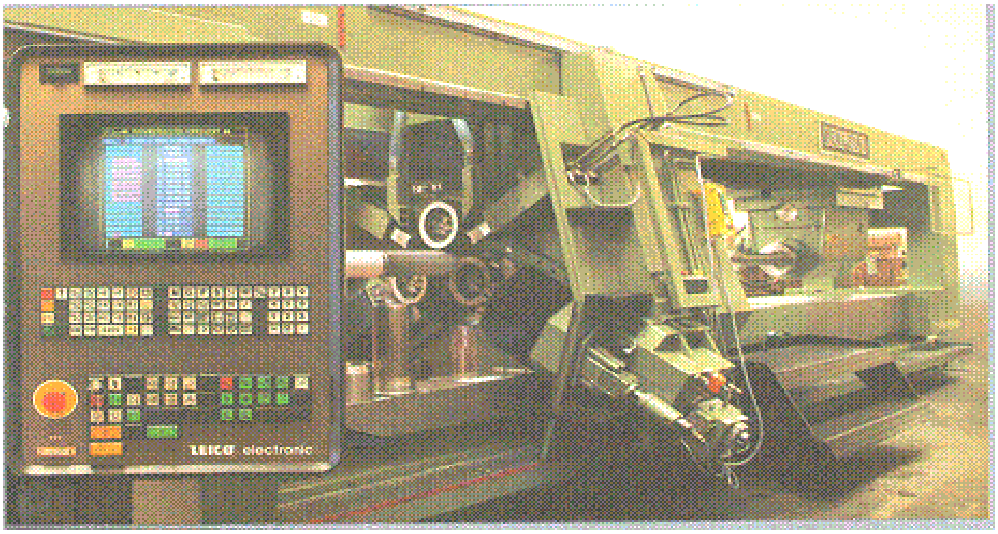


Fig. 6.1: Flow-forming Machine

Fig. 6.2: Arrangement of Mandrel & Rollers

VII. Material (SAE-4130) :

The material chosen for the present investigation of missile motor tube is SAE 4130 Chromium-molybdenum alloy steel (converted to electro slog refined grade). Because of its availability, low cost, and reasonably good cold formability, SAE 4130 steel was selected for the manufacture of thin wall, high strength seamless tubes in pressure vessel applications The ESR bar is cut into required length pieces & suitable preforms of required dimensions & hardness is prepared by subjecting to forging process. This is followed by normalizing heat treatment cycle, then end cutting outing & proof machining of preforms

The machined preforms are subjected to hardening and tempering heat treatment cycles. The hardness of preforms is checked and then subjected for ultrasonic testing and grain size checking. Mechanical properties of materials are greatly affected by the grain size of the materials. Fine grained steels offer more resistance to cracking, produce fine finish, offer better properties for deep drawing and can easily be deformed plastically. Then the finally prepared preforms will be subjected to cold working process on flow forming CNC machine.

VIII. Chemical Composition:

The composition of present investigation of missile motor tube is SAE 4130 Steel (converted to electro slog refined grade) is given below:

Chemical	**% Wt.**
carbon (c)	0.28% - 0.33%
silicon (si)	0.15% - 0.3%
Chromium (cr)	0.8% - 1.1%
Molybdenum (Mo)	0.15% - 0.25%
Manganese (Mn)	0.4% - 0.6%
Sulphur (s)	0.01%
Phosporus (p)	0.015%

IX. Design Of Preform:

The Required dimensions of the tube after forming is shown in fig

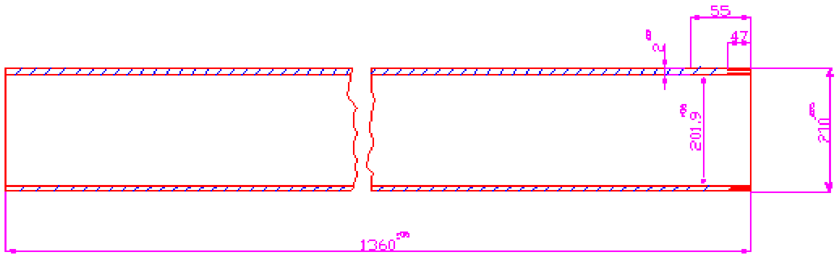


Fig. 9. 1: Dimension of the tube after forming

The bore size of the preforms is maintained at **202.1+0.05** in order to have sliding effect on the mandrel and to have easy loading of the component on the mandrel. Since the final thickness of the tube is **2+0.2mm 85 to 90%** reduction is taken.

Key process parameters:

- Preform shape (and process)
- Mandrel shape
- Mandrel speed
- Feed rate (axial velocity)
- Roller shape and layout
- Number of rollers
- Number of passes

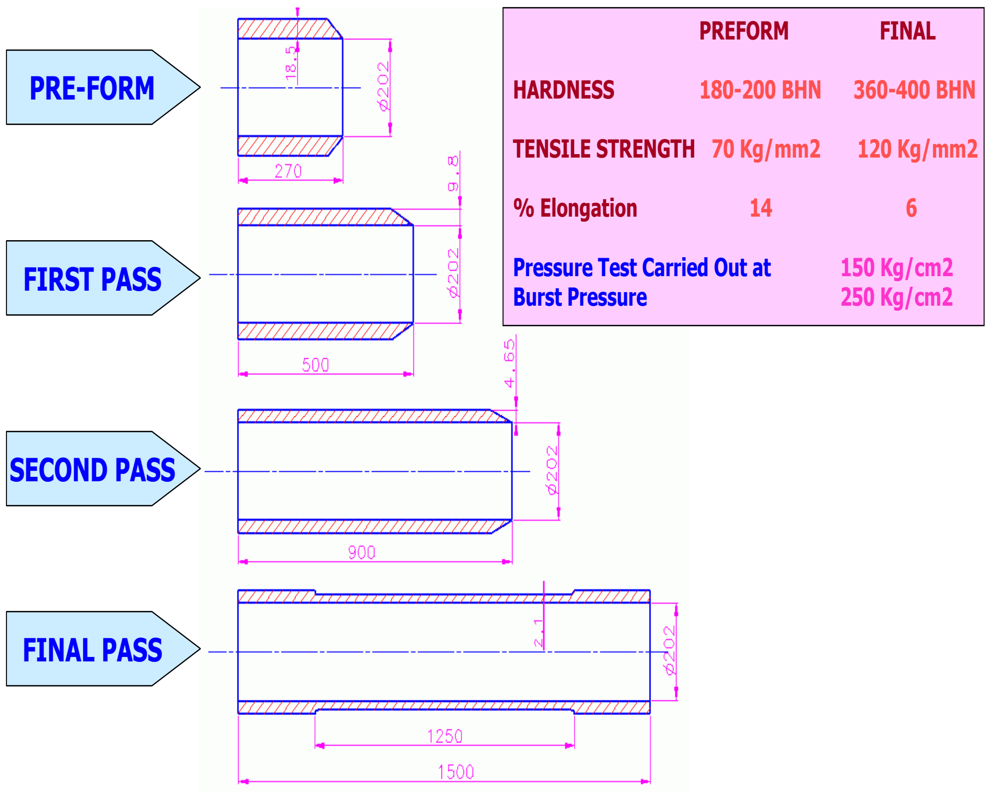


Fig. 9.2: Different Stages of Flow Forming

X. Application Of Taguchi Method For Optimization Of Process Parameters

10.1 Introduction

Taguchi method is a statistical method developed by Taguchi and Konishi. Initially it was developed for improving the quality of goods manufactured (manufacturing process development), later its application was expanded to many other fields in Engineering, such as Biotechnology [2] etc. Professional statisticians have acknowledged Taguchi's efforts especially in the development of designs for studying variation. Success in achieving the desired results involves a careful selection of process parameters and bifurcating them into control and noise factors. Selection of control factors must be made such that it nullifies the effect of noise factors. Taguchi Method involves identification of proper control factors to obtain the optimum results of the process. Orthogonal Arrays (OA) are used to conduct a set of experiments. Results of these experiments are used to analyze the data and predict the quality of components produced. Here, an attempt has been made to demonstrate the application of Taguchi's Method to improve the mean diameter characteristics of faced components that were processed on a spinning machine. Surface roughness is a measure of the smoothness of a products surface and it is a factor that has a high influence on the manufacturing cost. Surface finish also affects the life of any product and hence it is desirable to obtain higher grades of surface finish at minimum cost.

10.2 Approach To Product/Process Development

Many methods have been developed and implemented over the years to optimize the manufacturing processes. Some of the widely used approaches are as given below:

10.2.1 Build-Test-Fix

The "Build-test-fix" is the most primitive approach which is rather inaccurate as the is carried out according to the resources available, instead of trying to optimize it. In this method the process/product is tested and reworked each time till the results are acceptable.

10.2.2One Factor at a Time

The "one-factor-at-a-time" approach is aimed at optimizing the process by running an experiment at one particular condition and repeating the experiment by changing any other one factor till the effect of all factors are recorded and analyzed. Evidently, it is a very time consuming and expensive approach. In this process, interactions between factors are not taken in to account.

10.2.3 Design of Experiments

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

10.2.3.1 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.

10.2.3.2 Taguchi Method

The Full Factorial Design requires a large number of experiments to be carried out as stated above. It becomes laborious and complex, if the number of factors increase. To overcome this problem Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted. Taguchi thus, recommends the use of the loss function to measure the performance characteristics that are deviating from the desired target value. The value of this loss function is further transformed into signal-to-noise (S/N) ratio. Usually, there are three categories of the performance characteristics to analyze the S/N ratio. They are: nominal-the-best, larger-the-better, and smaller-the-better.

10.3 Steps Involved In Taguchi Method

The use of Taguchi's parameter design involves the following steps.

a. Identify the main function and its side effects.
b. Identify the noise factors, testing condition and quality characteristics.
c. Identify the objective function to be optimized.
d. Identify the control factors and their levels.
e. Select a suitable Orthogonal Array and construct the Matrix
f. Conduct the Matrix experiment.
g. Examine the data; predict the optimum control factor levels and its performance.
h. Conduct the verification experiment.

10.4 Approach To Experimental Design

In accordance with the steps that are involved in Taguchi's Method, a series of experiments are to be conducted. Here, Spinning operation on SAE-4130 components using forming has been carried out as a case study. The procedure is given below.

10.4.1 Identification of Main Function and its side effects

Main function: Forming Operation on SAE-4130 work piece using Spinning machine.
Side effects: Variation in Mean Diameter of the tube.
Before proceeding on to further steps, it is necessary to list down all the factors that are going to affect or influence the facing process and from those factors one has to identify the control and noise factors. The "Factors" that affect facing operation on a lathe machine are listed in the table.

Control Factors	**Noise Factors**
Mandrel Speed	Temperature
Roller Radius	Vibration
Feed Rate	Operator Skill
Coolant	Machine Condition

Table 10..4.1 Factors that affect Spinning Operation

After listing the control and the noise factors, decisions on the factors that significantly affect the performance will have to be ascertained and only those factors must be taken in to consideration in constructing the matrix for experimentation. All other factors are considered as Noise Factors.

10.4.2 Identifying the Testing Conditions and Quality Characteristics To Be Observed

Quality Characteristic: Mean Diameter
Work piece material: SAE-4130
Cutting tool: High Speed Steel Carbide
Operating Machine: Spinning Machine

Fig. 10.1: Machined Pre-form

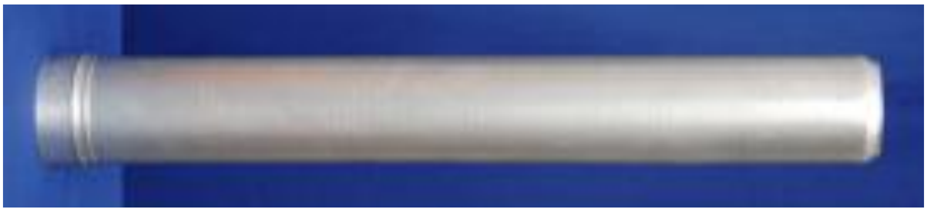


Fig. 10.2: Flow formed tube

10.4.3 Identify The Objective Function
Objective Function: norminal-the-Best
S/N Ratio for this function

$$S/N = 10 \times \log((\bar{Y}^2) \div \sigma^2)$$

Where, sigma square= variance,
and y = Mean Diameter in that run.

XI. Results and Discussions

10.5.1 Main effects

The main effects of process parameters are used to determine their influence on the response function. The factor main effects and their differences are analyzed by calculating the average value of S/N ratios of observations of the experiment. The main effects and their differences on the mean diameter are given in Table6. 4.5 The main effects plot for mean diameter is shown in Figure The change of roller feed from 45to 50 mm/min, increases the main effect S/N value by 6.34 and raise of roller feed from 50 to 55 mm/min decreases the main effect S/N value by 0.65. i.e., the process produces tubes with minimum variation in mean diameter when the feed is at level 2, where the S/N ratio is maximum. Lower value of roller feed rate (45 mm/min) produces, non-uniform plastic deformation as the roller passes slowly over the preform. This uneven plastic deformation leads to variation in mean diameter. When the roller feed reaches to 50mm/min, it becomes optimum and reduces localized uniform plastic deformation

which results in lower variation. And the feed rate increases further to 55mm/min, the forming forces becomes higher, this leads to larger variation in mean diameter from level 2 to level 3.

The increase of mandrel speed from 100to 110 rpm increases the main effect S/N value by 1.33 and from 110 to 130 rpm increases the main effect S/N value by 0.82.increases of the mandrel speed from 110 to 130 increases the mandrel effect s/n value by 2.15 .i.e., the process produces flow formed tubes with minimum variation in mean diameter when the speed is at level 3. At the lower mandrel speed, lower forming forces produce the tubes with smaller variation in mean diameter. As the speed of the mandrel increases to level 3, the optimized plastic deformation is reached

Simillarly, Roller Radius is optimised at 8 mm.

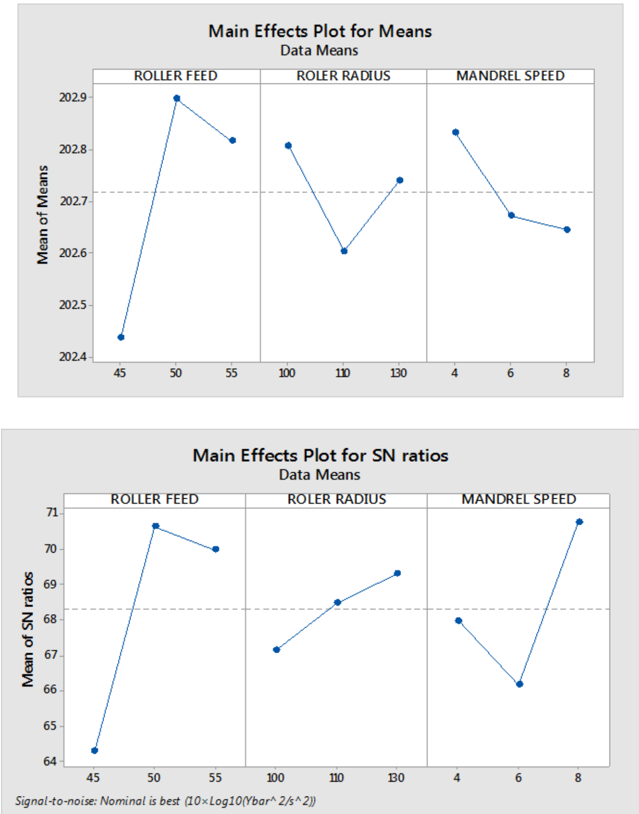


Fig. 10.3: Main effects plot for mean diameter

The relative slopes of linear graphs in Figure 3 indicate the significance of parameters. In the present study, it is clear that, the slope of line indicating the roller feed is more as compared to slopes of roller radius and mandrel speed. From the main effects and graphs of parameters, it is evident that the roller feed is having significant influence on the mean diameter of flow formed tube, followed by roller radius and andrel speed.

10.5.2. Optimum Conditions

The optimum condition for nominal mean diameter of flow formed tube is given in Table 6. It reveals that the roller feed should be at level 2 (50 mm/min), the mandrel speed should be at level 2 (110 rpm) and the roller radius should be at level 3(8mm) for production of flow formed tube with required nominal mean diameter. The model predicts an optimum value of 203.1 +/- 0.2 mm for mean diameter. The developed model produces tubes having mean diameter within the range of 202.9 to 203.3 mm.

XII. Conclusions:

Based on the experimental results and analysis made in the earlier chapter on flow forming of SAE 4130 steel tubes, the following conclusion are drawn.
The finishing roller radius should be lower than other two rollers to have uniform mean diameter and reduction in ovality. The roller radius should be fixed at 4 mm to have uniform mean diameter and reduction in ovality.
The hardness variation in pre-form should be minimized (5 to 10 BHN) to avoid thickness variation and ovality.
The hardness is increased up to 25-30% for 88% of thickness reduction. The geometrical accuracy becomes worse with the increment of thickness reduction.

1. Lower feed rates improve the surface finish, but ovality and variation in mean diameter increases. Therefore feed is optimized at 50 mm/min. The speed of the mandrel is arrived at 100-130 rpm to produce the tubes with good surface qualities.
2. Thickness reduction is optimized at 88% to manufacture tubes with good dimensional characteristics and surface qualities. The roughness of tube surface increases with increment of thickness reduction. Increase of the thickness reduction results in crystals refinement.
3. The hardness variation in the preforms tube should be as less as possible to avoid thickness variation and ovality. Yield and tensile strength increment are 14% and 30% for 88% thickness reduction.
4. The staggering of the rollers should be kept in such a way that there is a mini\mum of thickness of preforms tube.
5. The feed rate is arrived at 50 mm/min on SAE4130 Steels to obtain better ovality, thickness and mean diameter.
6. Though reduction in feed rate improves surface finish, but its effect is there on ovality and mean diameter, therefore it is optimized at 50 mm/min

Applications

i. Aerospace Industry.
ii. Automotive Industry.
iii. Boiler making Industry.
iv. Pressure Bottles.
v. Musical Instruments.

Future Scope Of Work

1. To study the effect of mechanical properties for different materials
2. To study the design of the preform for further improvement on geometrical parameters.
3. To study the influence of the metallurgical parameters like hardness, grain size, microstructure on flow forming process.
4. To study the utilization of NDT Techniques to minimize the defect during / after flow forming.
5. The same test can be conducted on different material to study the effect of mechanical properties of the material on the quality of the flow formed tubes.

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