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RESEARCH ARTICLE

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PRODUCTION OF SEAMLESS ROCKET MOTOR TUBE USING REVERSE FLOW FORMING PROCESS

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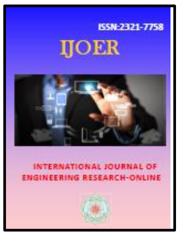

ABSTRACT

Flow-forming is an innovative, chip less cold metal forming process used to manufacture thin walled seamless tubes ,high precision tubes and other axis-symmetric components are produced by Progressive, continuous localized deformation. The flow forming is basically classified as forward flow forming and reverse flow forming depending upon the direction of material flow and in this work the process is Reverse flow forming.

The present work is carried out on the " Production of Seamless Tube by Reverse Flow Forming for Rocket Motor" on 4-axis CNC flow forming machine with a 3-roller configuration. Missile 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 with stand high temperature and pressures and should have high mechanical properties.

The aim of thee work is to analyze the effect of various parameters like roller radius, stagger, and hardness, mean diameter and feed on the final flow formed tube dimensions at different reduction rates on flow forming process of missile motor tube for pressure vessel application in aerospace engineering and missile technology. The material chosen for the present investigation of missile motor tube is SAE 4130 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. Ovality of the tubes, surface finish and thickness variation were also analyzed and it is found that feed rate is 50 mm/min for the final pass to flow from the SAE 4130 Steel for obtaining better geometry, thickness and mean diameter.

1. 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

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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 performs. 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.

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. 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. Mass production of small containment vessels for drum packages.

Various typical applications are shown in fig.8. Furthermore, flow forming produces a highly uniform, round and smooth, surface finish. Flow forming method also allows achieving high dimensional accuracies and required to mechanical properties.

Fig 1.1: Typical flow forming applications

Presently the aim of this paper is to analyze the effect of various parameters like roller radius, stagger, and hardness, mean diameter and feed on the final flow formed tube dimensions at different reduction rates on flow forming process of missile motor tube for pressure vessel application in aerospace engineering and missile technology. The material chosen for the study is **SAE-4130 Steel.** 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.

2. EXPERIMENTAL DETAILS

2.1 Introduction: In flow forming, as shown schematically in Fig, the blank is fitted into the rotating mandrel and the rollers approach the blank in the axial direction and plasticize the metal under the contact point. In this way, the wall thickness is reduced as material is encouraged to flow mainly in the axial direction increasing the length of the work piece. The flow of metal directly beneath the roller consists of two components, axial and circumferential.

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.

2.2 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 : 60 mm
4. Max. Flow forming dia : 600mm
5. Max. Flow forming length (Forward): 2000$_{mm}$
6. Max. Flow forming length (Reverse): 4000$_{mm}$
7. Stroke of Tail stock cylinder: 2400$_{mm}$
8. Total connected load of the machine: 375 KVA

The CNC machine program used given as appendix – 1

The control panel which is fitted in the CNC control switch cabinet contains all switches and keys required for programming and for the programmed control of the machine.

The machine control form is

N3 G2 X +/- 3.2 Z+/- 3.2 W 100 R5 S150 F160 M3

Where,

N : Record No
G : Path function
X Y, Z, and W : Desired value of position
F : Feed mm/min
S : RPM of spindle
M : miscellaneous functionR : Radius

2.1 Leifeld Flow Forming MACHINE

Fig 2.1: Flow-forming Machine

Fig 2.2: Arrangement of Mandrel & Rollers.

2.3 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.

2.4Chemical Composition: The composition of present investigation of missile motor tube is SAE 4130 Steel (converted to electro slog refined grade) is given below:

<u>**Chemical%wt**</u>

Carbón (C)	0.28% - 0.33%
Silicón (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%
Phosphorus (P)	0.015%

2.5Design of Preform: The Required dimensions of the tube after forming is shown in fig

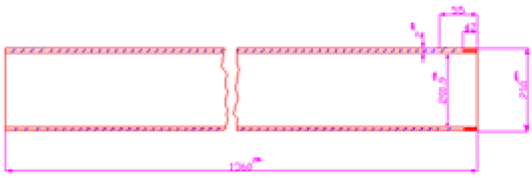

Fig 2.3: Dimension of the tube after forming

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.

The preforms thickness is arrived as follows:

$$\text{Percentage reduction} = \frac{\text{(Initial thickness (ti) - final Thickness } (t_f))}{\text{Initial thickness (ti)}} \times 100$$

i.e. $R = \{t_i - t_f / t_i\} \times 100$

$88 = \{t_i - 2.2 / t_i\} \times 100$

(Initial thickness (ti) = **18.5mm.**

Length of preforms is given by $Li/ L_f = t_f/t_i$ (from equal volumes principle)

$Li/ L_{f = tf}/t_i$

Where, Li is length of preforms, L_f is length of final component.

T_i is thickness of preforms, t_{ft} is thickness of final component

Add 6% to the above value for trimming as an allowance.

Li 1 =2.2/18.5 *1500 =178.4mm

$Li/ L_{f = tf}/t_i$

Li 2 =4.7/18.5 *300 =76.2mm

Li p = (178.4+76.2) *6/100 =15.24mm

Li =270mm. (178.4+76.2+15.24) =270MM

Li is length of perform is **Li =270mm**.

Length of preforms is given by $Li/ L_f = t_f/t_i$ (from equal volumes principle)

Where, Li is length of preforms, L_f is length of final component.

T_i is thickness of preforms; t_{ft} is thickness of final component

Add 6% to the above value for trimming as an allowance.

2.6 Machined Preform: The key to successful flow forming is the quality and design of the preform. The accuracy and finish of the final product directly reflect the dimensions and profile of the preform Material for the preforms was procured in the shape of forged billet.

Fig 2.4: The complete details of preforms forging

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

2.7 Plan of Experiment: The total reduction in thickness is about88 to 90% and the reduction in each pass is limited to 50-60%. It is decided to carry out the flow forming operation in three passes

Table 2.1: the percentage reduction in each pass is given below

SI No.	Pass No	Initial Thickness	Final Thickness	Initial hardness (HRC)	Final hardness (HRC)	% Reduction
12	First	18.5	9.5	21	28	48.6
3	Second	9.5	4.6	28	30	51.5
	Third	4.6	2.1	3	31	54.3

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The approximate flow forming process parameters are set from theoretical data available. That data is then suitably adjusted based on the experimental results to give the required mean diameter, Ovality and thickness of the tube. Fig 2 shows the tubes at various stages of reductions.

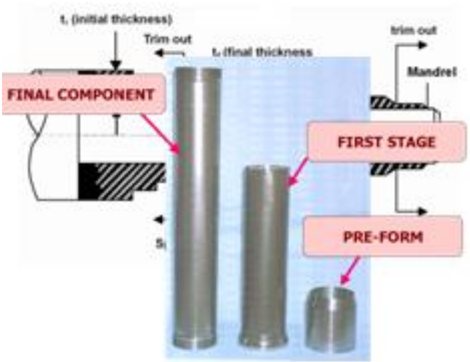


Fig 2.5: Machined Preform and its finished part.

2.8 Mechanical strength

The details about mechanical strength of preforms are given below,

Hardness: 210 to 230 BHN.

Tensile strength

- ➢ Ultimate Tensile Strength (UTS) : 90 kg/mm^2 (minimum)
- ➢ 0.2%Proof stress : 70 kg/mm^2 (minimum)
- ➢ % Elongation : 12% (minimum) of Gauge Length50mm.

The details of the after flow formed tube mechanical strength are given below,

Hardness: 310 to 360 BHN.

Tensile strength

- ➢ Ultimate Tensile Strength (UTS) : 120 kg/mm^2 (minimum)
- ➢ 0.2%Proof stress : 90 kg/mm^2 (minimum)
- ➢ % Elongation : 6% (minimum) of Gauge Length of50mm..

Table 2 Mechanical properties and dimensional tolerances of flow formed tube

	Mechanical Properties			Dimensional Tolerances		
	UTS(MPa)	0.2% yield strength (MPa)	%El	Ovality (mm)	Straightness(mm)	Surface roughness CLA (µm)
Specified	1200 (min)	900 (min)	6 (min)	0.3 (max)	0.15 (max)	—
Actual	1250–1350	950–1100	7–8	0.15–0.20	0.1–0.15	N5–N6

Tensile Tests

Positions of 3 points were recorded together with the force at 60Hz. The deformation calculated from the average deformation of the 3 pairs of points.

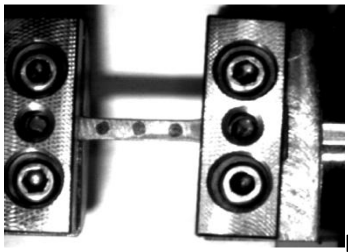
➢  **pairs**

Fig 2.6: Tensile samples before and after testing

2.9 Heat Treatment Cycles

The heat treatment cycles usually used for preforms preparation using SAE 4130 are

Hardening: Hardening is done at 500^{0}c for 1 hour to 3.25 hours & at 800^{0}c for 1 hour water quench.

Tempering: Temperingis done at 400^{0}c for 1 hour to 3.25 hours & 660^{0}c for 4 hours air cooled.

2.10 Hardness of Preform

The hardness of preforms must be checked at three points. One at face and other at the opposite face and the average taken. If the difference is too high (> 5-10 BHN) the preforms should not be used. The hardness variation allowed in a very small range about 5 BHN. For aluminum and other formable materials it is more, about 10 BHN.

While starting on a new product, the starting hardness is to be checked and then the parameters are determined such as speed, feed etc., This experiment was carried out on preforms having hardness variations in order to know the effect of hardness variation in the preforms on the final product. The parameters used are shown in appendix – 4. After flow forming the preforms having different hardness variation the final tube was measured for thickness. The values measured are shown in table 4.3.

Table 2.3 Variation of hardness with thickness

Sl. No	Hardness Of preforms		Hardness variation	Thickness	Thickness	Thickness Variation
	A	B	A-B	C	D	D-C
	Max	Min	(BHN)	Min	Max	(min)
1	207	171	36	2.4	3.35	0.95
2	224	205	19	2.3	2.35	0.5
3	223	215	8	2.2	2.28	0.08
4	225	220	5	2.1	2.15	0.05

2.11 Design of Mandrel: Due to the pressures involved in the flow forming process, flow form tools – i.e. rollers and mandrels must be made from hardened steel that is heat treated and drawn to a temper that makes the tool hard but yet not brittle. Since the metal is extruded in a rotary fashion rather than stretched over the mandrel, the flow form mandrel will last for many thousands of pieces, as long as care is taken during setup and the mandrel is stored properly. hence the mandrel takes the total load during forming process. Therefore the mandrel is made of high strength material with sufficient hardness. Due to high stresses prevailing during flow forming, the material selected for mandrel was HCHC A high carbon And High Chromium steel is called HCHCr material.

Normally consists carbon of 2% and Chromium of 12% Silicon and Manganese vary between 0.2-0.35%,this is a direct hardening material and can be hardened to 58-60 HRC.

This material is used for manufacturing press tools and sheering blades.

The diameter of the mandrel is designed to 202.05 ±0.01mm. A slight taper of about 0.01 to 0.02 is given on mandrel diameter for easy withdrawal of the tube after flow forming.

Diameter of mandrel at head stock end: $202.06^{+0.01}$

Diameter of mandrel at tail stock end: $202.05^{+0.01}$

Length of the mandrel from face of the drive ring:950mm

The detail of mandrel is shown in figure:

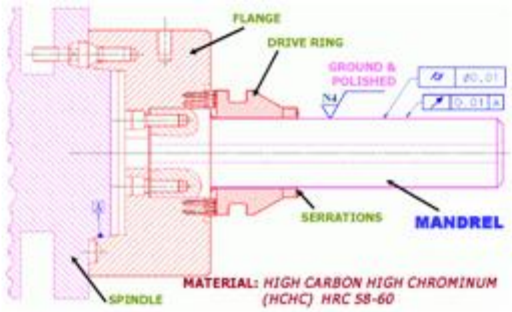
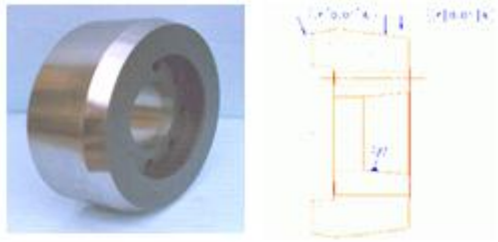


Fig 2.7: flow form mandrel Setup

2.12 Fixing Of Roller Radius

The experiments were carried out with keeping the parameters constant which are shown in appendix 2 and varying the roller radius. The three rollers are arranged at 1200 to each other as shown in fig. The X roller is the trailing roller (finishing roller), the Y- roller is intermediate roller and the Z- roller is the leading roller. Roller configuration is shown in figure. The component was flow formed with the roller radius in Table 2.7 and results obtained are recorded.



MATERIAL : High Speed Steel (HSS)

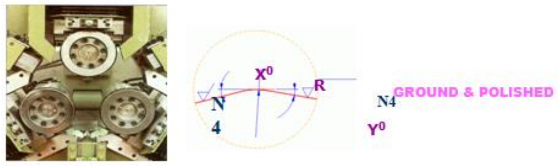


Fig 2.8: Roller geometry

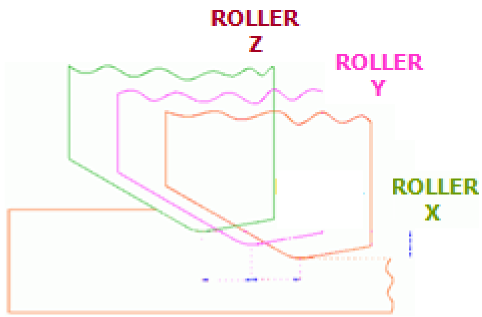


Fig 2.9: Arrangement of Three Rollers

RADIUS[R] : ***1R - 15R***

ENTRY ANGLE [X] : ***15^O – 30^O***

EXIT ANGLE [Y] : ***1^O - 10^O***

2.13 Program

Missile Tube First & Second Pass Setting Parameters

Work Offset

X = -175.31

Y = -173.93

Z = -170.61

W = -2000

Mechanical stopper

X = -182.80

Y = - 179.45

Z = - 179.60

Roller used

X= 20 8R 10

Y= 20 R12 10

Z = 18 R12 10

Stagger

A = 46.8

B = 31.0

Program for first & second pass

In Put Keys

The Program me records are entered via the input keyboard and the address keys. A record is composing of several words such as follows:

N - Record Number

G - Functions (Path Conditions – Special Functions)

XYZW - Set point positions.

F - Address for feed rate mm/min

S- Speed in 1/min for main spindle driveM

N 00	G	X	Y	Z	W	F	S	M
50	1	60	60	60	580	1200	-----	21
51		60	60	60	580	1200	----	----
52		60	60	60	580	1200	100	O3
53		60	60	60	580	1200	100	60
54		60	60	60	580	1200	100	68
55		20	20	20	580	800	100	----
56	01,64	9.81	11.04	14.45	540	200	100	----
57		9.81	11.04	14.45	530	100	100	----
58		9	12.15	15.3	520	50	100	----
59		9	12.15	15.3	332	50	100	----
60		60	60	60	332	1200	100	----
61		60	60	60	900	1200	100	----
62		10	10	10	900	500	110	----
63		5.18	6.21	9.59.	750	500	110	----
64		5.18	6.21	9.59	720	100	110	----
65		3.95	5.6	7.5	710	50	110	----
66		3.92	5.6	7.5	362	50	110	----
67		60	60	60	362	200	110	----
68		150	150	150	362	1200	110	O5
69		150	150	150	362	1200	-----	61
70		150	150	150	362	1200	-----	69
71		150	150	150	362	1200	-----	----
72		150	150	150	362	1200	-----	22

Missile Tube Final Pass Setting Parameters

Work offset

X = -175.15

Y = -175.83

Z = -175.87

W = -2000

Mechanical stopper

X = 182.50

Y = 180.70

Z = 183.00

Roller used

X = 30 R4 10

Y = 20 R4 10

Z = 30 R8 10

Stagger

X = 45.50

Z = 37.00

Program me For Final Pass Thickness 2.11 / 2.14:

NOO	G	X	Y	Z	W	F	S	M
150	O1	60	60	60	1050	1200	-----	21
151		60	60	60	1050	1200	-----	O3
152		60	60	60	1050	1200	130	60
153		60	60	60	1050	1200	130	68
154		60	60	60	1050	1200	130	-----

155	O1,64	6	6	6	1025	1200	130	-----
156		4.8	4.8	4.8O	1012	50	130	-----
157		1.11	2.43	3.65	1002	50	130	-----
158		1.39	2.48	3.64	465	50	130	-----
159		1.9	2.7O	3.9O	462	50	130	-----
160		4.6O	6	6	450	50	130	-----
161		100	100	100	450	1200	130	-----
162		100	100	100	450	1200	130	O5
163		100	100	100	450	1200	-----	61
164		100	100	100	450	1200	-----	69
165		100	100	100	450	1200	-----	-----
166		100	100	100	450	1200	-----	22

Table 2.4 Constant flow forming parameters with stagger for producing final component

Sequence of passes	**Roller Feed (Mandrel-roller gap) mm**			**Roller Stagger (mm)**		**Roller Spread a+b**	**Mandrel Speed (rpm)**	**Feed mm/min**	**Initial Thickness of preforms**
	X	**Y**	**Z**	**X-Y (a)**	**(Y-Z) (b)**				
1	9	12.5	15.3	6.8	9	15.8	100	50	18.5
2	3.95	5.6	7.5	6.8	9	15.8	110	50	9.5
3	1.11	2.43	3.65	5.5	3	8.5	130	50	4.6

TABLE 2.5 Roller radius (mm) VS Mean diameter (mm)

Roller radius(mm)	Mean diameter(mm)	Avg.Mean diameter(mm)
4	202.10,202.90,202.20,202.30,201.80,202.10	202.10
6	202.46,202.50,202.32,202.54,202.68,202.50	202.50
8	202.60,203.00,202.80,202.90,202.70,202.80	202.80
10	203.30,203.20,203.10,202.90,203.50,203.20	203.20

TABLE 2.6 Constant flow forming parameters with rollers in feed

Sequence of pass	**Roller configuration**			**Stagger**		**Mandrel Speed**	**Roller in Feed**		
	X	**Y**	**Z**	**X-Y**	**Y-Z**	**(rpm)**	**X**	**Y**	**Z**
	30	20	15						
1	8	12	12	6.8	9	100	9	12.5	15.3
	10	10	10						
	30	20	30						
2	8	12	12	6.8	9	110	3.95	5.6	7.5
	10	10	10						
	30	20	30						
3	4	4	8	5.3	3	130	1.11	2.43	3.65
	10	10	10						

Table 2.7 variation of mean diameter and ovality with roller configuration (final pass)

Expt No	Roller configuration	X⁰	R	Y⁰	Tol:202.0+0.2 Mean dia (mm)	Max: 0.3 Ovality (mm)
1	X	**20**	**10**	**10**	203.1 | 203.2 | 203.4	
	Y	**15**	**12**	**10**	204.3 | 203.4 | 203.6	
	Z	**15**	**12**	**10**	203.2	**1.2**
2	**X**	**30**	**8**	**10**	202.7 | 202.8 | 202.9	**0.9**
	Y	**20**	**8**	**10**	203.6 | 202.8 | 202.9	
	Z	**15**	**10**	**10**	**202.8**	
3	**X**	**30**	**6**	**10**	202.8 | 202.3 | 202.3	**0.5**
	Y	**20**	**6**	**10**	202.5 | 202.3 | 202.6	
	Z	**15**	**8**	**10**	**202.5**	
4	**X**	**30**	**4**	**10**	202.1 | 201.90 | 202.1	**0.2**
	Y	**30**	**4**	**10**	201.9 | 202.1 | 201.90	
	Z	**20**	**6**	**10**	**202.1**	

Further experiments were carried out with different roller radius and the measured values of mean dia and ovality obtained are as shown in table.

2.14 Staggering Of Rollers

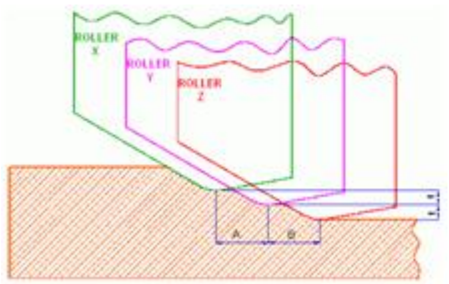


Fig 2.10: Stagger arrangements

The experiments were carried out by varying the stagger and keeping all the parameters constant. The parameters that are kept constant are shown in appendix – 3.

The arrangement of the roller plans are changed in each experiment the roller stagger is changed by moving X or Z rollers towards or away from the Y – roller. After carrying out the flow forming operation based on the results the stagger A or B are changed for subsequent experiments till the desired dimensional accuracy is obtained shown in Table 2.8.

Table 2.8 Variation of mean diameter and ovality with stagger

Sl.No	Stagger(mm)		Stagger Spread (A+B)	MEAN Dia (mm)	Ovality (mm)
	X-Y(A)	Y-Z(B)			
1	5.5	3	8.5	202.5	0.45
2	5.5	2.4	7.9	202.35	0.3
3	4.9	2.4	7.3	202.10	0.2

2.15 Feed Rate

This experiment was carried out to know the effect of feed rate on the surface finish, thickness and ovality. The experiments were conducted with different feed rates in final pass. The other parameters that are kept constant are shown in appendix – 4.

After flow forming of the components with different feed rates, feed rates, the measured values of surface finish, ovality and the thickness are tabulated in the table 2.9.

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Table 2.9: Variation of parameters with feed rate

Expt no	Feed rate Mm/ Min	Surface Finish (inside) µm	Surface Finish (outside) µm	Mean dia In mm	Ovality Mm	Thickness In mm
1	40	0.59 0.58 0.61 0.57 0.59	2.8 2.7 2.9 3.2 2.9	202.3	0.35	2.0
2	45	0.63 0.61 0.65 0.62 0.63	3.03 3.04 3.02 3.05 3.03	202.2	0.25	2.05
3	50	0.68 0.69 0.67 0.69 0.68	3.2 3.3 3.1 3.4 3.2	202.1	0.2	2.1
4	55	0.74 0.73 0.75 0.76 0.74	3.3 3.1 3.5 3.2 3.3	202.2	0.23	2.15
5	60	0.78 0.77 0.75 0.76 0.77	3.46 3.47 3.45 3.48 3.47	202.25	0.3	2.2

Different Passes of Reverse Flow Forming Missile Tube

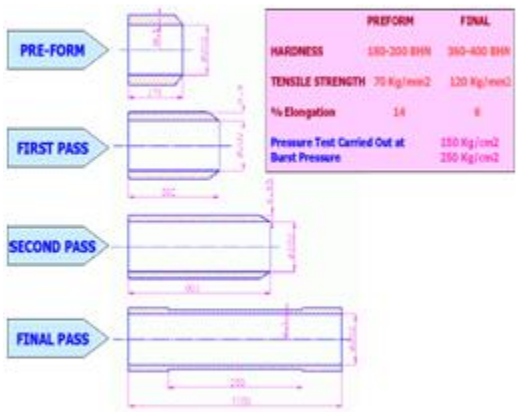

Fig 2.11: Different passes of reverse flow forming for missile tube

2.17 Testing Equipment

The Inspection of various parameters like hardness of preforms, thickness, ovality, diameter and surface finish are carried out after each experiment. The instruments used for the above findings are given below.

2.17. Ultrasonic Thickness Meter

The wall thickness of the tube is checked with ultrasonic thickness meter CALIPER CL204.

2.17.2 Bore Dial Gauge

The ovality of the tube is measured by a dial gauge. The resolution of the instrument is 0.01 mm. the difference between the maximum & minimum diameter given the ovality of the tube. The maximum and minimum diameter of the tube at four places of one are taken and averaged. This is repeated at every 100 mm length of the tube & readings are recorded.

2.17.3 Hardness Measurement

The hardness variation in pre-form should be minimized (5 to 10 BHN) to avoid thickness variation and ovality. EQUITIP-D Hardness tester was used for measuring the hardness of the preforms. It is an extremely light weight portable hardness tester. Frank hardness tester was used for determining the hardness at different reduction.

2.17.4 Surface Finish Measurement

The assessment of surface texture of the tube is done by FORM TALYSURF instrument. The system incorporate a traverse unit which houses a two axis laser infers metric transducer coupled to a pivoted stylus.

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3. ANALYSIS OF EXPERIMENMTAL RESULTS

3.1 Introduction

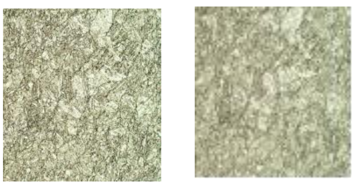
Experimental trials are conducted on a CNC flow forming machine with three rollers to investigate and analyze the experimental results of the process parameters on the dimensional characteristics and surface qualities of SAE 4130 Steel (converted to electro slog refined grade) is flow formed tubes. The results and discussion are given subsequently. They analyzed the influences of various process parameters on the diametric growth of tubes.preliminary experiments were conducted to establish the process parameter to obtain proper ovality, mean diameter, thickness inside surface finish of the finished tube when the process parameters are established, tests were carried on SAE 4130 tubes and observed results one given below.

3.2 Grain Structure

By a pre calculated amount of wall reduction, in one or more passes, the material is compressed above its yield strength, plastically deformed and made to flow. The desired geometry of the work piece is achieved when the outer diameter and the wall of the preforms are decreased and the available material volume is forced to flow longitudinally over the mandrel. Due to these grains after forming approximately changes from grain size of 6 to 8 - 10 to 12. According to ASTM.

Fig 3.1: Grain Structure

Cross-sectional view of the rollers' footprint on the work piece and the corresponding grain structures for each area. Shown on the left (thick section) is the preform starting wall. On the far right is the flow formed wall



a) b)

Microstructure in the hardened condition

A) Flow formed part and b) machined part

Fig 3.2: Microstructure in the hardened condition

3.3 Mean Diameter

The effect of finding roller radius against mean diameter on the finished tube was observed and results are shown in figure 5.1. It is observed that large nose radius of the roller will tend to increase mean diameter of the tube. Since larger nose radius of the roller will have larger contact and hence the roller will tend to increase the circumferential dimension. This is due to larger forces when the roller radius is high and which will create more spring back effect. It is also observed in figure 5.3 that change in stagger spread will also affect the mean diameter

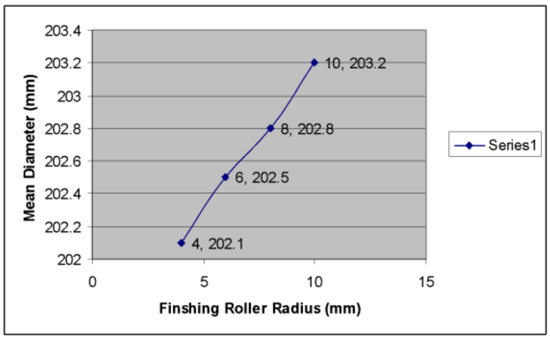
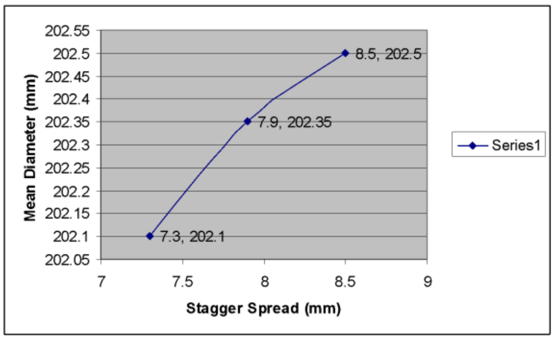


Fig 3.3: Variation of Mean Diameter with Roller Radius



3.4: Variation of Mean Diameter with Stagger

3.4 Thickness Variation

The effects of hardness variation in the preforms against the thickness variation along the length of the tube were observed and results are mentioned in Fig 5.5. It is observed that large variations in hardness in the preforms will result in large thickness variations in the finished tube. The hardness variation in pre-form should be minimized (5 to 10 BHN) to avoid thickness variation and ovality. This is because inhomogeneity (hard sports, inclusions, uneven rate of cooling) in the material

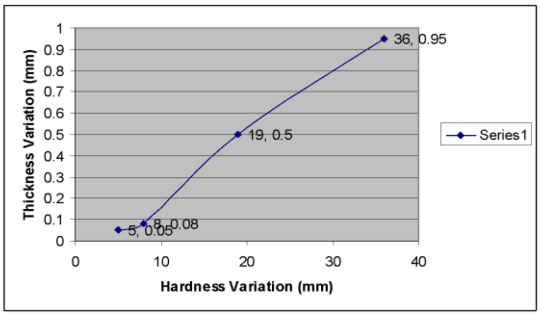


Fig 3.5: Hardness Variation vs. Thickness Variation

3.5 Ovality

Fig 5.6 represents the effect of finishing roller radius against the ovality of the tube. It is observed that for smaller roller radius the ovality is less when compared to the ovality of tubes formed with large roller radius.

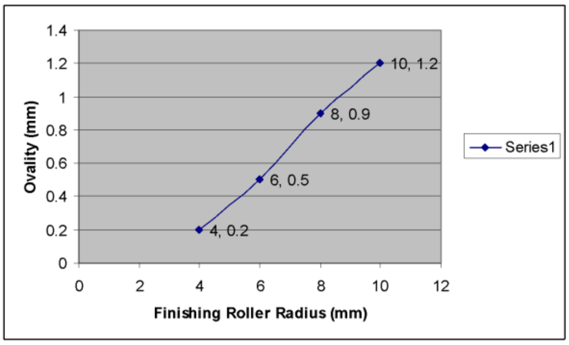


Fig 3.6: Variation of Ovality with Finishing Roller Radius

The effect of stagger spread against the ovality of the tube was observed and results are mentioned in Fig 5.7 it observed that when stagger spread is less the ovality is less and increases with increase in stagger spread. The roller radius should be fixed at 4 mm to have uniform mean diameter and reduction in ovality... It is observed that the increase at high feed rates the ovality is more and decreases up to a point and again starts increasing gradually feed this is due to non-flow formed residual stresses

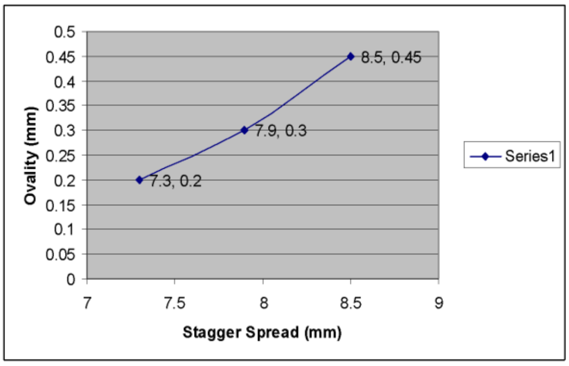


Fig 3.7: Variation of Ovality with Stagger Spread

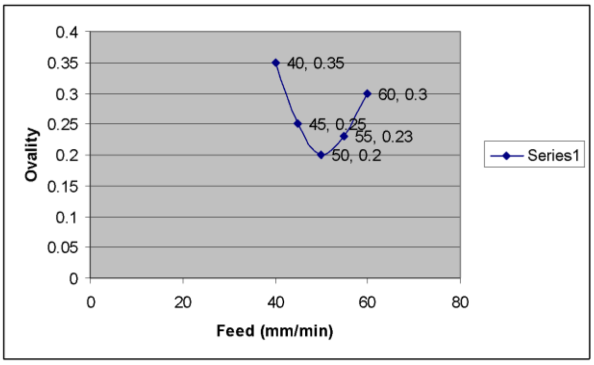


Fig 3.8: Variation of Ovality with Feed

3.6 Surface Finish

The effect of feed against surface finish (inside and outside the tube) observed and results are shown in Fig 5.9 and 5.10. It is observed from the result, that the increase in feed the surface roughness (inside and outside the tube) increases. Lower feed rates improve the surface finish, but ovality and variation in mean diameter increases. Therefore feed is optimized at 75 mm/min.

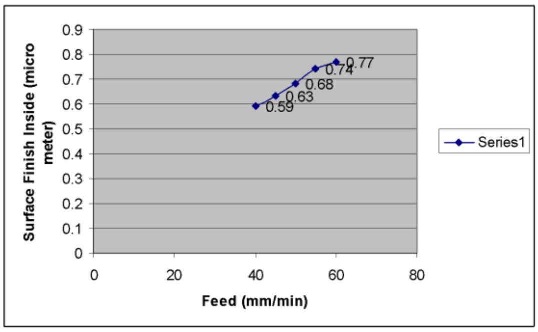


Fig 3.9: Feed vs. Inside Surface Finish

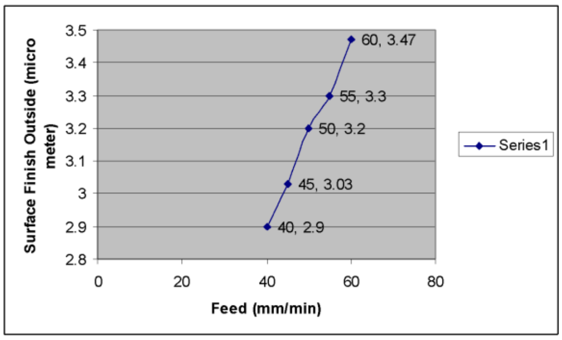


Fig 3.10: Feed vs. Outside Surface Finish

3.7 Thickness

The effects of feed against thickness are observed and results are present on Fig 5.11. It is observed that the effect of feed on thickness is very small i.e. with increase in feed rate the uncut chip thickness which will increase the thickness of the formed tube. Lower feed rates improve the surface finish, but ovality and variation in mean diameter

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increases. Therefore feed is optimized at 75 mm/min

Thickness reduction is optimized at 30% to Manufacture tubes with good dimensional characteristics and surface qualities.

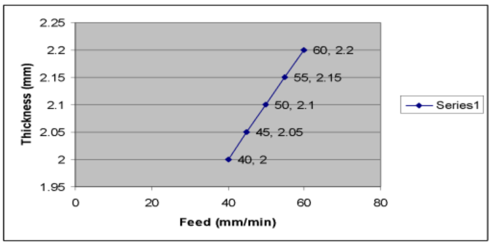

Fig 3.11: Feed vs. Thickness

3.7 Hardness

The hardness variation in pre-form should be minimized (5 to 10 BHN) to avoid thickness variation and ovality. The effect of percentage reduction in material against the hardness along the axial direction of the tube was measured and observed results are mentioned in Fig.5.12. It is observed from stage reduction the hardness is increase gradually. It is observed that after certain percentage of reduction there is no increase in hardness. The increase in hardness is due to continuous work hardening effect. Beyond certain reduction there is not much work hardening.

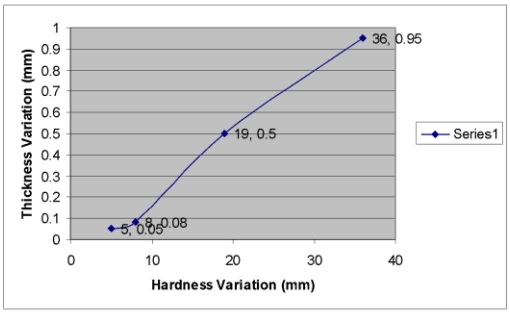

Fig 3.12: Hardness Variation VS thickness variation

APPENDIX-1 (Program)

Missile tube first & second passes setting parameters

Work offset

X = -175.31

Y = -173.93

Z = -170.61

W = -2000

Mechanical stopper

X = -182.80

Y = - 179.45

Z = - 179.60

Roller Used

X= 20 8R 10

Y= 20 R12 10

Z = 18 R12 10

Stagger

X = 46.8, Z = 31.0

Program for First & Second Pass

In Put Keys,

The Program me records are entered via the input keyboard and the address keys. A record is composing of several words such as follows:

N - Record Number

G - Functions (Path Conditions – Special Functions)

XYZW - Set point positions.

F - Address for feed rate mm/min

S - Speed in 1/min for main spindle driveM

N 00	G	X	Y	Z	W	F	S	M
50	1	60	60	60	580	1200	-----	21
51		60	60	60	580	1200	----	----
52		60	60	60	580	1200	100	O3
53		60	60	60	580	1200	100	60
54		60	60	60	580	1200	100	68
55		20	20	20	580	800	100	----
56	01,64	9.81	11.04	14.45	540	200	100	----
57		9.81	11.04	14.45	530	100	100	----
58		9	12.15	15.3	520	50	100	----
59		9	12.15	15.3	332	50	100	----
60		60	60	60	332	1200	100	----

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61		60	60	60	900	1200	100	----
62		10	10	10	900	500	110	----
63		5.18	6.21	9.59.	750	500	110	----
64		5.18	6.21	9.59	720	100	110	----
65		3.95	5.6	7.5	710	50	110	----
66		3.92	5.6	7.5	362	50	110	----
67		60	60	60	362	200	110	----
68		150	150	150	362	1200	110	O5
69		150	150	150	362	1200	-----	61
70		150	150	150	362	1200	-----	69
71		150	150	150	362	1200	-----	----
72		150	150	150	362	1200	-----	22

Missile tube final pass setting parameters

Work offset

X = -175.15

Y = -175.83

Z = -175.87

W = -2000

Mechanical Stopper

X = 182.50

Y = 180.70

Z = 183.00

Roller Used

X = 30 R4 10

Y = 20 R4 10

Z = 30 R8 10

Stagger

X = 45.50

Z = 37.00

Program me For Final Pass Thickness 2.11 / 2.14

NOO	G	X	Y	Z	W	F	S	M
150	O1	60	60	60	1050	1200	-----	21
151		60	60	60	1050	1200	-----	O3
152		60	60	60	1050	1200	130	60
153		60	60	60	1050	1200	130	68
154		60	60	60	1050	1200	130	-----
155	O1,64	6	6	6	1025	1200	130	-----
156		4.8	4.8	4.8O	1012	50	130	-----
157		1.11	2.43	3.65	1002	50	130	-----
158		1.39	2.48	3.64	465	50	130	-----
159		1.9	2.7O	3.9O	462	50	130	-----
160		4.6O	6	6	450	50	130	-----
161		100	100	100	450	1200	130	-----
162		100	100	100	450	1200	130	O5
163		100	100	100	450	1200	-----	61
164		100	100	100	450	1200	-----	69
165		100	100	100	450	1200	-----	-----
166		100	100	100	450	1200	-----	22

APPENDIX – 2

Constant flow forming parameters with stagger for producing final component:

Sequence of passes	Roller Feed (Mandrel-roller gap) mm			Roller Stagger (mm)		Roller Spread a+b	Mandrel Speed (rpm)	Feed mm/min	Initial Thickness of preforms
	X	Y	Z	X-Y (a)	(Y-Z) (b)				
1	9	12.5	15.3	6.8	9	15.8	100	50	18.5
2	3.95	5.6	7.5	6.8	9	15.8	110	50	9.5
3	1.11	2.43	3.65	5.5	3	8.5	130	50	4.6

APPENDIX – 3

Constant flow forming parameters with roller configuration for producing final component

Sequence of pass	Roller configuration			Roller in feed			Feed mm/min	Mandrel Speed (rpm)
	X	Y	Z	X	Y	Z		
1	30 8 10	20 12 10	15 12 10	9	12.5	15.3	50	100
2	30 8 10	20 12 10	30 12 10	3.95	5.6	7.5	50	110
3	30 4 10	20 4 10	30 8 10	1.11	2.43	3.65	50	130

APPENDIX – 4

Constant flow forming parameters with rollers in feed

Sequence of pass	Roller configuration			Stagger		Mandrel Speed (rpm)	Roller in Feed		
	X	Y	Z	X-Y	Y-Z		X	Y	Z
1	30 8 10	20 12 10	15 12 10	6.8	9	100	9	12.5	15.3
2	30 8 10	20 12 10	30 12 10	6.8	9	110	3.95	5.6	7.5
3	30 4 10	20 4 10	30 8 10	5.3	3	130	1.11	2.43	3.65

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 geometrical accuracy becomes worse with the increment of thickness reduction.

- 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.
- 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.
- The staggering of the rollers should be kept in such a way that there is a minimum of thickness of preforms tube.

FUTURE SCOPE OF WORK

- To study the design of the preform for further improvement on geometrical parameters.
- To study the influence of the metallurgical parameters like hardness, grain size, microstructure on flow forming process.
- 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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- In this Project **Ms. Kalyani Kolli** has helped us a lot to complete this Project and She is working as **Software Engineering Analyst** at **Accenture.**

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