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An Improvement of Flow Forming Process for Pressure Vessels by Four Rollers Machine

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***Abstract*—**Flow forming is widely used in many industries, especially in defence technology industries. Pressure vessels requirements are high precision, light weight, seamless and optimum strength. For large pressure vessels, flow forming by 3 rollers machine were used. In case of long range rocket motor case flow forming and welding of pressure vessels have been used for manufacturing. Due to complication of welding process, researchers had developed 4 meters length pressure vessels without weldment by 4 rollers flow forming machine. Design and preparation of preform work pieces are performed. The optimization of flow forming parameter such as feed rate, spindle speed and depth of cut will be discussed. The experimental result shown relation of flow forming parameters to quality of flow formed tube and prototype pressure vessels have been made.

***Keywords*—**Flow forming, Pressure vessel, four rollers, feed rate, spindle speed, cold work.

I. Introduction

HIGH PRESSURE VESSELS or HPV are widely used in many applications and industrial. High strength thin wall tube is designed for production of HPV and variety of fabrication method can be used such as forging, machining, extrusion etc. Flow forming Technology is commonly used for manufacturing of pressure vessel, especially in defence application. High performance of HPV can be obtained by flow forming such as high strength, high pressure, light weight and excellent surface finish. Considering in economic, this technique has low tooling and operation cost, chipless and very fast.

From previous process, rocket motor case, considering as HPV are manufactured by flow forming process and 3 rollers flow forming machine are commonly used [1], [2]. Because of limitation of product length, the welding process also necessary for production of a long rocket motor [3].

A. Flow Forming Technology

Flow forming is cold metal forming process which means the temperature of workpiece should not be lower than material recrystallization temperature. The process starts from hollow cylindrical workpiece called preform and fitted into rotating mandrel, than apply compression force (axial and radial) to outer surface of preform by rollers to increase the length and reduce the thickness to designed diameter.

Two direction of flow forming can be defined and shown in Fig. 1. Forward flow forming is suitable for the tube no longer than the length of mandrel. The preform should be open and close end frame and deformed material move in the same direction of roller feed rate. Backward flow forming is suitable for the tube longer than the length of the mandrel

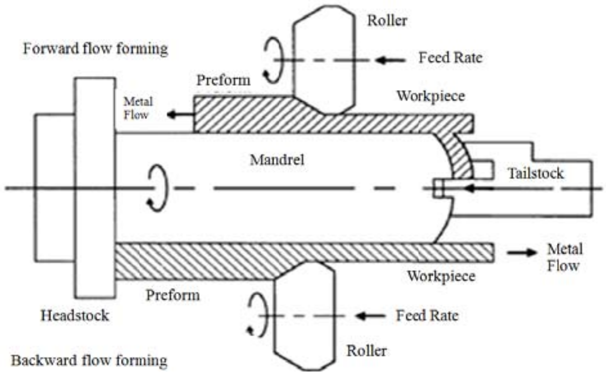

Fig. 1 Schematics of forward and backward flow forming

Design of preform tube is based on the principle of constant volume and material flow formability depends on properties and mechanism. The configuration and geometry of roller also effect to accuracy of the product [4]-[7]. Flow forming machine have been designed with variety of roller configuration. One and two rollers machine were built at the beginning of development and three rollers machine is widely used at present. Four rollers machine is the modern configuration flow forming concept and the manufacturer claimed that is optimum in terms of balance roller forces and high productivity. Comparisons of roller configuration are illustrated in Fig. 2.

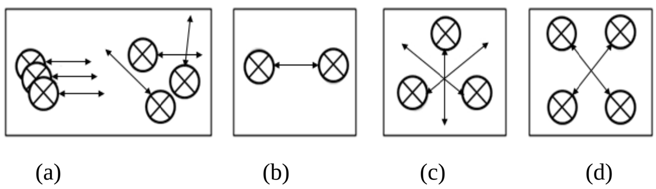

Fig. 2 Schematics of force of roller in each configuration (a) One roller (b) Two rollers(c) Three rollers (d) Four rollers

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TABLE I
PROPERTIES OF MATERIALS USED FOR AEROSPACE APPLICATION

Material	Design yield strength [ksi]	Modulus of elasticity, 1000 [ksi]	Density [lb/in^3]	Heat treatment	Remarks
HY steel:					
HY-80	80	29.5	0.285	Quench and temper	No heat treatment required after welding
HY-130/150	130-150	29.5	0.285		
Low alloy steel:					
4130	150-180	29.0	0.283	Quench and temper	
4335V	180-200	29.0	0.283		Heat treatment required after welding
D6aC	180-240	29.0	0.283		
Maraging steel:					
Grade 200	200	27.5	0.289	Solution anneal and age	Age only after welding
Grade 250	240	27.5	0.289		
Grade 300	280	27.5	0.289		
HP steel:					
9 Ni-4 Co-0.250	180-220	28.5	0.28	Quench and temper	Heat treatment required after welding for 0.450 alloy
9 Ni-4 Co-0.450	260-300	28.5	0.28		
Titanium:					
Ti-6Al-4V	150	16.0	0.167	Solution anneal and age	Age before weld; stress-relieve after welding
Aluminum alloys:					
2000 Series	36-65	10.3	0.10	Solution heat anneal and age	Heat treatment required after welding
5000 Series	30-40	10.3	0.10	No heat treatment	
6000 Series	37-47	10.3	0.10	Solution heat anneal and age	Heat treatment required after welding
7000 Series	60-68	10.3	0.10	Solution heat anneal and age	Resistance welding only

B. Material

Varieties of materials are used for production pressure vessel. Groups of material used for aerospace application are shown in Table I. Titanium and Aluminum alloys are used in aerospace aircraft due to its light weight and strength requirement. In defence industry, high strength, low alloy steel are chooses for rocket motor case production and flow forming technology can improve mechanical properties of material to meet the requirement [8]-[11]. From literature reviews, AISI 4130 steel is commonly used in military rocket motor case manufacturing [12]-[14].

II. EXPERIMENT AND MEASUREMENT

A. Experiment

In previous process, the tube produced by flow forming machine for 2 pieces after that connect it together by welding. But the welding process use more time about 6 hrs for preparing, welding and test and has more defect. For Improve process to reduce cost and time, also eliminate defect from the previous process Hence, we design a new process by cut the welding process and x-ray test off and produce a long the tube at length of 4300 mm. The comparative between the previous process and the new process are illustrated in Fig. 3.

From requirement of studied, pressure vessel tube with approximately 300 mm outside diameter, 4,300 mm length and 3.5 mm wall thickness need to be flow formed and four rollers CNC flow forming machine was used. To improve strength of materials by cold work, the rang about 80-84% thickness reduction can be used, for this study selected 82.5% reduction of tube wall thickness have been designed and initial thickness or perform were calculated as [15]:

$$RA = \frac{t_i - t_f}{t_i} \qquad (1)$$

where t_i is the initial preform thickness, t_f is the final perform thickness after deformation, RA is the percentage thickness reduction of the preform.

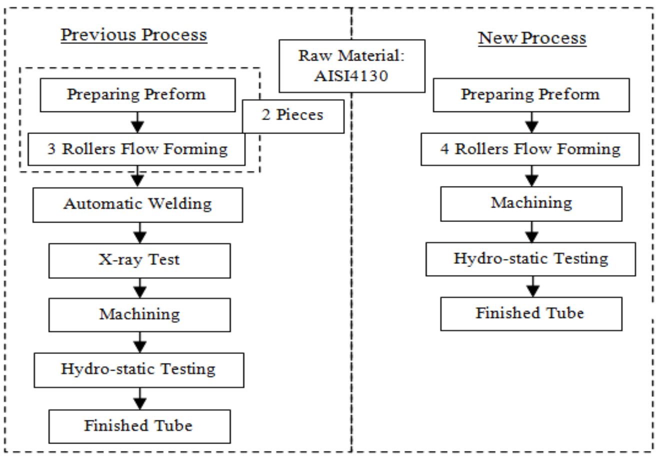


Fig. 3 Schematic of the process of produce HPV

By theoretical of constant volume, dimension of perform also can be computed as.

$$[\tfrac{1}{4}\pi[D_0^2 - D_i^2]L]_t = [\tfrac{1}{4}\pi[D_0^2 - D_i^2]L]_p \qquad (2)$$

where presents flow formed tube, p is the preform, D_0 is the outside diameter, D_i is the Inside diameter and L is the Length of perform. And dimension of preform tube after computed are illustrated in Fig. 4.

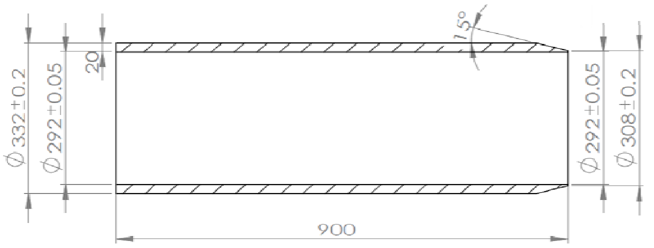


Fig. 4 Preform dimensions in millimeter for this experiment

This experiment used 4 passes flow forming. Three passes forward flow forming and one pass backward flow forming were designed by CNC program and thickness reduction percentage in each pass are shown in Table II. Designed percent of thickness reduction should be less than 67% thickness reduction [16] because it's used less force to compress the material movement.

TABLE II
THE PROGRAM DESIGN FOR THICKNESS IN EACH PASS OF FLOW FORMING PROCESS

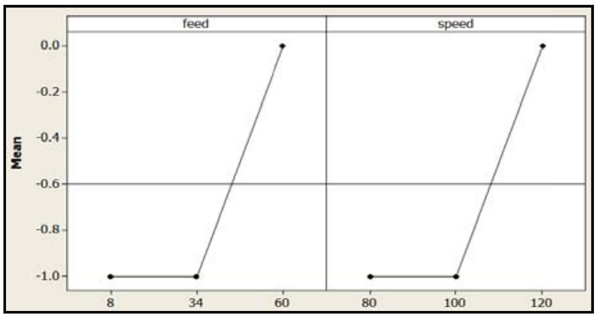
Pass No.	Beginning thickness of preform [mm]	Programmed thickness [mm]	Designed % Thickness reduction	% Thickness reduction (Cumulative)
1	20.0	11.8	41.0%	41.0%
2	11.8	8.2	30.5%	30.5%
3	8.2	5.3	35.4%	73.5%
4	5.3	3.5	34.0%	82.5%

Two factors, feed rate and spindle speed, of flow forming process were studied. Factorial Design in Minitab program have been used to solve the effect and interaction between feed rate and spindle speed to thickness and surface quality of flow formed tube. The range of 60-80 mm/min feed rate and 80 – 120 rpm spindle speed were used to investigated and the result are shown in Table III. And Fig. 5 where 1 is acceptable and -1 is unacceptable interaction.

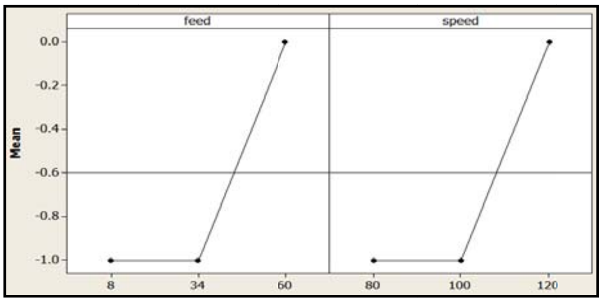
TABLE III
THE RESULT OF TESTING PARAMETER WITH THE QUALITY OF TUBE

Parameter		Result	
Feed rate [mm/min]	Spindle speed [rpm]	surface	thickness
60	120	1	1
60	80	-1	-1
8	80	-1	-1
8	120	-1	-1
34	100	-1	-1

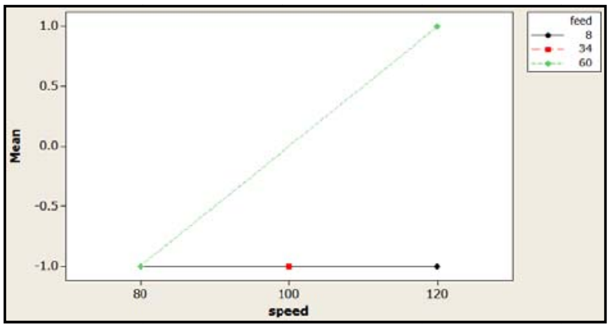
The result demonstrated that in Figs. 5 (a), (b) each feed rate and spindle speed are effect with the quality of tube such as surface and thickness and Figs. 5 (c), (d) the interaction of feed rate and spindle speed are also affect to flow forming thickness and surface roughness. Feed rate of 60 mm/min and 120 rpm spindle speed parameters will be used in this experiment.



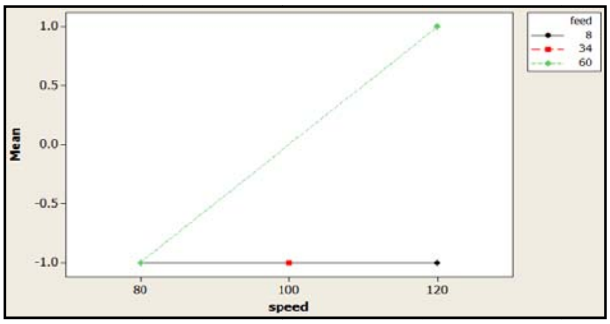
(a)



(b)



(c)



(d)

Fig. 5 The interaction of two factors for surface and thickness (a) Main Effects Plot for Surface (b) Main Effect Plot for Thickness (c) Interaction Plot for Surface (d) Interaction Plot for Thickness

TABLE IV
THE RESULTS OF THICKNESS AND HARDNESS IN EACH PASS OF FLOW FORMING PROCESS

Pass No.	Beginning thickness of preform [mm]	Programmed thickness [mm]	Measured thickness [mm]	Final hardness [HRC]	% Thickness reduction	% Thickness reduction (cumulative)
1	20.0	11.8	13.6	16.9	32.0%	32.0%
2	13.6	8.2	9.7	20.9	27.2%	50.5%
3	9.9	5.3	6.6	24.7	33.3%	67.0%
4	6.6	3.5	3.6	33.0	45.5%	82.0%

TABLE V
THE COMPARATIVE OF THE RESULTS BETWEEN PREVIOUS PROCESS AND NEW PROCESS

	Hardness [HRC]	Tensile Strength [MPa]	Hydro static test at 22 MPa.	Burst Test [MPa]
Previous Process	29.0	934	Pass	23.4
New Process	33.0	984	Pass	23.9

B. Measurement

From samples, the measurement of all dimensions and surface hardness of work piece were performed in each pass of flow forming. The tensile strength of final flow formed tube also test in circumferential direction. Due to application of the HPV, hydrostatic test with expecting pressure of 220 MPa or 3,190 psi and burst test were performed by using the same parameter of flow forming work piece [17], [18].

III. RESULTS AND DISCUSSION

The wall thickness of the work piece and surface hardness in Rockwell C scale from each flow formed passes are measured and the average values are illustrated in Table IV. The thickness reduction percentages are also calculated. The average thicknesses in each flow formed passes are higher than program values shown the spring back of materials after pass through the rollers. The comparative of thickness between programmed and measured in each pass of flow forming process are shown in Fig. 6 and the measured values of thickness in pass 1 and 2 are different from the programmed values about 1.9 and 1.7 mm but during pass 3 and 4 the measured values of thickness are slightly close to the programmed values.

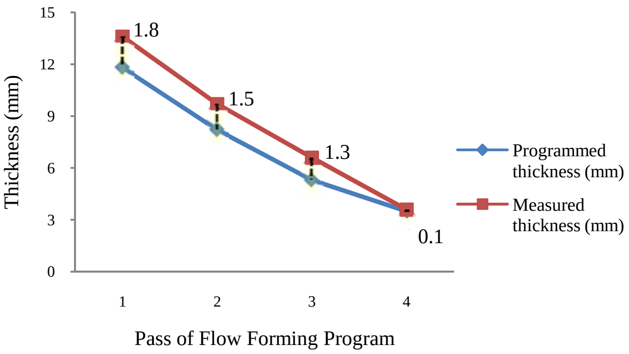


Fig. 6 The comparative of percentage thickness reduction of flow forming process

It can be considered that spring back of material during the flow forming process is related to the depth of cut in each pass. Anyway, in the final pass, the tube wall thickness was closed to the designed dimension and can be accepted. And the comparison between previous process and new process are illustrated in Table V. Hardness of work piece is increased in each pass and the strength in final pass also increased from raw material yield strength of 547.6 MPa to 984 MPa, approximately 44.38% improvement and also more than previous process approximately 5.5%. Hydrostatic test of 22 MPa is accepted and burst pressure of 3611 psi or 24.9 MPa can be proved that the flow forming parameters and new process achieved the minimum the expected mechanical property and better than previous process.

IV. CONCLUSION

This experiment can be concluded that

1) Interaction between feed rate and spindle speed are related with the quality of tube.
2) At 82.5% reduction of thickness is sufficient for minimum mechanical property requirement.
3) Tensile strength of the new process is increasing about 5.5% from the previous process.
4) Improvements of the new process include no defect, less manufacturing cost and shorten process time.

V. FUTURE WORK

1) For manufacturing, a higher level of feed rate and spindle speed should be studied.
2) Interaction with other factors should be study as depth of cut, spring back and the optimum value of percent thickness reduction etc.

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