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Full Length Research Paper

Experimental studies on the characteristics of AA6082 flow formed tubes

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Flow-forming is an innovative, chip less metal forming process used to manufacture thin walled seamless tubes and other axi-symmetric components. Experiments were conducted to form annealed AA6082 alloy tubular pre-forms into thin walled seamless tubes on CNC flow forming machine with a single roller. The process parameters selected for the present investigation are roller radius, mandrel speed, roller feed, thickness reduction, etc. The characteristics of flow formed tube chosen are ovality, mean diameter, thickness variation, surface finish, etc. The effects of these process parameters on the dimensional characteristics and surface quality of flow formed tubes have been studied. The optimum process parameters are proposed to manufacture the tubes with good dimensional characteristics and sound surface quality. It has been found that, roller radius of 4 to 8 mm, thickness reduction ranging from 30 to 35%, mandrel speed of 150 rpm and roller feed in the range of 100 to 130 mm/min formed the tubes with sound characteristics.

Key words: Flow-forming, AA6082 alloy, ovality, mean diameter, surface quality.

INTRODUCTION

Flow-forming is an eco-friendly, chip less metal forming process which employs an incremental rotary point deformation technique. Flow forming process is employed for the production of thin-walled seam less tubes, cylinders and other axi-symmetrical components used in the field of automobile, aerospace and defense sectors. Chang et al. (1998) investigated on the tube spinnability of full-annealed and solution-treated AA 2024 and 7075 aluminum alloys. Lee and Lu (2001) studied the flow forming of cylindrical tubes using rolling mechanism and to analyze force of the flow forming. Wong et al. (2004) studied incremental forming of solid cylindrical components using flow forming principles. Makoto et al. (2005) investigated on compression spinning of circular magnesium tube with heated roller. Rajan et al. (2002) made experimental studies on the effect of heat treatment of pre-form on the mechanical properties of AISI 4130 steel flow formed tubes. Lakshman Rao et al. (2009) conducted experiments to study influence of flow forming parameters on surface finish and surface roughness of copper tubes. However, very little work has been reported on the flow-forming of AA6082 tubes.

Park et al. (1997) analyzed the tube spinning process by upper bound stream function method. Various quality issues are associated with flow forming process. Important dimensional and surface characteristics like ovality, mean diameter, surface roughness, cracks and scales are to be controlled to produce the defect free flow formed tubes.

Ram Mohan and Mishra (1972) evaluated the forces in the power spinning of tubes based on the plastic deformation method and correlated with experimental values. Rajanish and Singhal (1995) studied shear spinning technology to manufacture long thin walled tubes. They proved that mechanical properties of shear

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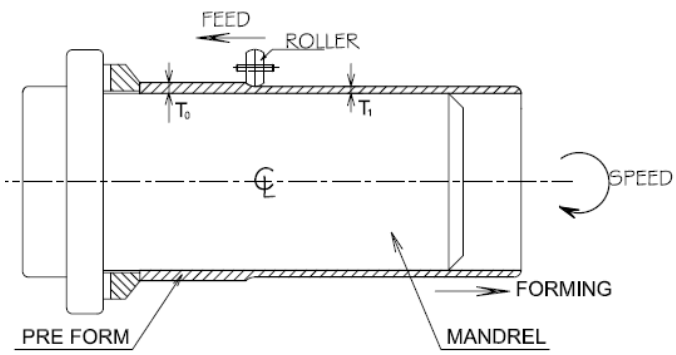

Figure 1. Principle of flow forming.

spun tube improve considerably. Wong et al. (2005) studied the effect of roller path and geometry on flow forming of solid cylindrical components using flat face and non-orthogonal rollers. They found that roller feed rate and reduction influences the geometry of formed part. Liu et al. (2002) analyzed the stress and strain distribution in conventional spinning under different roller traces with elasto-plastic FEM method and concluded that, stress and strain distribution is smaller in involute trace of roller. Kawai et al. (2001) studied flexible shear spinning of truncated conical shells with general purpose mandrel. They found that truncated conical shells can be manufactured with a certain degree of accuracy by die less shear spinning. Davidson et al. (2008) studied the quality of flow-formed AA6061 tubes. They proposed the optimum process parameters for flow forming of AA6061 alloy with good surface qualities. Razani et al. (2011) studied the out-of-roundness of an annealed and flow-formed AISI 321 steel tubular pre-form for various levels of effective process parameters using Taguchi's approach. Srinivasulu et al. (2011) optimized the process parameters for minimum surface roughness in flow forming of AA6082 tubes employing Design of Experiments.

Different process parameters such as roller radius, mandrel speed, roller feed, thickness reduction, initial heat treatment condition and variation in hardness of pre-form material influence the dimensional and surface characteristics of flow formed components, which are material specific. The major problems encountered during the flow forming of AA6082 pre-forms are larger ovality, greater thickness variation, poor surface finish and increased mean diameter. However, no work has been reported on dimensional characteristics of flow forming of AA6082 tubes. The main purpose of present investigation is to manufacture AA6082 tubes with sound dimensional and surface characteristics by flow forming. The present research is focused to study the influence of various processes parameters on dimensional and surface characteristics of AA6082 flow formed tubes. The optimum flow forming processes parameters are proposed to produce tubes with sound characteristics.

EXPERIMENTAL PLAN

Flow forming process

Flow forming is an advanced, chip less metal forming process used for production of precision, thin-walled seamless tubes. The flow forming process requires smaller forming forces as compared to other metal forming processes. The pre-form is locked to the mandrel with serrations and rotates at the same speed along with it. In flow forming, the pre-form is elongated on the rotating mandrel by means of mechanically guided rollers. The forming roller follows the contour of the mandrel with a preset gap. The gap between the rotating mandrel and the roller acts as an orifice through which the metal flow occurs. 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 Figure 1.

Flow forming equipment

Experiments are performed on CNC flow-forming machine with a single roller. 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 pre-form 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. It is desired to produce AA6082 seamless tubes with sound dimensional and surface characteristics.

Materials

The material used for the present investigation is AA6082 alloy. The major alloying elements are Al-1.2, Mg-1.0, Mn-01.3, Si-0.50, Fe-0.25, Cr-0.1 and Cu. AA6082 alloy has medium strength, good machinability and weldability with excellent corrosion resistance. Addition of manganese controls the grain structure, which results in superior strength. The alloy age hardens by formation of Mg_2Si precipitates. This is the alloy with strength higher than AA6061 alloy. AA6082 alloy has an ultimate tensile strength of 340 Mpa, yield strength of 310 Mpa and hardness of 95 BHN. This alloy is used in heavy duty structures in rail coaches, hydraulic systems, mining equipment, pylons, towers, automobile, ship building, aero space and missile applications.

Pre-form design

The design of pre-form was based on two factors namely maximum possible deformation and constant volume principle. These pre-forms were manufactured by hot forging. Generally, 15% allowance is provided on the diameter for machining and other allowances. The pre-form was then annealed at a temperature of 550°C for two hours to take the precipitation into solution and quenched in water to retain solute in solution. The flow-forming mandrel is made of AISI-D2 tool steel and hardened to 63 HRC. A slight taper is given in the mandrel for easy ejection of the product. The machined pre-form is shown in Figure 2.

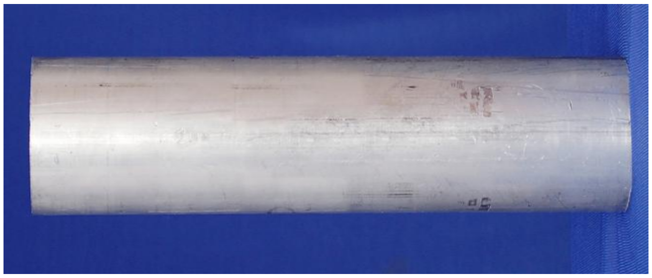

Figure 2. Machined pre-form.

Table 1. Variation of ovality with roller radius.

Exp. No.	Roller radius (mm)	Ovality (mm)
1	4	0.10
2	8	0.45
3	10	0.86
4	12	1.32
5	15	0.98

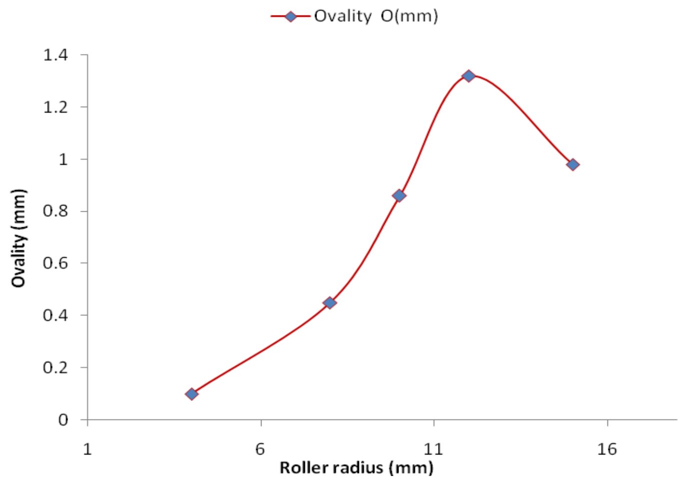

Figure 3. Effect of roller radius on ovality.

RESULTS AND DISCUSSION

Experimental trials are conducted on a CNC flow forming machine with single roller to study the effect of process parameters on the dimensional characteristics and surface qualities of AA6082 flow formed tubes. The results and discussion are given subsequently.

Effect of roller radius

Experiments are performed with different rollers having the radius 4 to 15 mm, to study the effect of roller radius on the characteristics of flow formed tubes. It is found that ovality of the tube is less at smaller radius of the roller and it increases with radius. This is due to the fact that smaller radius produces smaller forming forces, and produces the tubes with smaller ovality. The variation of ovality with roller radius is given in Table 1. The effect of roller radius on the ovality is shown in Figure 3.

The mean diameter of flow formed tube was found to increase with the roller radius. The radial force is proportional to radius of the roller. A rise in radius of the roller increases circumference dimension of the tube due to higher radial force, which leads to larger mean diameter. The variation of mean diameter with roller radius is given in Table 2. The effect of roller radius on the mean diameter is shown in Figure 4.

Effect of mandrel speed

Lower mandrel speed produces the tubes with scratch marks on the surface. As the speed increases the surface defects are covered and results in smooth finish. When the speed increases to higher value, the finish is very good up to certain limit, but finish reduces with increase in speed due to vibrations at higher speed. The flow formed tube with scratch marks due to lower mandrel speed is shown in Figure 5.

Effect of roller axial feed

Experiments are conducted by varying the feed rates with a range of 25 to 150 mm/min. The variation of ovality with roller feed is given in Table 3. The effect of roller feed on the ovality is shown in Figure 6. Smaller feed rates produced the tubes with larger internal diameter. This is due to the fact that, the plastic deformation produced in axial direction lagged behind, as the roller travels slowly at lower feed rate. Hence, the material deforms in radial direction instead of axial direction and diameter of the tube opens. The flow form tube with larger ovality is shown in Figure 7.

The ovality of the flow formed tubes first increases and then decreases with the feed. Lower feed rates produce deformation in radial direction, which results in larger ovality. As the feed increases to higher value, the plastic deformation is retarded due to fast movement of roller through the tube and produces larger ovality. The higher feed rates combined with smaller thickness reductions produced the tubes with higher ovality.

The variation of surface roughness with roller feed is given in Table 4. The surface roughness of the tube with feed rate is given in Figure 8. Higher feed rates (more than 90 mm/min) formed the tubes with roller marks on the surface. As the roller transverse fast the mandrel, the plastic deformation is retarded. Lower feed rates produced the tubes with good surface finish. The surface roughness of the tube was found to be increased with

Table 2. Variation of mean diameter with roller radius.

Exp. No.	Roller radius (mm)	Mean diameter (mm)
1	4	42.10
2	8	43.50
3	10	43.80
4	12	44.30
5	15	45.50

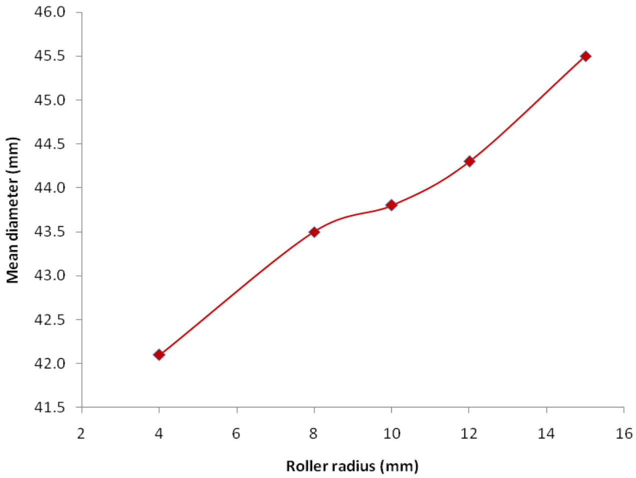

Figure 4. Effect of roller radius on mean diameter.

Figure 5. A flow formed tube with scratch marks on the surface.

Table 3. Variation of ovality with roller feed.

Exp. No.	Roller feed (mm/min)	Ovality (mm)
1	25	0.32
2	50	0.41
3	75	0.10
4	100	0.48
5	125	1.35

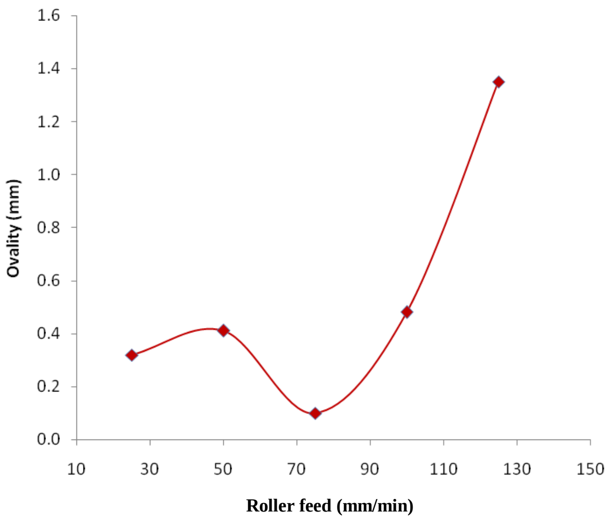

Figure 6. Effect of roller feed on the ovality.

feed. It is observed that high speed combined with lower feed rate produces the tubes with good surface characteristics.

Effect of thickness reduction

The percentage reductions of thickness ranging from 25 to 75% have been tried. Smaller thickness reductions produced tubes with scale marks on the surface and also resulted in cracks on the inner side and surface of the tube. This is due to strain hardening and non-uniform plastic deformation between the contact regions. Higher thickness reductions developed the roller marks on the surface of the tube. Thickness reduction of 30 to 35% was found to be optimum to manufacture the tubes with good dimensional and surface qualities. The flow formed tube with surface cracks due to smaller reductions is shown in Figure 9.

Effect of variation in hardness of pre-form

Pre-forms with variations in hardness of ranging from 5 to 20 BHN have been used to investigate the effect of hardness variation on thickness of tubes. It is found that large variation in hardness of pre-form formed the tubes with higher thickness variation. The in-homogeneity in the pre-form material due to presence of inclusions, uneven rate of cooling, hard spots, leads to uneven loading results in either bulk flow or non-uniform flow of material which produces more variation in thickness of flow

Figure 7. A flow formed tube with large ovality problem.

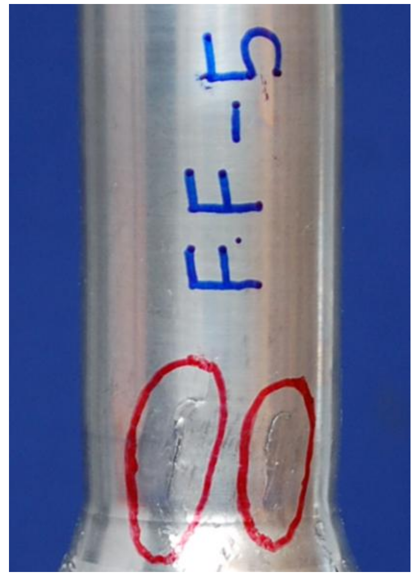

Figure 9. A flow formed tube with surface cracks.

Table 4. Variation of surface roughness with roller feed.

Exp. No.	Roller feed (mm/min)	Surface roughness (μm)
1	25	2.80
2	50	3.50
3	75	5.80
4	100	8.60
5	125	9.50

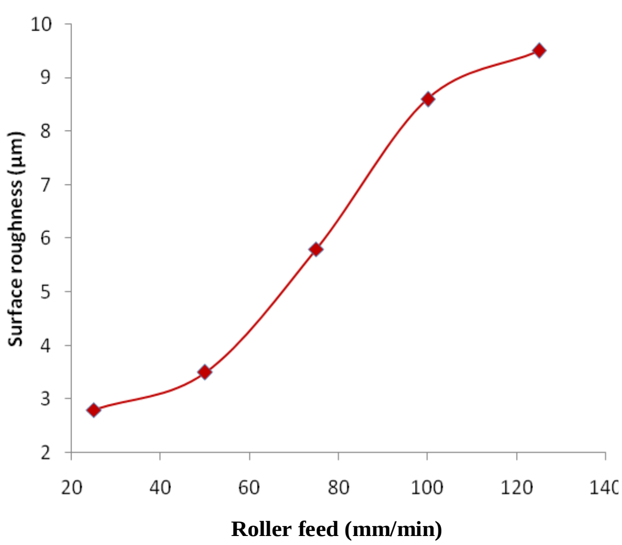

Figure 8. Effect of roller feed on the surface roughness

Table 5. Variation in thickness with hardness variation of pre-form.

Exp. No.	Hardness variation (BHN)	Thickness variation (mm)
1	5	0.02
2	8	0.05
3	10	0.09
4	15	0.12
5	20	0.15

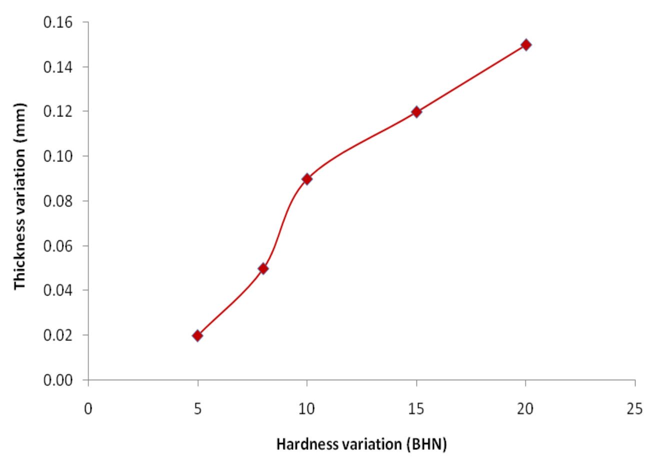

Figure 10. Effect of hardness variation on thickness variation of the tube.

formed tubes. The thickness variation with variation in hardness of pre-form is given in Table 5. The variation in thickness of tube with hardness variation is shown in Figure 10.

Effect of initial conditions of pre-form

Experiments are conducted to find out the effect of

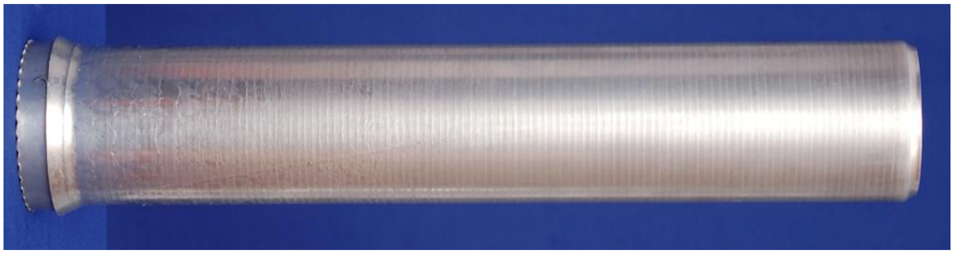

Figure 11. A flow formed tube with optimized process parameters

annealing time and temperature to form the tubes with good deformation and no surface damage. The flow-formed tubes with scaling defect and cracks are produced when pre-forms are annealed for 45 to 60 min. The pre-form annealed for 90 to 130 min produced good surface qualities and proper deformation.

Effect of gap between pre-form and mandrel

An optimum gap is required between the pre-form and mandrel to manufacture the flow formed tubes with smaller ovality and good surface characteristics. Larger gap between mandrel and pre-form results in radial deformation, and produces tubes with diametral growth resulting in larger ovality. Smaller gap leads to rough surface and scale marks on the inner side of the tube due to sticking of pre-form to the mandrel, and it becomes difficult to remove from the mandrel. A gap of 1 to 2 mm was found suitable to produce good surface qualities and easy removal from mandrel. A flow formed tube produced with optimized process parameters is given in Figure 11.

Conclusions

In the present study, the effects of process parameters on the flow-forming of AA6082 tubes have been experimentally investigated. The roller radius, the roller axial feed, the thickness reduction, the variation in hardness of pre-form and the initial heat-treatment condition are found to have significant effect on the dimensional characteristics and surface qualities of the flow formed tube.

The following conclusions are made on the flow forming of AA6082 tubes with good dimensional and surface qualities:

1. The hardness variation in pre-form should be minimized (5 to 10 BHN) to avoid thickness variation and ovality.
2. The pre-form should be annealed at 550°C for 100 to 110 min.
3. The roller radius should be fixed at 4 mm to have uniform mean diameter and reduction in ovality.
4. Lower feed rates improve the surface finish, but ovality and variation in mean diameter increases. Therefore feed is optimized at 75 mm/min.
5. The speed of the mandrel is arrived at 150 rpm to produce the tubes with good surface qualities.
6. Thickness reduction is optimized at 30% to manufacture tubes with good dimensional characteristics and surface qualities.

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