Residual Stress Measurement of Reverse Flow Formed Components by X-ray Diffractometer

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This paper describes the residual stress measurement of thin - walled Al-alloy tubes by x-ray diffractometer. The tubes were manufactured by reverse flow forming process. The results have been compared with the residual stress values of pre-formed tubes.

Introduction

Reverse flow forming is a latest technology and is being used to manufacture thin walled tubes to withstand greater hoop stresses and to produce precise tubes to very close tolerances. Residual stresses which develop during manufacturing stage may affect distortion and/or dimensional stability of flow formed tubes. Residual stresses are present in virtually every manufactured product or assembled structure although their effects are often not evident until the product or the structure is subjected to external loads or exposed to an adverse enviroment.

Residual stresses may be of tensile or compressive type. Residual stresses of any kind can adversely affect dimensional stability. The ability to measure residual stresses accurately, quickly and easily would ensure their magnitudes to be controlled to some extent,at least by the tailoring of manufacturing or assembling processes, and would also enable the design engineers to properly account for their presence.

Several techniques are available to measure the residual stresses:

Non-Destructive Methods:

- ☐ Ultrasonic wave method
- ☐ Photoelastic technique
- ☐ Magneto-optic method
- ☐ Neutron differentiation
- ☐ X-ray diffraction

Destructive Methods:

- ☐ Hole drilling

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- ☐ Surface removal
- ☐ Sectioning technique
- ☐ Broken hausen noise test

X-Ray Diffractometer

The X-ray diffraction method is based on the lattice strains, the changes in the sparings between crystalographic lattice planes which are produced to induce residual stresses. A portable unit which is capable of measuring very quickly was used. In this method the volume of surface material interrogated by x-ray beam was very small and the lattice strain which was measured has reflected the combined influences of both micro and macro stresses acting in that location.

The portable x-ray diffractometer (having air cooled tube with Cr anode) is operated with 30KV to run necessary safety lights and solenoid; to activate safety interlocked (manually/automatically controlled) shutter. The later maximises detector life, operating the x-rays only when a profile is being accumulated. The source size is in between 0.25 to 3mm diameter. The diffracted x-rays are detected using a linear position sensitive proportional center. The detector is rigidly fixed to the x-ray tube in the orientation and rotated by stepped motor around an arc with radius of 140mm and an angular resolution of 0.04. The stepped motor is driven by a bipolar device controlled by a microprocessor with an IEEE parallel interface for communication.Data reduction reporting and overall control is carried out by a computer.

Reverse Flow Forming

In the reverse flow forming process, the materials are deformed to desired sizes over a rotating mandrel by 3-forming rollers which are arranged equidistant and 120 to each other. This is a cold forming process. The forming operation is started near the head stock. A schematic representation of reverse flow forming is given in fig.1

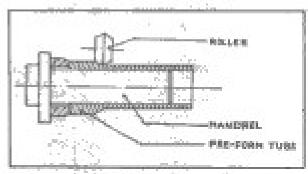

Fig. 1: Reverse flow forming process

Experimental Procedure

The experiments were conducted on the flow formed tubes of A1 Alloys. The chemical compositions of alloys

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are listed in the table-1. The dimensions of preform tubes are given in fig. 2(a).

The preform design was based on two factors namely:

- Constant volume
- Maximum deformation

Table — 1: Chemical Composition									
Composition	Cu	Mg	Si	Fe	Mn	Zn	Ti	Cr	A1
Alloy-1	0.1	0.5	0.6	0.5	0.4	0.1	0.2	0.25	Rest
Alloy-2	0.5	1.0	0.4	0.5	0.4	0.2	0.2	0.15	Rest

The preform tubes were manufactured by hot forging, having 2 to 3mm machining allowance on internal and external diameters. The thickness and length of preform tubes were respectively 10mm and 300mm. The dimensions of finished tubes after reverse flow forming are shown in fig. 2 (b).

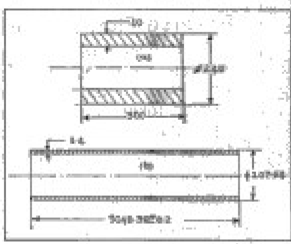

Fig. 2 : Dimensions (mm) before and after reverse flow forming (a) preformed tube (b) finished tube

Table — 2: Chemical Composition of Electrolyte	
Acetic Acid	40%
Ortho phosphoric acid	30%
Nitric Acid	20%
Water	10%

The residual stresses were measured in the preform tubes (before reverse flow forming) and in the finished tubes (after reverse flow forming). The residual stresses were measured at each location in five directions by XRD. The surfaces of the tubes were cleaned by electro polishing to determine the residual stresses at different locations. The composition of electroyte is given in Table-2. The diffractometer was calibrated on 4cm x 4cm coupons cut from the parent material. The coupons were mounted on the diffractometer with holder adjusted in such a way that the layer containing A1 particles was on the diffractometer axis. The position of the XRD peaks in the axial and transverse directions were determined at different angles. During the residual stress measurement, the region around the peak was scanned manually in a point code at 0.05— 20 intervals and the resulting peak positions were fitting a Gaussion conclusion function to the delta points.

Table — 3: Residual Stress, Mpa				
	Alloy — 1			
Location	Preform	Reverse Flow form	Preform	Reverse flow form
1	18.4	26.2	16.0	20.4
2	16.8	22.5	9.3	13.5
3	13.2	18.5	11.6	16.3
4	12.5	19.7	10.2	18.2

Results and Discussion

The maximum total deformation in alloy — 1 and alloy— 2 were 83% and 87%. The final thicknesses of reverse flow formed tubes were 1.4mm and 1.5mm respectively for alloy - 1 and alloy-2. As total volume of material remains constant, the length of reverse flow formed tubers were 3048.30mm and 3072.50mm respectively. A length of 20 to 25% was cut to give triming on both the ends.

The measured residual stresses in preforms and reverse flow formed tubes are given in table-3. It can be seen that the residual stresses in the preform tubes of alloy-2 are lower than those in the preform tubes of alloy-2. This is due to the increased contents of cu and mg in alloy-2. The residual stresses were found different in the different locations in the preformed tubes. There was an increase in residual stresses in reverse flow forming for both the alloys. This could be due to the introduction of elastic stresses during the reverse flow forming. The residual stress pattern before and after reverse flow forming for identified locations remained the same. The lowest value of residual stresses were found on land.

Conclusions

- Increase of Mg and cu contents reduces the residual stresses in the Al Alloy.
- There is an increase in residual stresses during reverse flow forming.
- The magnitude of residual stresses varies from one location to another one.

References:

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