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Technical Paper

Effect of flow forming on mechanical properties of high density polyethylene pipes

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A B S T R A C T

Flow forming is a single rotary-contact-point cold-forming process, in which the thickness of a tubular pre-form is reduced while its length increases without any change in internal diameter. Although metal flow forming has been studied by many researchers and industries, there does not appear to be any published study on the flow forming of polyethylene pipes. The main purpose of this study was to find out the applicability of flow forming on polyethylene pipes and the effects of process parameters on mechanical properties of polyethylene flow formed parts. The experiments were carried out using HDPE80 tubular pre-forms. Thickness reduction ratio, feed rate and rotation speed of mandrel were considered as variables. An L9 orthogonal array of Taguchi method was applied to carry out the experiments. Tensile and impact tests were performed to examine the failure behavior of specimens. Scanning electron microscopy (SEM) was implemented to find out the relation between mechanical properties and microstructure of the material. Stress at break, yield Stress, percentage of elongation at break and impact endurance were measured as indicators of mechanical properties. It was found that mechanical properties of HDPE increase significantly during flow forming. The solid state deformation makes material more oriented and anisotropic that leads to an enhancement in mechanical properties of HDPE. Through SEM it was found that the material experiences a transformation from an isotropic spherulite structure into an anisotropic lamellar-fibrous structure at large deformation.

1. Introduction

Flow forming is a single contact-point cold-forming process, in which the thickness of a pre-form is reduced whilst its length increases without any change in the internal diameter. Flow forming is a simple, chip-less and cost-effective forming process to produce tubular products with a high degree of mechanical and dimensional properties [1,2]. In flow forming a pre-form is fitted to a rotating mandrel. An external force is applied to the outer diameter of pre-form by roller(s); the rollers move along the axis of mandrel to reduce the wall thickness of the pre-form. The length of part is increased while its thickness decreases due to the law of conservation of volume. The axial movement of rollers is called *feed*. There are two modes of flow forming associated with the process, *backward* and *forward* flow forming [3]. In forward flow forming material flows ahead of the rollers in the same direction as the rollers feed. In backward flow forming material flows in the opposite direction of rollers feed, Figs. 1 and 2 show the modes of flow forming schematically [3].

Ameliorating the mechanical properties, sound finished surface, high dimensional accuracy, simple tool design, low cost and high productivity are some advantages of flow forming. [4,5]. Many experimental, analytical and numerical studies have been presented about metal flow forming. Davidson et al. [6] experimentally studied the effect of flow forming parameters on the surface quality of flow formed aluminum tubes. Roy et al. [7] introduced an analytical model to predict the shape of roller/work piece interface. Molladavoudi et al. [4] established an experimental study to examine the effects of thickness reduction on mechanical properties of aluminum tubes.

Although metal flow forming has been studied by many researchers and industries, there does not appear to be any published study on the flow forming of polyethylene pipes. This study was performed to examine the effect of flow forming on mechanical properties of polyethylene pipes.

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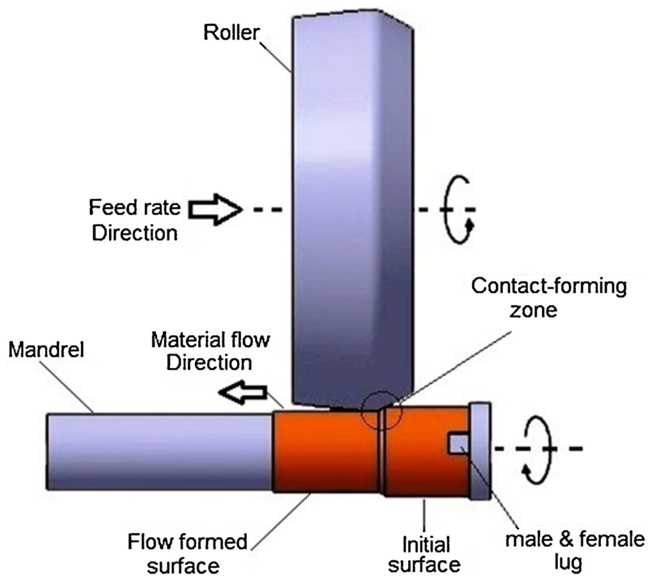

Fig. 1. Backward Flow forming [3].

2. Experimental

2.1. Equipment

A single roller backward flow forming machine was used to conduct the experiments. The machine was an NC lathe which was converted to a flow forming machine. A set of roller and mandrel was designed and manufactured to mount on the cross slide of the lathe. A steel mandrel with a male lug was secured by the chuck of lathe on one end and by the tailstock on the other end. Throughout the process the rotation speed of mandrel was applied in RPM (rotation per minute) and feed rate of roller in mm/rev. To apply the thickness reduction an equation was considered as thickness reduction ratio, Eq. (1) represents this ratio. Where t_o is initial wall thickness of pre-form and t_f is the wall thickness of flow formed part.

$$\text{Thickness reduction ratio} = \frac{t_o - t_f}{t_o} \quad (1)$$

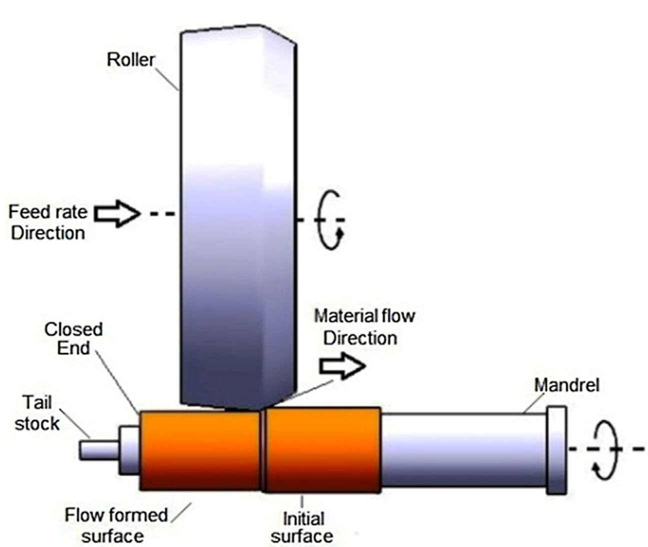

Fig. 2. Forward Flow forming [3].

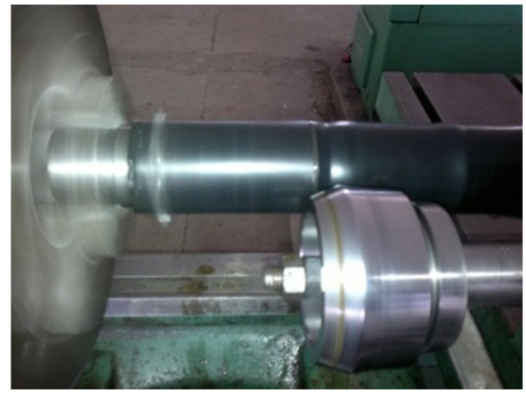

Fig. 3. Flow forming machine.

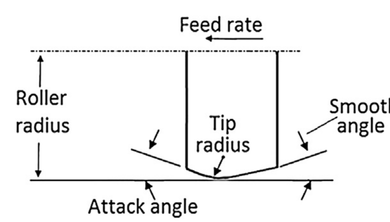

Fig. 4. Details of roller geometry.

Table 1
Roller geometrical details.

Roller radius	Attack angle	Tip radius	Smooth angle
120 mm	30°	2.5 mm	6°

Fig. 3 shows the general set-up of the flow forming machine during forming. Fig. 4 shows the details of roller geometry schematically, Table 1 represents the dimensions of roller. To avoid heating effects during flow forming an intense flow (0.5 l/s) of coolant was used to cool down the parts (roller and mandrel).

2.2. Material

The material used for the pipes, was a copolymer of polyethylene HDPE80 in black color with a blue line along the tube to show and magnify the probable torsion of material. Table 2 shows the technical properties of HDPE 80 [8]. The tube specimen had an external diameter of 63 (±0.1)mm, an internal diameter of 51 (±0.1)mm and a length of 200 (±0.1)mm.

2.3. Design of experiment

An L9 orthogonal array of Taguchi method was used to conduct and analyze the experiments. Taguchi method is a simple, systematic and rapid design of experiment tool. By using Taguchi method it is possible to study a process with only a small number of experiments. Thickness reduction ratio, rotation speed and feed rate were considered as variable parameters. Three levels

Table 2
Technical properties of HDPE 80 [8].

	Unit	Value
Density	g/cm^3	0.940
Yield stress endurance	MPa	20–22
Breaking elongation	%	>600
Elasticity modulus	MPa	700–1000
Hardness	Shore D	40