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Comparison of mechanical and metallurgical properties of hollow and solid forged products

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Abstract

Some mechanical and metallurgical properties of hollow and solid long forged products are compared. The metallurgical properties include such micro- and macro-structural characteristics as the grain size and grain flow patterns. Mechanical evaluation was performed by means of hardness testing. Some theoretical analyses were also carried out. The results indicate that the hollow or mandrel forged products possess better properties. Both the mechanical and metallurgical properties are more uniform and homogeneous through the thickness direction in such products. By contrast, in the solid forged parts, there is a gradient in the micro- and macro-structural properties from the surface to the internal areas. These non-uniformities can reduce the quality and reliability of such products and cause manufacturing problems in the processes that follow.

Keywords: Radial forging; Mandrel forging; Mechanical properties; Metallurgical properties; Grain flow

1. Introduction

Long hollow parts are produced by several methods; these include: hollow or mandrel forging, solid radial forging followed by drilling or machining, the welding of rolled plates, hot extrusion, and centrifugal casting. Among the above, forging is often preferred because this process can produce parts of high quality, but involves less production time and cost as well as material waste. Radial forging was first developed in Austria in 1946. It was initially used for the hot forging of small parts and the cold forging of tubes over mandrels. Current applications include: bars with round or prismatic cross sections, stepped solid shafts and axles, stepped hollow shafts, performs for turbine shafts, thick walled tubes, the necks and bottoms of solid bottles, couplings and joints, etc. [1–5].

During the hot forging of hollow products, the mandrel is water cooled to remove the heat absorbed from the workpiece. The purpose of the mandrel is to prevent the inner wall of the tube from collapsing and to form the diameter of the inner wall. The ingots used for solid and hollow forging should possess excellent metallurgical and workability characteristics [6,7] and so they are often produced by the electro slag remelting (ESR) process [8]. ESR leads to significant reductions in the sulfur content and to some reductions in the phosphorus, silicon and niobium contents [9]. The radial forging of a solid cylinder is illustrated schematically in Fig. 1 and that of the mandrel forging of tubes in Fig. 2.

Lahoti and Altan analyzed the deformation mechanics of radial forging by using the slab method [10]. They divided the deformation zone into three distinct regions: (a) the sinking, (b) the forging, and (c) the sizing zones. Domblesky et al. investigated the radial forging of large diameter tubes and multiple pass radial forging by using the finite element method [11,12]. They obtained the distribution of temperature, strain rate and strain in the deformation zone by this technique. They also determined the effect of the speed of axial feed on some of these parameters.

Khare and Sikka investigated the mechanical properties of 9Cr-1Mo mandrel forged (i.e., saddle forged) steel cylinders and compared them with the properties of products manufactured by other processes, such as the welding of rolled plates [9]. They evaluated the variation of mechanical properties, such as the hardness, impact energy, tensile properties, ductility, creep

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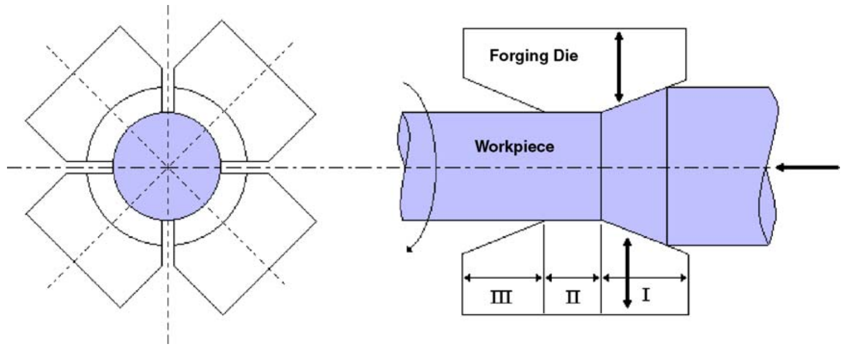

Fig. 1. Schematic diagram of the radial forging of a solid cylinder.

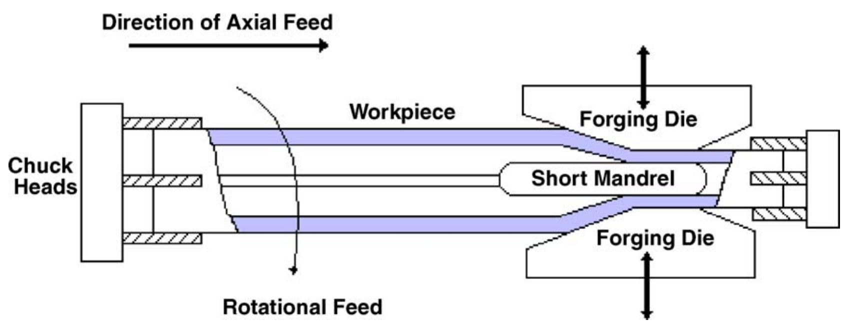

Fig. 2. Schematic view of the mandrel forging process used for producing tubes.

and fatigue properties, J-integral and metallurgical properties, such as the microstructure and macrostructure, across the wall thickness. Laporte and Khare studied the mechanical and metallurgical properties of thick-walled cylinders forged out of Inconel 625 [13].

In this research, some mechanical and metallurgical properties of mandrel and solid forged products are compared. The results show that the hollow forging process is preferable to solid forging for producing tubes and thick-walled cylinders in most cases. These results are in good agreement with theoretical analyses.

Table 1
Chemical composition of the ESR ingot employed for the solid forging process

Element	Wt.%
C	0.31
S	0.004
P	0.007
Si	1.06
Mn	0.91
Cr	0.88
Al	0.020
Fe	Balance

2. Experimental procedure

For evaluation of the differences between the properties of hollow and solid forged products, it is essential to produce specimens made by both processes. The chemical compositions and heat treatments after forging should be similar for the two sets of specimens so as to minimize variations in the material and processing parameters. This is the approach that was followed in the present investigation.

2.1. *Solid forging production history*

The initial ingot was forging stock cast by the electro slag refining (ESR) process. The solidified ingot macrostructure included columnar grains that lay largely along the ingot longitudinal direction. The chemical composition is presented in Table 1.

The ingot was of circular cross section with an initial diameter of 590 mm. The heated ingot was first forged into a square cross section 400 mm × 400 mm using a 3150 t open die press. In the final step, the square ingot was forged into a cylinder 275 mm in diameter using a radial forging machine (RFM). During the above steps, the ingot temperature was held in the range 1150–850 °C, when the temperature dropped below this range, the ingot was reheated as necessary. The forged product was annealed at a temperature of 880 °C; the annealing time was dependent on the thickness (1 min for each mm). Specimens were cut from longitudinal cross-sections as shown in Fig. 3.

2.2. *Mandrel (hollow) forging production history*

The initial ingot was again produced by ESR; however, in this case, the diameter of the cylindrical ingot was 570 mm. The chemical composition of this ingot was similar to that of the earlier ingot and is presented in Table 2.

Table 2
Chemical composition of the ESR ingot employed for the hollow forging process

Element	Wt.%
C	0.29
S	0.003
P	0.007
Si	0.96
Mn	0.92
Cr	0.9
Al	0.018
Fe	Balance