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EXPERIMENTAL STUDY OF ROTARY COMPRESSION FOR HOLLOW PARTS

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The paper describes rotary compression, a new method for producing hollow parts. First, a prototype machine for this process is described. The machine was designed and constructed at the Lublin University of Technology. Next, selected experimental results of the rotary compression for hot worked hollow parts made of C45 steel are presented. The discussion of the results focuses on the effect of kinematic parameters on this forming process.

Keywords: forming, rotary compression, hollow parts, experimental tests

INTRODUCTION

It is a common trend in machine design to replace solid parts with their hollow counterparts. As a result, machines and devices have lower mass, while at the same time their operational properties are retained. This fact is of vital importance particularly for the automotive and aerospace industries, since reduced mass of vehicles and aircraft means lower fuel consumption and, thus, reduced emissions.

Hollow parts are mainly produced from semi-finished products obtained by metal forming methods because semi-finished products produced thereby exhibit good mechanical properties, which results–among others–from the fact that their fiber continuity is retained. These metal forming methods include drawing, spinning, rotary forging, hydro-forming, cold extrusion (often combined with deep drilling) and cross wedge rolling [1-6]. Numerous research centers have been working on developing new methods for producing hollow parts. One of such newly developed methods is rotary compression designed at the Lublin University of Technology. The present study will describe this method.

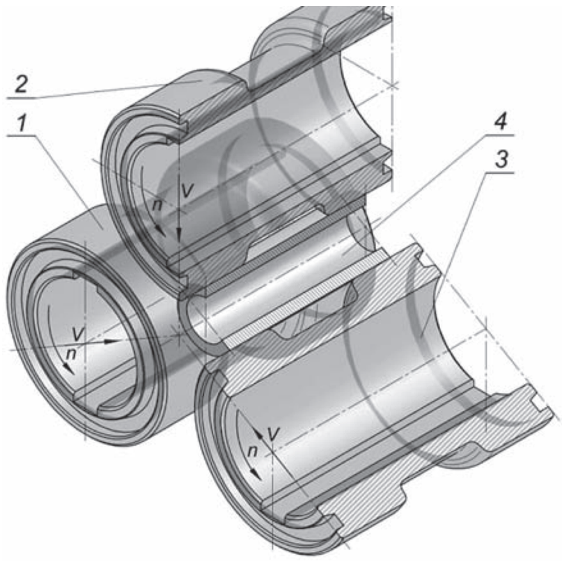

Figure 1 Schematic design of the rotary compression process: a) start of the process, b) end of the process; 1, 2, 3 – tools, 4 – billet

DESIGN OF ROTARY COMPRESSION

In rotary compression (Figure 1), the workpiece (tube or sleeve) is reduced by means of three tools (rolls) that rotate and at the same time make translational (linear) motion towards the axis of the workpiece. The tools are stepped rolls and their contours correspond to the geometry of the workpiece. Due to the action of the tools the outer diameter of successive steps of the workpiece is reduced, while the thickness of the billet wall increases. This effect is beneficial given strength and, often, constructional reasons. Compared to current techniques for producing hollow parts, rotary compression offers numerous benefits, including enhanced mechanical properties of parts, higher production output, lower implementation and production costs, reduced material consumption and labor costs; not to mention the fact that the process is relatively easy to run and can be both mechanized and automated [7, 8].

PROTOTYPE MACHINE FOR ROTARY COMPRESSION

The experiments of rotary compression were performed using a prototype machine, the design of which is shown in Figure 2. The machine consists of 6 fundamental elements: a frame, a power unit, a gear box, a

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system of rolls, a hydraulic power unit for the rolls, and a measuring system. The frame is a welded openwork structure made of channel bars with a square section. The power unit comprises a gear motor consisting of two elements: an electric three-phase motor and a bevel-cylindrical two-stage gear. The torque transmitted from the gear motor is distributed by the gear box to three working shafts. The actual rotary compression process is performed in the roll system which consists of three radially moving slides with the working shafts fixed therein. The working shafts and the tools (forming rolls) mounted on them rotate in the same direction at a constant velocity. The three slides and the tools are radially displaced by the above mentioned hydraulic power system consisting of three hydraulic cylinders, a hydraulic power unit as well as a set of valves and hydraulic distributors. The measuring system takes measurements of forces and kinematic parameters during the process. It consists of a torque convertor that takes digital measurements of torque during forming; a displacement sensor that measures velocity and position of the tools; pressure measuring sensors (the pressure results are then used to determine the force exerted by the tools on the workpiece). A technical specification of the machine is given in Table 1.

EXPERIMENTAL TESTS ON ROTARY COMPRESSION

The billet used in rotary compression were C45 steel tubes which had an outer diameter of 38 mm, a wall thickness, g, of 5 mm and a length, L, of 120 mm. The tubes were first heated in an electric chamber furnace to a forming temperature of approx. 1 150 °C and then placed with the pliers in a special feed mechanism for maintaining the billet's position in the machine's working space (created by three rotating rolls). In a subsequent stage, the rotating and radially moving tools made the billet rotate, thus reducing the diameters of end steps of the workpiece. Once the slides travelled the path corresponding to the required diameter reduction, the translational motion was stopped to begin the sizing of the workpiece shape in further revolutions of the rolls. In the final stage of the process, the tools opened radially and the finished product was ejected from the machine's working space in the feed mechanism. The outer contour of a part produced by rotary compression is shown in Figure 3. During the process, the rolls were rotating in the same direction at a constant velocity n = 36 rpm and at the same time they were moving in the linear (radial) direction at a constant velocity v that ranged between 3 and 9 mm/s.

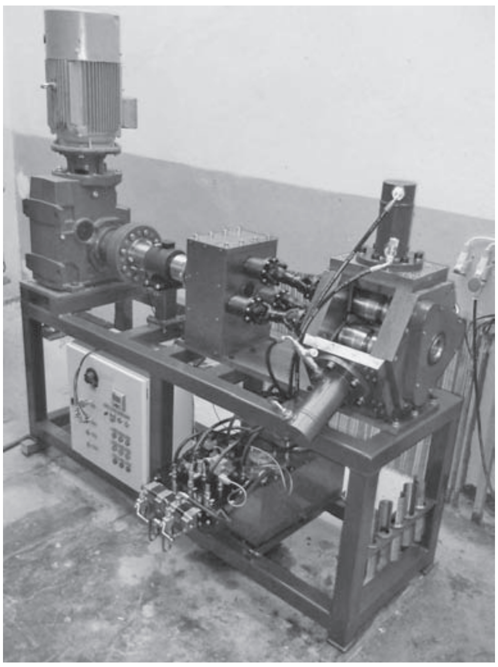

Figure 2 Prototype machine for rotary compression

The main objective of the experiments was to determine the effect of linear velocity of the rolls (their rotational velocity was maintained constant) on the rotary compression process. The experiments found that each of the applied velocities of the rolls (v ranging between 3 and 9 mm) ensures the producing of parts with the required external shape (Figure 4). Importantly, too, it was found that the values of the velocity v affect the thickness of wall of the formed step.

Table 1 **Specification of the prototype machine for rotary compression**

Parameter	Value
Engine power / kW	22
Maximum roll torque / Nm	2 200
Rotational velocity of the rolls / rpm	36
Translational velocity / mm/s	1,5 - 15
Maximum force of the rolls / kN	150
Maximum length of the compressed element / mm	160
Maximum diameter of the billet / mm	60
Minimum diameter of the step / mm	19
Roll diameter / mm	100 - 130

Figure 5 illustrates the variations in wall thickness of one of the parts produced by rotary compression as compared to wall thickness of the billet. It can be observed that the formed step has a varying wall thickness, its maximum values being located in the central region of the step. Owing to the radial flow of the material, the wall thickness practically increases along the entire length of the produced step. The slight thinning in the wall thickness observed at the part's end is caused by the part's elongation and will be removed after the shortening of the product's length.

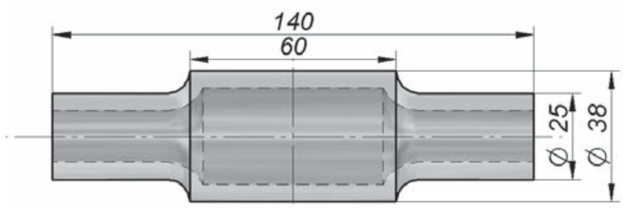

Figure 3 Shape of the semi-finished products produced in the experiments

As can be seen in Figure 6, increasing the linear velocity of the rolls leads to an increase in thickness of the wall of the compressed step. This undoubtedly results from a more rapid reduction of the workpiece in the radial direction, which is accompanied by a limited flow of the material in the longitudinal (axial) direction.

The application of higher velocities of the rolls is desired, as it shortens the time of forming parts (it increases the production output). Importantly, the force of the tools does not really change (Figure 7). This effect can be attributed to a decreased temperature of the material in the part's region being formed (the heat is carried away to the tools); this temperature decrease is the higher, the longer the forming time (velocity of the rolls is lower). This, in turn, leads to a decreased plasticity and higher forces, the values of which are close to those recorded in the processes run at a higher linear velocity of the rolls.

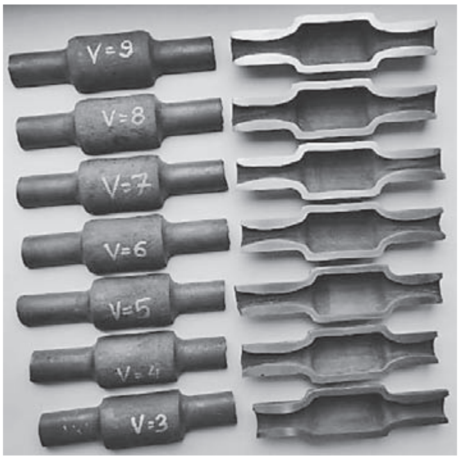

Figure 4 Products produced in the experimental investigations of the effect of linear velocity the rolls

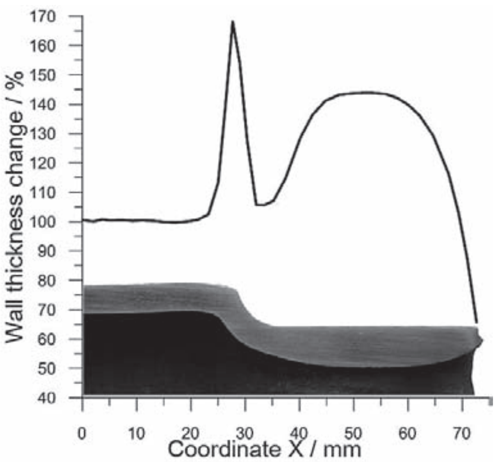

Figure 5 Wall thickness of the workpiece (perpendicular to the axis of the workpiece) produced at linear velocity v = 9 mm/s

The data obtained in the experiments demonstrate that there is a clear dependence of the torque on the linear velocity of the rolls (Figure 8). A decrease in the velocity leads to a clear drop in the maximum torque (from 1 468 Nm at v = 9 mm/s to 948 Nm at v = 3 mm/s). This results from a higher ovalization of the workpiece cross section caused by an increase in the velocity v, which leads to the moving of the resultant force on the material-tool contact surface away from the axis of the workpiece.

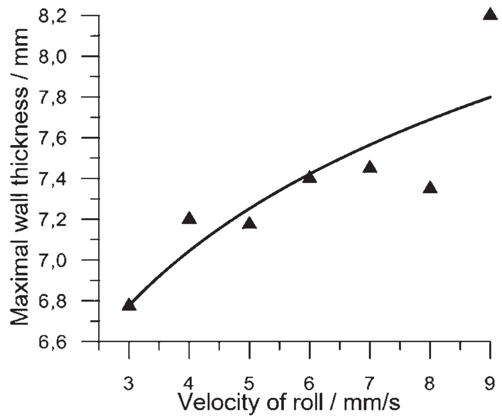

Figure 6 Effect of the linear velocity v of the rolls on the increase in maximum wall thickness of the compressed step

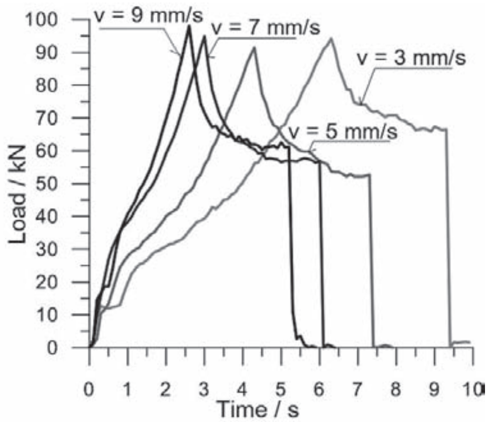

Figure 7 Effect of the linear velocity v of the rolls on the forces acting on the roll in rotary compression

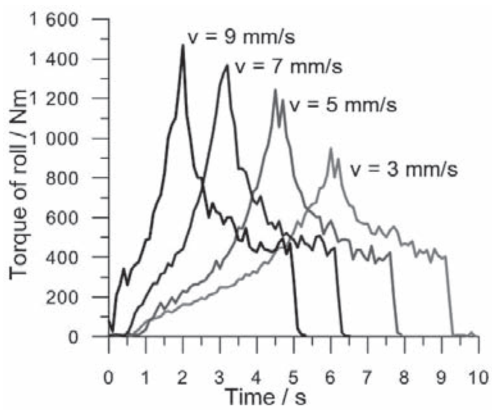

Figure 8 Effect of the linear velocity v of the rolls on torque in rotary compression

CONCLUSIONS

The paper discussed a new process for producing hollow parts called rotary compression. In this process, parts are formed by three rolls that perform rotational and translational motion at the same time. A prototype machine used in the experimental tests of producing hollow parts is described. Based on the preliminary experimental results, it was found that:

- rotary compression can be applied to produce axisymmetric hollow parts;
- to increase the output of the rotary compression process, the higher linear (radial) velocity of the rolls should be applied;
- increasing the linear velocity of the rolls leads to an increase in wall thickness of the compressed step;
- the increase in the linear velocity of the rolls does not practically affect the magnitude of the forming forces; however, it leads to a clear increase in the torque of the rolls.

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Note: The professional translator for English language is M. Jung, Lublin, Poland