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ARTICLE

Development of Technology and Equipment for Non-destructive Testing of Defects in Sewing Mandrels of a Three-roll Screw Mill 30-80

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ABSTRACT

The conditions of heating and cooling of piercing mandrels made of 4X5MFS steel of a three-roll screw mill 30-80 in the production of a closed cavity of steel vessels of small volume are determined. It is established that multiple cycles of heating up to 600 °C and cooling with water up to 80 °C for about 7 seconds/1 cycle lead to the formation of ridges, shells and cracks on the surface and in the volume of the tool. The loss of structural strength of the material leads to the breakdown of the mandrel during the stitching process. The technique and equipment of magnetic powder control have been developed to establish the dynamics of the growth of internal and external defects of mandrels. An equation is obtained that allows determining the increase in the number of defects in the sewing tool of a screw rolling mill. The technology of non-destructive testing made it possible to develop a rational plan for replacing the sewing mandrels, which allows for predicting the appearance of defects leading to a complex breakdown of the deforming tool at the NPO Pribor machine-building enterprise.

Keywords: Screw rolling mill 30-80; Piercing mandrel made of 4X5MFS steel; Vessel made of 50 steel; Temperature; Crack; Magnetic powder control of hidden defects

1. Introduction

Automation of rolling production in mechanical engineering and metallurgy makes it possible to ensure high quality and low cost of flat, round and shaped rolled products [1,2]. One of the most popular types of rolled products for quality control today is steel vessels of the responsible purpose of small internal volume. That is why for the hot production of semi-finished products, lines consisting of screw

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rolling mills with a sewing mandrel installed along the axis are increasingly used [3-5].

The technology provides for significant heating temperatures of the initial bars-blanks to ensure the continuity of the process of screw rolling, stitching and final heat treatment of products. The high temperature of about 2/3 of the melting makes it possible to ensure the high plasticity of the deformed material [5,6].

The heating of semi-finished products affects the deforming tool by heat transfer of the contacting surfaces [7,8]. The outer surface of the heated metal comes into contact with massive rolling rolls, which are continuously cooled by water. For this reason, their heating rarely exceeds critical values that reduce mechanical properties and lead to the formation of thermal stresses and defects on the surface and in the volume of the rolls [9,10]. The inner surface of a small volume vessel is formed by a mandrel with a low mass, without the possibility of cooling during flashing [11-13]. The time of the piercing cycle and the subsequent extraction of the mandrel from the vessel cavity is not infrequently sufficient to warm up the material to the temperature of the beginning of phase rearrangements [14]. Intensive cooling with water allows us to exclude the influence of temperature on the mandrel at the moment of inactivity. However, in this case, there is a risk of the formation of thermal stresses due to the reverse rearrangement of the crystal lattice leading to the formation of cracks in the volume of the tool [15,16]. Multiple cycles of intensive heating and cooling increase the risk of tool breakage and failure of the process line [17,18]. Therefore, this work was aimed at developing technology and equipment for non-destructive testing of unacceptable defects in sewing mandrels.

The purpose of the work was the development of technology and equipment for non-destructive testing of defects in sewing mandrels of a three-roll screw mill 30-80.

2. The methodology of the experiment

The experiment was carried out during the hot production of vessels made of steel 50 on the production line of the BF JSC NPO Pribor, which includes heating equipment, a three-roll screw mill 30-80 with a rotating mandrel installed along the axis with the possibility of moving along the axis of the firmware. The vessel was extracted with a “P” shaped stop. The initial rod-blank had dimensions of a length of 70 mm diameter of 40 mm. The rolling speed was 1.2 m/s. The rhythm of rolling and stitching, including the extraction of the vessel from the mandrel, is about 7 seconds. The deformed vessel was diverted along the stream and fell into the quenching tank. **Figure 1** shows the main line of the screw rolling mill 30-80.

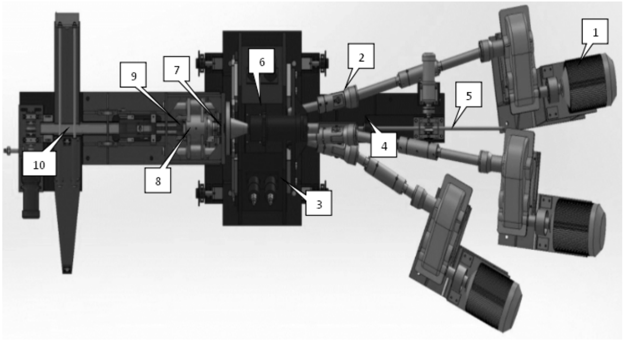
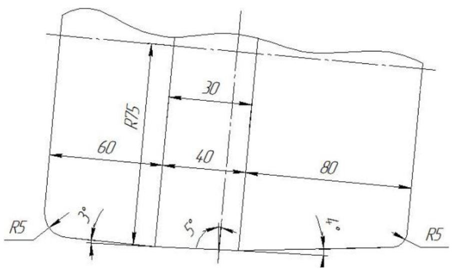


Figure 1. The main line of the screw rolling mill is 30-80.

The rolling mill line consisted of 1—asynchronous motor with a power of 50 kW each with a rotation speed of 1250 revolutions per minute, 2—gimbals transmitting the moment of rotation, 3—gearboxes, 4—guide chutes, 5—pusher rod, 6—rolling cage, 7—rotating mandrel, 8—mechanism fixing the position of the mandrel relative to rolling axes, 9—stop removing the vessel from the mandrel, 10—diverting stream.

The scheme of production of steel vessels on the production line: The initial rod-billet was heated in an induction and resistance furnace to a temperature of about 1160 °C, after which it was rolled and not completely stitched with a rotating mandrel, after which it was removed with a U-shaped stop and diverted to the quenching tank along the gutter. Water cooling of the rolling rolls was carried out continuously, and the mandrels were at the time of extraction from the cavity of the vessel.

Figure 2 shows the geometric dimensions of the deforming tool and steel vessels at the outlet of the processing line.



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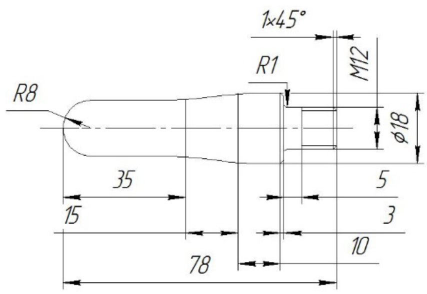

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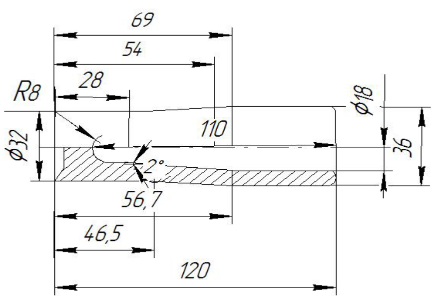

c

Figure 2. Geometric dimensions: a—rolling rolls, b—sewing mandrel, c—steel vessel at the outlet of the processing line.

Figure 2a shows the permissible geometric dimensions of 3 pieces of identical rolling rolls made of 35 HGSA steel that are part of the equipment of the rolling mill 30-80, **Figure 2b** shows the geometric dimensions of the working part of the piercing mandrel made of 4X5MFS steel, **Figure 2c** shows the geometric dimensions of the completed product in the form of a vessel made of ST50 material. Permissible deviations from the dimensions in **Figure 2** are not more than ± 0.1 mm.

The heating temperature of the mandrel was determined using an optical pyrometer SEM 1600 after its extraction from the vessel cavity.

The magnetic particle inspection method is a universal way of detecting defects in a deforming tool. The method is based on the occurrence of magnetic field inhomogeneity in places of discontinuity of ferromagnetic material, including steel and iron-based alloys.

The formation of internal defects of the sewing mandrel was investigated in accordance with GOST 56512-2015 “Non-destructive testing. Magnetic powder method”. For this purpose, the design of the mandrel magnetization equipment was developed. **Figure 3** shows the developed magnetization setup of the sewing mandrels.

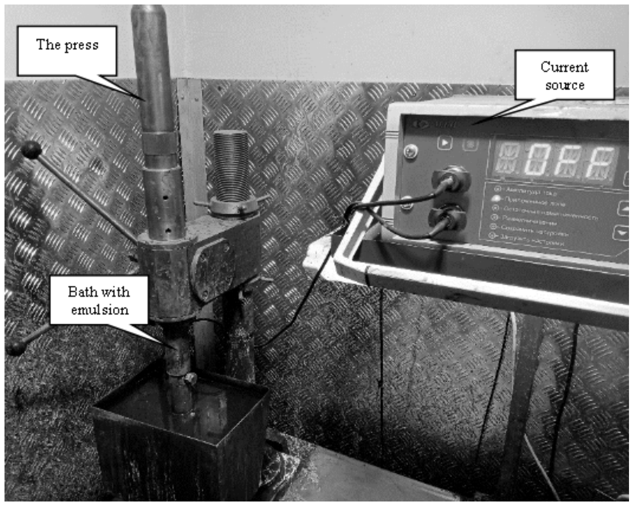

Figure 3. Installation of magnetization of sewing mandrels.

MD-I was used as a direct current source. The magnetization parameters were a current of 2 V, and a voltage of 160 A. Iron powder with a particle size not exceeding 0.001 mm was used as an indicator. The amount of powder was about 1/8 of the carrier liquid, which included: 1/3 kerosene, 1/3 soap solution, and the rest of industrial oil and 20. Defects on the surface of the mandrel were determined after the release of a batch of vessels from 250 to 1200 pieces.

The sequence of technological operations when checking the sewing mandrel for hidden defects:

- mechanical cleaning of the surface from dirt and scale layer with sandpaper grain size 80.
- preparation of the suspension consists of intensive mixing in the bathroom.
- the mandrel was installed on the lower electrode, the upper electrode was moved along the screw of the press all the way to the opposite part of the mandrel.

● magnetization took place in 2 seconds between the electrodes immersed in the suspension, under the action of the applied field, the particles moved in the area of magnetic disturbances, which indicate external and internal defects of the material.

● defects of mandrels were determined visually.

Measurements of traces of accumulations of iron powder were carried out with an electronic calliper.

3. The results of the experiment and their discussion

The heating temperature of the sewing mandrel was studied at an interval of 10 mm from the toe of the mandrel. Its bow is taken as the beginning of the countdown. **Figure 4** shows the results of measurements of the heating of the mandrel of the screw mill 30-80.

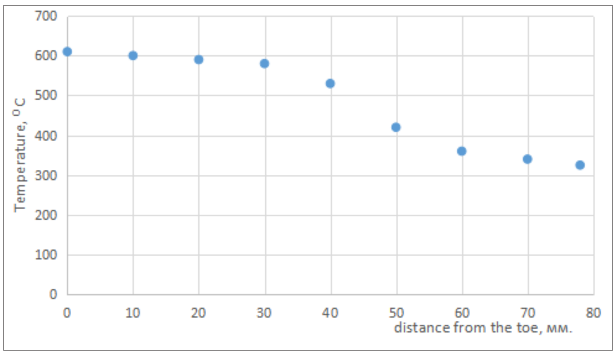

Figure 4. The results of measurements of the heating temperature of the screw machine mandrel 30-80.

Based on the temperature measurements carried out, it can be assumed that the main formation of mandrel defects will occur in the nasal region and further decrease due to the cyclical heating modes shown in **Figure 4** and cooling with water up to 80 °C.

The stitching mandrel of a three-roll screw mill 30-80 was examined after the formation of the vessel cavity. The check interval was every 250 pieces of vessels. **Figure 5** shows the development of defects in the outer surface and inner volume of the sewing mandrel after the formation of the vessel cavity.

The defects shown in **Figure 5** indicate the influence of heating cycles up to 600 °C and cooling to 80 °C at intervals of 7 seconds. After the release of 250 pieces. there are no accumulations of powder on the surface of the mandrel, its surface is smooth. After the release of 500 pieces in the transition area of the diameter from 16 to 18 mm, a longitudinal risk is visible with a length of about 9 mm and a depth of up to 1.2 mm. After the release of 750 pieces of semi-finished products, external shells with a depth of up to 1.1 mm and a diameter of about 3 mm are added to the longitudinal risks in the same area. In the nasal part, there is a pitted surface in small and frequent shells. With the release of 1000 pieces, a pronounced accumulation of magnetized powder is observed in the nasal vessels at a distance of about 10 mm, which suggests the formation of through fistulas. On the side surface of the mandrel, external defects do not grow in length, but their depth increases by about 30%. After the release of 1200 pieces, the mandrel toe collapsed at a distance of about 5 mm and a crack formed at a distance of about 20 mm. The experiment was stopped.

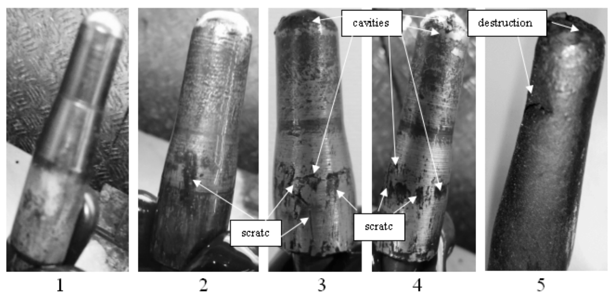

Figure 5. The development of defects in the outer surface and inner volume of the sewing mandrel after the formation of the vessel cavity: 1—250 pieces, 2—500 pieces, 3—750 pieces, 4—1000 pieces, and 5—1200 pieces.

The evolution of the growth of defects in a 4X5MFS steel sewing mandrel during the release of steel vessels, with an interval of 250 pieces. The area of defect formation was measured, as well as determined in the area of their formation at a distance of 50 mm from the toe of the mandrel. The total surface area at this length was 2811 mm^2. The sum of the outer area of powder accumulations indicating the formation of internal defects was taken into account. **Figure 6** shows the effect of the number of rolled vessels on the area of defects on the surface of the sewing mandrel.

Based on the measurements carried out, it can be concluded that with an increase in the firmware cycles, the number of defects increases and reaches maximum values of about 12% of the studied outer surface with the release of 1000 pieces of vessels. The increase in the number of defects is subject to the developed second-order polynomial equation with a determination coefficient equal to 99%.

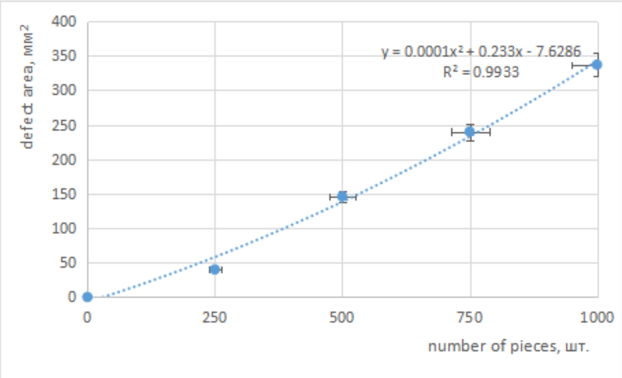

Figure 6. The effect of the number of rolled vessels on the area of defects on the surface of the sewing mandrel.

4. Conclusions

1) Testing of the design and technology of magnetic powder inspection of defects of the piercing mandrel made of 4X5MFS steel of a three-roll screw mill 30-80 was carried out. It has been established that with an increase in the number of rolled products, there is an increase in the number of external and internal defects. A rationally planned interval of replacement of mandrels for the production of steel vessels of about 1000 pieces has been determined.

2) A significant influence of the number of rolled vessels on the growth of the area of shells and cracks on the sewing mandrel has been established. It is shown that the critical area of defects at which the destruction of the deforming tool can occur is about 12% of the total area of the mandrel under study. A second-order polynomial equation is obtained that allows determining the increase in the number of defects of the mandrel surface with a determination coefficient equal to 99%.

3) The development of a system and technology for non-destructive quality control of the screw mill mandrel allowed us to develop a rational plan for replacing the piercing mandrels, which allows us to predict the appearance of defects leading to complex breakage of the deforming tool at the 30-80 mill, which ensured an increase in the efficiency of production of steel vessels at the NPO Pribor machine-building enterprise.

Author Contributions

The contribution of the authors consists of the developed methodology and equipment for checking the quality of the mandrel surface. An equation has been developed to determine the growth of defects in the mandrel surface from the number of vessel cavities formed. The technology of non-destructive testing of the presence of mandrel defects made it possible to develop a forecast for the replacement of the deforming tool.

Conflict of Interest

There is no conflict of interest.

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