Structure and mechanical properties of a wedge-rolled steel skelp

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Abstract. Using the example of steel 50CrMnV, we present the regular changes in the structure and mechanical properties of the metal product with a wedge-shaped longitudinal section obtained by hot rolling of a skelp with the highest reduction rate of 40% and data on the structure of its deformation zone.

Keywords: spring steel, structure, mechanical properties, skelp, hot rolling, reduction rate

1. Introduction

Many metal products are exposed to cyclic loads during operation [1-3]. Due to the fact that the process of crack generation and propagation is local, the critical factor in fatigue failure is not the average resistance to deformation and failure under static loading, but local characteristics and their combinations [4,5]. The process of die forging is accompanied by uneven deformation, which leads to heterogeneous distribution of structure and mechanical properties over the product [6-8]. The effect of plastic deformation on fatigue strength is carried out both at the micro level, when it changes the density and structure of lattice imperfections and at the macro-level when retained stress occur and remain due to nonuniform deformation of the blanks. It is known [9-13] that the effect of homogeneous prior deformation on fatigue strength is not unambiguous [14-17]. Thus, plastic deformation in the zone of homogeneous deformations leads, as a rule, to an increased cycle life of metal products. However, hardening at degrees smaller and greater than homogeneous plastic deformation can negatively affect fatigue resistance. During operation, springs are exposed to cyclic loads, both in the air and in the corrosive environment. There is little information on the assessment of fatigue strength of specific products [9,18]. This is due to the fact that the study of nonuniform deformation in a specific technological process of metal forming, until recently, had significant difficulties [19-21]. Therefore, the study of the structure and mechanical properties of the obtained spring sheets is of great practical importance.

In this paper, using the example of steel 50CrMnV, the structure changes and mechanical properties of the metal product with a wedge-shaped longitudinal section obtained by hot rolling of a skelp into a wedge are shown.

2. Research methods

The spring sheet manufacturing technology includes induction heating of a blank (hot-rolled skelp of rectangular cross-section) and forming operations: punching the central hole, rolling both ends of the blank to a wedge with non-drive rolls (rolling speed 200 mm/sec) and wrapping the lugs. The cycle time is 17-19 seconds. Then the skelp is heated, bent and heat-treated according to the factory technology (oil quenching and tempering), followed by shot peening of its surface. The use of hot-rolled skelps of cross-section to manufacture springs has a number of features. Rolling the blank into a wedge is carried out in one pass, which means a different degree of deformation along the length of the rolled sheet; the production is
formed by two main technology ing surf CrMnV ect examples were cut out in the selected areas for mechanical testing and, the mechanical actual deformation zone in depends on the. Thus, the faster [70x763]IOP Conf. Series: Materials Science and Engineering 1100(2021) 012010 doi:10.1088/1757-899X/1100/1/012010 different strain intensity. particular at a maxim rolled blank it deformation ε 20%, blank to the fact that the periodic process. In the first case, wedge Products with a wedge 3. The sizes of mosaic blocks (coherent scattering a roller). The deformation rate is 5 mm/min. Fatigue tests of flat samples (GOST 25.502 one middle thickness of the rolled blank and heat treated state. Metallographic testing was performed using an "Epitup" microscope at magnification >300. The zones of cross-sections after rolling and heat treatment were studied. After picric etching the grain size was measured, the size changed depending on the reduction degree (along the rolled plate). The study of hardness was carried out in the cross sections of the selected zones according to the Rockwell method according to GOST 9015 in three levels: in the middle of the rolled thickness, in two layers separated from the surfaces by 2 mm. Along the width of the skelp, five punctures were made, 75 mm in size, with an interval of 15 mm and side margins of 7.5 mm. Stretching was performed in accordance with GOST 1497-84 on the all-purpose machine UME-10TM (with a strain gauge), on flat samples 2 mm thick, made of longitudinal blanks of selected zones in three layers (the upper one – in contact with a stationary plate; the middle one – the middle thickness of the rolled blank and the lower one - rolled by a roller). The deformation rate is 5 mm/min. Fatigue tests of flat samples (GOST 25.502-73) were carried out according to the cantilever bending with a symmetrical cycle with a frequency of 1500 cycles/min at room temperature according to a "rigid" loading mode. Impact tests were carried out on samples with a U-shaped incision in accordance with GOST 9454, made from transverse blanks of the selected zones. To study changes in the fine structure (substructure) of rolled metal, the method of x-ray diffraction analysis was used. The sizes of mosaic blocks (coherent scattering zones) and the magnitude of microstresses on the diffractometer DRON-2 were determined. Fatigue tests of springs were carried out with a loading frequency of 0.6 Hz on the spring stand, before the fracture of any sheet.

3. Results and discussions

Products with a wedge-shaped surface obtained by forming are widely used. At the same time, obtaining a wedge-shaped surface in the workpiece is performed by two main technology processes: stretching and rolling. In the first case, hammer forging is used, in the second one – rolling on special equipment: forge rolling machines and rolling mills. The process of rolling a rectangular-section skelp into a wedge is a periodic process. However, unlike longitudinal rolling, it has a constantly changing zone of deformation, due to the fact that the rule of forming is set by a moving tool – a roll, which, in addition to translation movement, goes perpendicular to the rolled surface of the workpiece. The results of studies of the rolled blanks of spring sheet made of steel 50CrMnV showed uneven thickness of layers of the rolled blanks, depending on the reduction rate with a certain regularity. From the start of rolling to the degree of deformation ≤ 20%, the layers in contact with the tool (roll) have the greatest deformation intensity, and then it shifts to the layers in contact with the stationary plate of the rolling mill.

In order to study the structure of the actual deformation zone in the strip of rectangular cross-section blanks of spring steel sheet 50CrMnV, the uneven strain state of a workpiece thickness was evaluated, and in particular the zone of maximum intensity (deformation zone), depending on the reduction rate, as well as microstructure of the actual deformation zone.

As for the first aspect, the mechanical properties of the material were studied by the thickness of the rolled skelp. To do this, the skelp was cut out of blanks by EDM process on plates 2 mm thick.

Speaking about the second one, the structure of the actual deformation zone was analyzed on a section of the longitudinal section of the skelp at the point of its contact with the roll, fixed by stopping the process, in particular at a maximum reduction rate of 40%. The assessment was carried out by identifying zones of different strain intensity. In addition, mathematical modeling of the process by the finite element method (FEM) was performed using the DEFORM software package.

It is established that if during cold processing, as the deformation rate increases, there is an increase in the deformation resistance (hardening), then during hot processing, the processes of hardening and softening occur simultaneously. The recrystallization rate depends on the deformation rate. Thus, the faster recrystallization proceeds, (it is determined by an increase in ductility and a decrease in strength properties),
the greater the deformation rate preceded. In other words, the deformation is associated with a significant metal softening. The strip temperature was monitored during rolling using an infrared pyrometer “Micron MSOP” (USA). The measurement results showed that there was no temperature drop, and rolling was performed at a constant temperature. The analysis of the yield strength and hardness values showed uneven softening, both in thickness and in the cross section of the rolled strip at different degrees of reduction.

Thus, in the longitudinal section, the greatest softening, and as a result, the greatest degree of deformation correspond to:
- at reduction rate up to 23% - metal layers on the side of the skelp, while the difference is in the range of 10-15%;
- at reduction rates from 23% to 40% - layers that are adjacent to the stationary plate of the rolling mill; in cross section:
- with the reduction rate $\varepsilon \approx 23\%$ at the edge of the skelp, the yield strength was in the range of 542...745 MPa, in the middle - 622...719 MPa;
- with the reduction rate $\varepsilon \approx 40\%$ along the edge of the strip, the yield strength was in the range of 434...647 MPa, in the middle-581...674 MPa.

The obtained results are confirmed by data on the "crown shape" of the rolled blank, depending on the reduction rate. For small reduction rates $\varepsilon \approx 4\%$, the greatest broadening is in the layers of the strip on the rolling side. With a subsequent increase in the reduction rate, the greatest broadening goes to the layers near the stationary plate of the rolling mill.

Strength characteristics: yield strength and temporary failure resistance confirm the above-mentioned nature of uneven changes in hardness along the length of the hot-rolled blank. At the same time, some discrepancy in the results can be explained by the fact that the samples for the tensile test were made from layers of hot-rolled metal that have uneven mechanical properties both in width and in thickness. For small deformations, the rolled layer has the greatest hardening.

Changes in the ductility parameters: percentage extension and contraction, and impact hardness are similar to changes in strength characteristics. The difference is that they have an extreme minimum. At the same time, the changes in the strength and ductility of the hot-rolled and heat-treated metal in deformation are almost identical [9]. However, the following differences occur in a heat-treated blank: increase in strength characteristics: hardness by 1.5 times, strength and yield strength by 1.52 times; decrease in ductility by 2.5 times, impact strength by 1.25 times.

The results of fatigue tests in general confirmed the data in strained condition in terms of mechanical properties. Metal layers that have a high intensity of recrystallization processes, and as a result, better healing of structural defects obtained during deformation, had a longer service life [22].

4. Summary
Along a hot-rolled blank, with increasing degree of deformation, the strength increase, and the ductility index decrease, passing through an extremum in the range of degrees of deformation of 15-20%, depending on the metal layer.

The hardening obtained in the process of hot rolling is partially preserved after the final treatment, while the nature of strength characteristics and ductility of the metal of the rolled blank and the blank after the final heat treatment in deformation is the same.

The studies of hot-rolled and heat-treated metal indicate different conditions for the formation of a hot-deformed structure and its influence on the final mechanical properties of the spring sheet. Layers with the most intensive recrystallization have a higher cycle life in a wedge-rolled blank, which causes better healing of structural defects during deformation.

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