Technological assurance of the quality of deformed steel products in mechanical engineering

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Abstract. The article shows the influence of fibrous structure and non-metallic inclusions on the mechanical properties of steel products. The macrostructure of forging the crankshaft was investigated and the places of exit of the elimination zones to the surface of the car part were established. Based on this, there are proposed ways to improve the quality of deformable steel products in the machine building industry.

One of the main disadvantages of heavily loaded vehicle parts such as gears, shafts and other parts is the dispersion of their strength and durability. The duration of the work of the same type of parts made of the same steel grade, processed and hardened in the same production conditions differs several times. The reasons for the significant dispersion in the durability of parts are different, namely, they can be a consequence of the presence of metallurgical defects in the alloy, design and technological features and operating conditions of the vehicle. Therefore, solving the problems of stabilizing the strength and durability of various parts at the maximum level can be achieved on the basis of an integrated engineering approach, linking indicators and criteria of metallurgical, design, technological and operational types into a single system. The reasons that cause destabilization of the properties of finished products were studied. A change in metallurgical defects of steel during the technological redistribution of metal in machine-building production was revealed and the possibility of improving the properties of parts by forming a favorable macro- and micro-structure in the cross section of a metal product is shown [1].

At the engineering design stage of the part, the main emphasis on the part of the workers is on the selection and initial state of the stock of material that is used to manufacture the metal product. The physical and mechanical properties of the articles depend to a large extent on the manufacturing scheme of the parts, since they decisively affect the process of forming the metal structure.

High level of properties of parts is achieved in case of application of plastic deformation method in process cycle. This operation has a positive effect on the macro- and microstructure of steel. The crystalline dendritic structure of the cast steel workpiece undergoes significant changes during plastic deformation. Properly assigned and performed modes of plastic deformation contribute to elimination of porosity, infusion of microdefects, crushing and rational orientation of non-metallic inclusions and carbides, grain grinding and formation of optimal arrangement of fibrous structure and deformation texture [2]. The complex effect of the process parameters of hot plastic deformation processing (temperature, speed and degree of deformation, etc.) has a significant effect on the shape of the structural components, and as a result, increases all the indicators of the mechanical properties of the metal.
The direction of the fibers, or the macrostructure of the metal products, has a significant effect on the strength of the steel parts, since the mechanical properties of steel during tests along or across the fibers differ sharply. In the example of a steel sample 45 in the longitudinal direction, the strength and ductility of the steel are higher than in the transverse direction (normalization 860°C, tempering of 640 °C).

To make a strong part by forging or hot forging from rolled stock, it is necessary to use high strength of rolled stock in the longitudinal direction. In the finished part, the fibers should be axially directed and enveloped so that there are no break points or cut fibers during subsequent machining. The incorrect direction of the fiber along the main working sections of the part causes a decrease in mechanical strength and premature destruction of the finished products. During the engineering phase, it is also necessary to consider the possibility of radial arrangement of fibers, which, due to several circumstances, can inevitably be obtained on the part.

The central zone of rolled stock deserves special attention, since it concentrates non-metallic inclusions, there is porosity and other disadvantages that adversely affect the properties of the metal. This fact causes lower mechanical properties of the central zone with respect to the peripheral zone. As practice shows, when such a zone is shifted to the most loaded sections of the part, premature destruction of the product during operation is observed [3].

An illustrative example is the tooth breakage of a gear in the base of which there is a liquor square displaced from the central zone during plastic deformation of the metal in the forging manufacturing step (figure 1).

![Figure 1](image1)

**Figure 1.** Macrostructure of section of parts with location of liquefaction square at tooth base (a) and in central part (b) of gear.

In addition, the release of liquor zones to the surface can cause "spotty" hardness and the formation of quench cracks on forgings and parts during heat treatment (figure 2) and after grinding.

![Figure 2](image2)

**Figure 2.** The liquefaction square in the section of the part macro profile.
As a result of experimental studies, on a specially prepared workpiece subjected to hot bulk stamping on KGShP, they were clearly convinced about the possibility of internal metal layers reaching the forging surface (figure 3).

The metal blank was a square of 150 × 150 mm, in which the metal was removed from the central zone by drilling and a rod of Ø50 mm from another steel brand was installed in this place, which differed in degree of etchability from the metal of the original blank. In this way, a contaminated rolled stock zone was simulated with, and these are the liquor square, central porosity and other imperfections that reduce the mechanical properties of steel [4]. After heating up to 1230 ± 10ºS of the combined billet, volumetric stamping was carried out. Samples were taken from various sections of the obtained forging and templets were made that corresponded to the cross-sections or longitudinal sections of the part. As a result of hot macrotreating of templets in a 50% solution of hydrochloric acid, the location of heterogeneous materials was revealed. In separate cross sections, the exit to the surface of the central zone is not visible [5].

However, in most cases, such a zone comes out or is close to the surface, including it is present in the zone of fillets and oil paths. Metal of rod on surface of forging is clearly manifested on templets of longitudinal section. This is shown in figure 4.
To a large extent, the viscosity of steel depends on the content of sulfur: the temperature threshold of cold water in steels with a sulfur content of 0.005% and 0.03% differs by 30-40°C.

In any steel in some quantities there are elements that are gases - oxygen, nitrogen and hydrogen. Gases, even if contained in hundredths and thousandths of a percent, have a significant effect on the properties of the metal. Penetration impurities (nitrogen and oxygen), concentrating in grain-boundary volumes and forming emissions of nitrides and oxides, along the grain boundaries, increase the cold flow threshold and reduce resistance to brittle destruction. Oxides are stress concentrators and significantly reduce, especially in case of their accumulation, the endurance limit and can serve as a center of destruction of the part in operation.

These arguments show a significant decrease in the structural strength of parts that have non-metallic inclusions on the surface and especially if they are present in areas of loaded sections (fillets, holes, splines) [6].

Premature failure of metal products is often the result of brittle destruction of the material. The size of the grain, the amount, size, shape and nature of the distribution of non-metallic inclusions, central porosity, liquation manifestations of various kinds, etc., have a great influence. Many of these factors are inherited by the metal of the finished products from the cast state of the alloy and often have a negative effect. This is evidenced by the revealed center of destruction of the part, the beginning of which was a non-metallic inclusion, located even in the depth of the metal (figure 5).

![Figure 5. Non-metallic inclusion - the center of part destruction.](image)

Thus, when developing the technology and designing the die tooling, it is necessary to achieve the correct metal flow during plastic deformation and create a rational fibrous structure, as well as prevent the central zone from leaving the area of the most loaded zones and to the surface of the part.

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