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Key concepts for production of high-quality parts

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Abstract. The paper reveals the negative effect various stress raisers have on the part cyclic resistance. It proposes the innovative solutions to eliminate the segregation occurrences in steel, mitigate the negative effects of crack-like defects, and towards the design features required in part fillets.

1. Introduction

The performance capability and operating life of vehicle parts depend on many factors. The high-priority task for experts from the different fields (mechanical engineer, metallurgist, field engineer, etc.) is to find root causes of low product durability, develop and implement innovative engineering and process solutions aimed at producing high-quality and competitive vehicle parts.

The objective of this paper is to develop and substantiate the design, metallurgical, process and engineering solutions towards higher field reliability and durability of vehicle parts.

The paper presents the most representative and effective solutions to increase the fatigue strength of steel parts used for different purposes – ball joints for vehicle drive axles, crankshafts, crosses and gear wheels.

2. Body text

The design solutions adopted at the design and road bench test stage play an important role in ensuring the reliability and durability of products. A notable example is provided by the experimental studies of the impact of fillet radius (Rf) at the transition from hub Ǿ105 mm to flange (Fig. 1) in the vehicle ball joint on its durability [1]. The bench tests showed that with a fillet radius of 0.5 mm the average durability (28 parts tested) was 0.076×10^6 cycles, with a radius of 2.5 mm it was 0.142×10^6 cycles, with a radius of 4.0 mm it was 0.268×10^6 cycles, with a radius of 8.0 mm it was 0.524×10^6 cycles. These results revealed that the part durability (N) depends on the fillet radius (Rf) in its weakest section:

$$\lg N = 5 + 0.1\, Rf$$

The fillet radius should be minimum 4.3 mm to ensure the target vehicle mileage (350 000 km) and rule out a destruction failure of a ball joint. The fatigue strength of parts can be additionally increased by 21-34% if parts are toughened by thermal residual stresses arising from accelerated cooling after tempering from a temperature of 630-650°C [2]. After water cooling the compressive residual stresses occur on the part surface due to a significant temperature difference (~500°C) between the product surface and core. At the product design stage a similar approach should also be used for other part regions where stress is concentrated (keyslots, grooves, collars, thread, holes, etc.).

As stress raisers in parts are unavoidable their negative impact can be minimized by shot peening. The proper shot size and properties together with its effect on the surface help to create high compressive stresses in the problem areas and thus increase the durability of parts significantly for cyclic load operation [3].

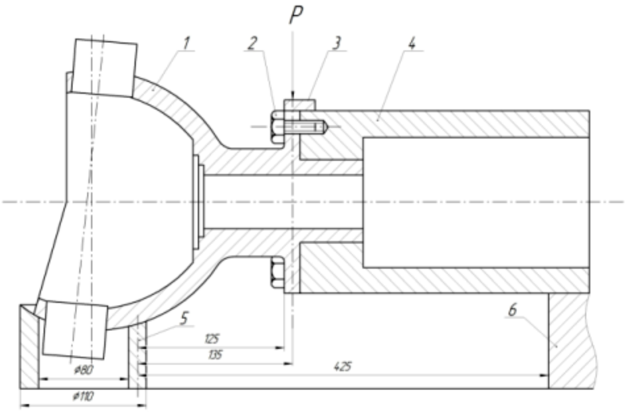

Figure 1. Load distribution in a ball joint: 1 – ball joint; 2 – fastening bolts; 3 – plate; 4 − pipe; 5 – pivot ring; 6 – rectangular-shaped bearing.

Among various negative metallurgic factors affecting reliability and durability of steel products the most critical ones are undoubtedly segregation occurrences and a degree of alloy contamination with endogenous and exogenous inclusions. The greatest danger comes from chemical and structural steel heterogeneity like a segregation square and especially in cases of segregate emersion to the highest stressed regions in a product. Figure 2 shows the failed gear. The cause of its failure was the segregation square which had been shifted towards the part tooth root at the hot working stage of the metal work-piece [4].

The method of investigating metal flow at hot forging was developed to eliminate unwanted micro- and macrostructures in steel products arising during process metal conversion in the machine production [5]. This method helps to find different shifting metal regions in the die cavity and, if necessary, control flows even in complex-shaped products by designing an accurate working die contour.

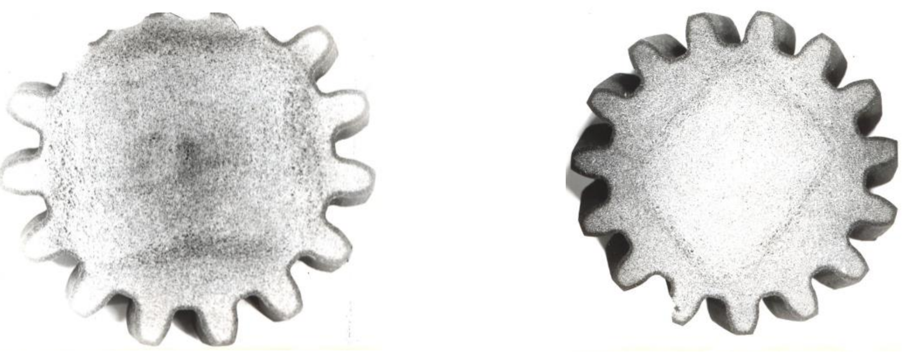

Figure 2. Macrostructure of part sections with the segregation square found at the gear tooth root (a) and center (b).

The crack-like stress raisers resulting from process metal conversion decrease the steel resistance to dynamic and static loads significantly. Such defects include folds, laps, undercuts, marks, etc.

Mechanical engineers should focus their efforts on complete removal of such stress raisers from a part surface or their elimination by shot peening. The greatest effect is achieved by using combined cold working process: first, impacting with large-sized shots, then relieving the stresses, and finally impacting with small-sized shots [3, 6]. The shot size for each stage depends on the type and size of a defect.

3. Conclusions

1. The design solutions were proposed to help make a rational choice of fillet radius in the mating areas of a part for high field reliability of products.
2. The method of investigating metal flow at hot forging was proposed to eliminate unavoidable metallurgy-related stress raisers in the parts. Subsequently, it prevents segregation occurrences and other steel defects from coming up to the surface.
3. It is recommended to use shot peening in order to increase the filed durability of products with inherited stress raisers of different origin.

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