INTERNAL STRESSES AND CRACK INITIATION IN ASYMMETRICALLY HARDENED STEEL BARS SUBSEQUENTLY SURFACE MACHINED BY GRINDING

L. Kosec*, F. Kosel**

During surface hardening internal stresses occur in steel, exerting a positive effect on load carrying capacity of a machine part. The magnitude and distribution of internal stresses depend among others also on the geometry of the hardened surface. When in the next step the hardened surface is machined by grinding, the system of internal stresses can undergo a substantial change due to the newly occurred stresses induced by grinding. The extent of this change is very often such that during or after the grinding process, cracks are initiated on the surface. An analysis was made of the internal stresses in a bar with a uniformly and asymmetrically hardened surface as well as of additional stresses induced by grinding.

INTRODUCTION

The initiative for the investigation was given by the high frequency of defects found in the form of cracks on the surface of machine parts to which surface hardening and subsequent grinding have been applied. An analytical solution and experimental investigation of a simplified example of this problem had been described in a paper presented at the 5th ECF Conference /1/. This contribution treats a more concrete example taken from industrial practice, and analyzes the internal stresses in a steel part having an asymmetrically hardened surface, Fig. 1.

ANALYTICAL APPROACH TO THE PROBLEM OF CRACK INITIATION

Cracks occur on the thinnest part of the hardened layer of the surface. The resulting residual stresses in this part are a consequence of the stresses due to phase transformations σ_1^k, thermal stresses due to hardening σ_2^k, a consequence of martensite tempering σ_1^B and of the effect of thermal load in grinding σ_2^B:

1. Due to the transformation of austenite into martensite, the following residual stress is present at the ambient temperature

$$\sigma_1^k(T_0) = -\sigma_{0,2}^k(T_0) \tag{1}$$

where: $\sigma_{0.2}^k(T_0)$ is the plasticity limit at the ambient temperature.

2. The process of cooling the layer from the quenching temperature

* Faculty of Technology and Nature Science, Dept. of Metallurgy
** Faculty of Mechanical Eng., E.Kardelj University, Ljubljana, YU

T_k to the ambient temperature T_o induces internal stresses which are dependent on the geometry of the layer and rheological properties of the steel in the temperature field /1/. This dependence is given by the Boltzmann-Volterra integral equation. For the plasticity limit at the temperature T_k this is:

$$\sigma_2^k(T_k) = \left\{\varphi_k[T_k(t)] - \int_0^t R_k(t-\tau)\varphi_k[T_k(\tau)]d\tau\right\}\frac{\beta_2}{\beta_1} = \sigma_{0,2}^k(T_k)\frac{\beta_2}{\beta_1} \qquad (2)$$

where

t - time; T_k - temperature of hardening when the stress-strain state passes into Hooke's region; $\varphi_k(t)$, $R_k(t-\tau)$ - rheological properties of the martensite dependent on time. The following parameters can be found from Figure 1.

$$\beta_1 = 2 + \frac{2}{sh^2\xi_1 + sh^2\xi_o}\left[\frac{(1+ch\,\xi_1)\,sh\,\xi_o}{sh(\xi_1-\xi_o)} - sh^2\xi_o\right]$$

$$\beta_2 = \frac{2}{sh^2\xi_1 + sh^2\xi_o}\left[\frac{(1+ch\,\xi_o)\,sh\,\xi_1}{sh(\xi_1-\xi_o)} - sh^2\xi_o\right]$$

$$\xi_o = Areash\left(\frac{a}{r_o}\right);\ \xi_1 = Areash\left(\frac{a}{r_1}\right);\ e = a(cth\,\xi_o - cth\,\xi_1)$$

$$\mu = \frac{r_1}{r_o};\ T_k = \frac{2\,\sigma_{0,2}^k(T_k)}{(1-\mu)\alpha(T_k)E(T_k)(1+\nu)\beta_1} + T_o$$

(3)

3. The influence of the tempered martensite occurring in a very thin layer of the hardened surface, is described by the expression:

$$\sigma_1^B(T_o) = \sigma_{0,2}^B(T_o) \qquad (4)$$

where $\sigma_{0.2}^B(T_o)$ is the plasticity limit of the tempered martensite at the ambient temperature T_o.

4. The influence exerted on the stress state by the cooling during the grinding process is defined by the rheological equation:

$$\sigma_2^B(T_B) = \sigma_{0,2}^B(T_B) = \varphi_B[T_B(t)] - \int_0^t R_B(t-\tau)\varphi_B[T(\tau)]d\tau \qquad (5)$$

where $\varphi_B(t)$, $R_B(t-\tau)$ - are functions of the machining properties of the tempered martensite depending on temperature and time; T_B - temperature at which, during the cooling process, the stress-strain state passes into Hooke's region

$$T_B = \frac{\sigma_{0,2}^{B}(T_B)}{(1+\nu)\,\alpha(T_B)\,E(T_B)} + T_0 \tag{6}$$

The resulting stress remaining in the tempered martensite layer after the heat treatment and grinding procedures is

$$\sigma_R(T_0) = -\sigma_{0,2}^{k}(T_0) + \sigma_{0,2}^{k}(T_k)\frac{\beta_2}{\beta_1} + \sigma_1^{B}(T_0) + \sigma_2^{B}(T_B) \tag{7}$$

Cracks do not occur if

$$\sigma_R(T_0) < \sigma_{zr}^{B}(T_0) \tag{8}$$

where $\sigma_{zr}^{B}(T_0)$ - breaking strength of the tempered martensite.

CONCLUSION

The investigations have confirmed that in a non-uniformly thick layer of the hardened surface stresses are higher than in an axi-symmetric case, Figure 2. This means that, in cases of non-uniformly thick hardened layers, the thickness of the layer has to be greater than in cases of layers with constant thickness. In the steel possessing a proportion of 0.4 %C, 1.2 % Cr and 0.2 % Mo cracks occurred on the thinnest areas of the hardened surface, and that always on the places where due to grinding the martensite got tempered.

REFERENCE

/1/ Kosec L. and Kosel F. "Cracks initiation in heat-treated and ground steel" Proceedings of the 5th European Conference on Fracture, Vol. 1, 1984

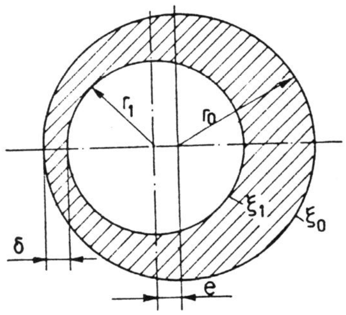

Fig.1 - Geometry of the hardened layer

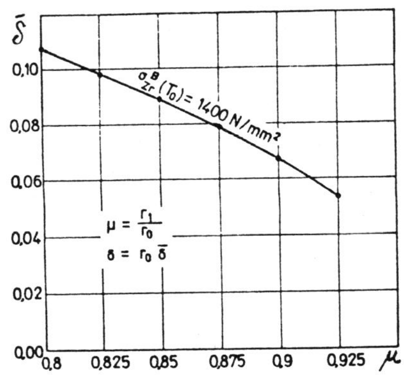

Fig.2 - Critical depth
$\bar{\delta}$ - relative critical depth
μ - ratio of radii