An analysis of the effects of burnishing in internal broaching

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The finite element analysis gives the stresses and deflections of the broach and workpiece while cutting and burnishing. This has been achieved by developing a suitable finite element program for solving linear and non-linear material behaviour problems. The broach has been considered to behave elastically. In case of burnishing, the stresses on the workpiece result in yielding, and hence, non-linear material behaviour is considered for the workpiece. The program has been further modified to compute residual stresses on the broached component. The movement of a single burnishing tooth through the workpiece is simulated in a step-by-step manner, leading to residual stresses on the broached surface. The burnishing tooth and corresponding portion of the workpiece are modelled using FEM. The effect of tool-work interference and the ratio of radial to axial force on the stresses and deflections while burnishing have been studied. The residual stresses left behind on the broached component have been analytically evaluated.

Key words: broaching, broach, residual stress, burnishing, Finite Element Method (FEM)

1. INTRODUCTION

The broaching process has some unique features. Most of the machining processes require more than one operation to produce the specified finish and accuracy. The required surface integrity is attained after roughing and finishing, by adjusting speed, feed and depth of cut. However, in broaching, a single tool provides roughing, finishing and burnishing operations. Burnishing teeth lead to considerable strain hardening of the workpiece, thus, sometimes avoiding further heat treatment. The combined effect of finishing and burnishing teeth provide the accuracy and surface finish.

Improved bore accuracy and better finish were produced by broaches having both cutting teeth and burnishing teeth [1]. It was also observed that a high class tooth surface finish reduced the probability of seizing and built-up edge formation and helped to improve the burnished surface quality. A universal strength calculation procedure was proposed for the burnishing rings of heavy duty broaches [2]. The proposed method was used to design a composite deformation broach of increased strength. There is not much information available on the burnishing action of a broach.

In this paper, the burnishing tooth and workpiece have been modelled to obtain stresses and deflections in the tool and workpiece during burnishing. The broach has been considered to behave elastically. In case of burnishing, the stresses on the workpiece result in yielding, and hence, non-linear material behaviour is considered for the workpiece. The burnishing action has been simulated by considering the movement of burnishing load on the workpiece surface in a step-by-step iterative manner leading to the computation of residual stresses on the workpiece surface. A burnishing tooth and corresponding portion of the workpiece are modelled as shown in Figs. 1 and 2. The burnishing forces are assumed to be distributed exponentially along the contacting regions of the burnishing tooth and workpiece as shown in Figs. 1 and 2. The analysis is carried out for different tool-work interferences. In order to simulate the burnishing action, burnishing force is moved along the length of the inner surface. Discretization of the workpiece for the calculation of the residual stresses is shown in Fig. 3.

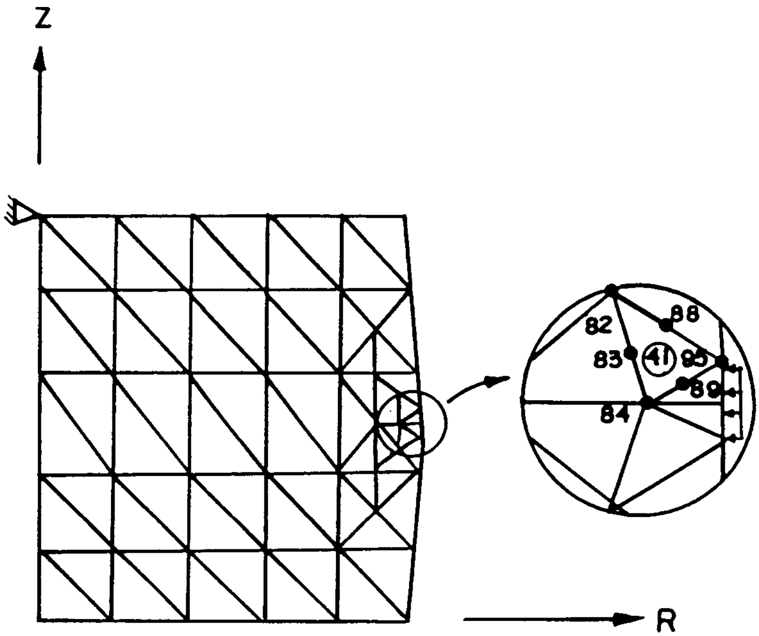

Fig. 1. Discretization of the burnishing tooth.

2. RESULTS AND DISCUSSION

In the analysis of the burnishing, the workpiece yields only at a few elements near the inner surface. Comparing the results for a material which behaves in an elastic-perfectly plastic manner and for a material which displays strain hardening, it is seen that there is only a marginal increase in the burnishing stress for the latter case. As an example, the burnishing stress obtained for an element on the workpiece at the tool-work interface has

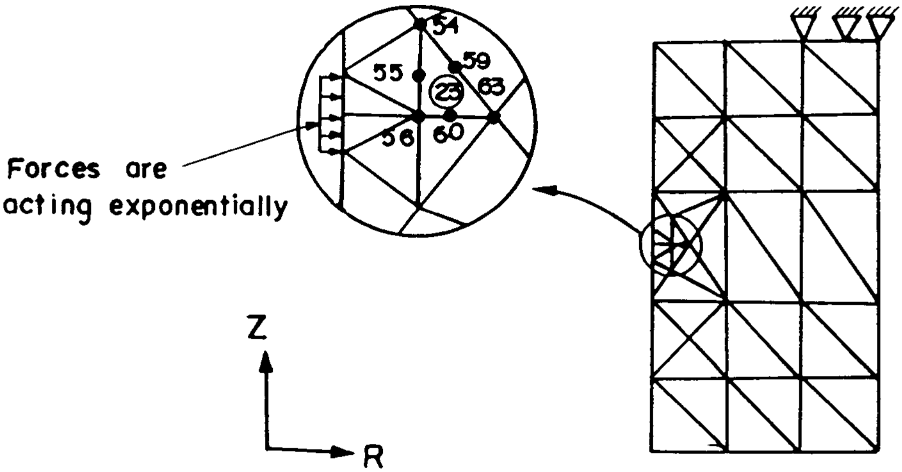

Fig. 2. Discretization of the workpiece for burnishing

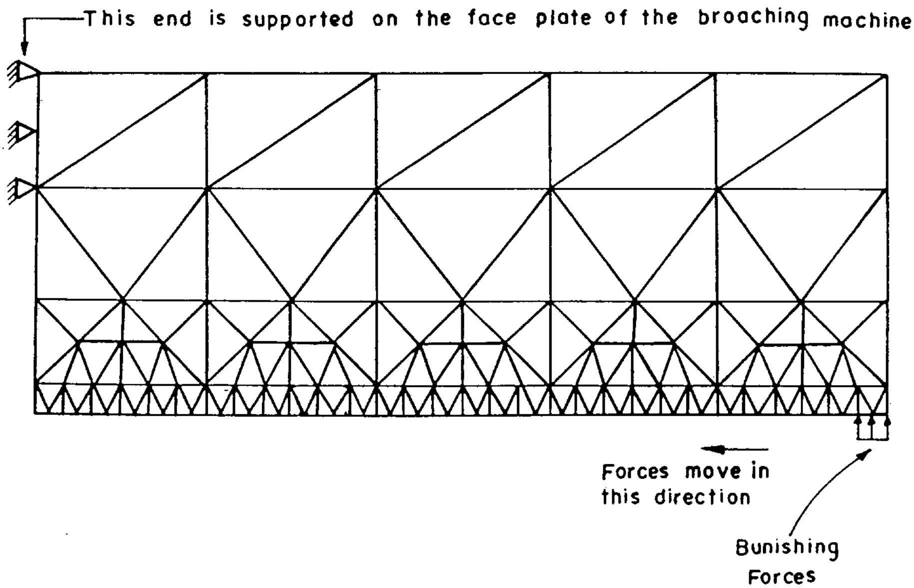

Fig. 3. Discretization of the workpiece for calculating residual stress.

$\sigma_r = -1351\ \mathrm{N/mm^2}$ without strain hardening and $\sigma_r = -1352\ \mathrm{N/mm^2}$ with linear strain hardening (strain hardening = 0.2 E). In this study, the elastic–plastic material behaviour is considered. In the calculation of the residual stresses a relatively small value (10 μm) of tool-work interference is considered. High interferences increase the computational time and cause yielding at the inner surface even during unloading.

2.1 Stresses on the burnishing tooth

The stress distribution along the periphery of the burnishing tooth is shown in Fig. 4. Burnishing stresses are found to be highly compressive at the tool-work interface. The trailing portion of the burnishing tooth has compressive stresses while the leading end has marginally tensile stresses.

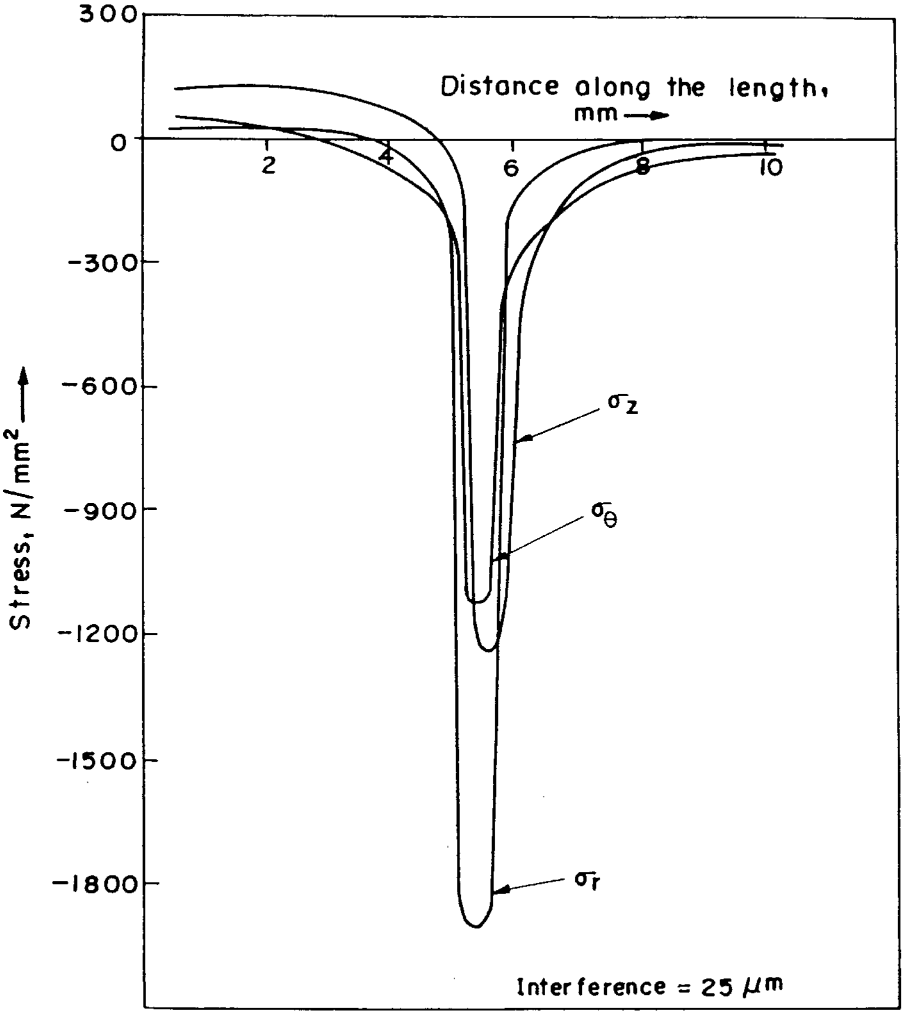

Fig. 4. Stresses along the periphery of the burnishing tooth.

2.2 Stresses on the workpiece while burnishing

Stresses on the workpiece along its length while burnishing are plotted in Fig. 5. Stresses at the burnishing tooth-workpiece interface are compressive. Fig. 6 shows stresses along the thickness of the workpiece during burnishing. Stresses are compressive near inner surface, and drop to tensile or low compressive values as the distance along the thickness (radius) increases. Along the length of the workpiece, at the trailing end σ_r and σ_θ are tensile and at the interface all the stresses are compressive.

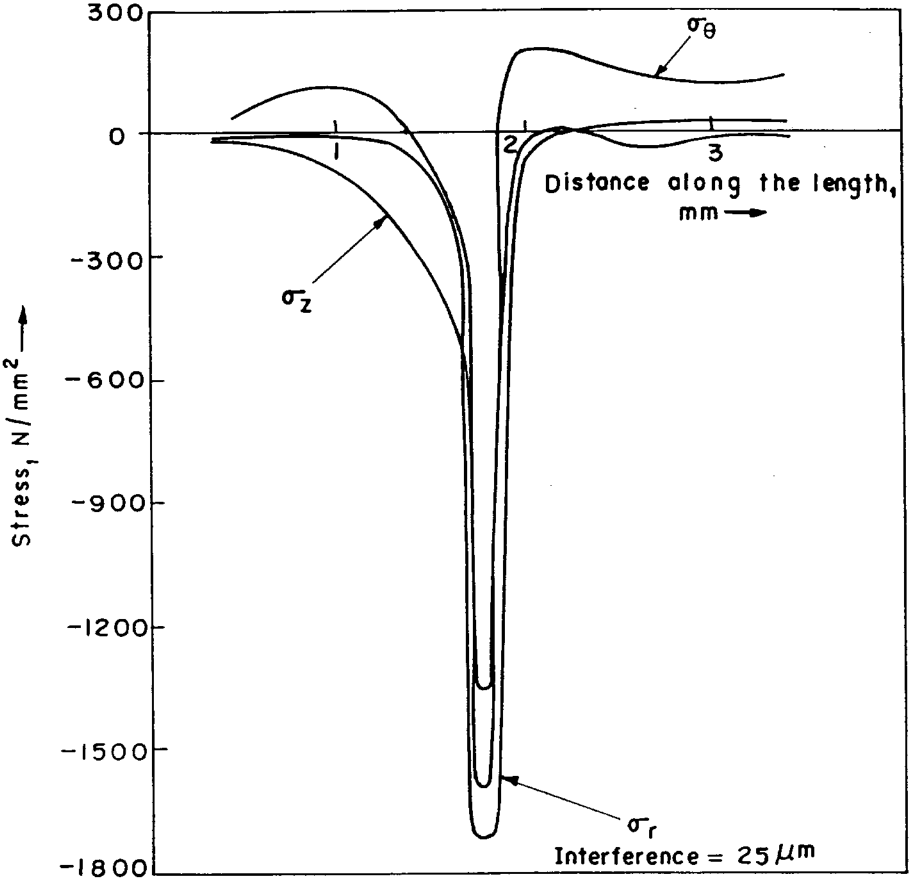

Fig. 5. Stresses along the length of the workpiece under the burnishing tooth.

2.3 Dimensional changes in burnishing for different tool-work interferences

The interference is obtained by adding the absolute values of the tool deflections and workpiece deflections at the interface. In case of burnishing tooth, elastic material properties are assumed, while for the workpiece non-linear material behaviour is assumed. The cutting forces are changed to get different values of tool-work interferences. Different ratios of the radial to axial forces are assumed in the case of low carbon steel. The variation of change in dimension with tool-work interference for different ratios of axial to radial forces is plotted in Fig. 7. Dimensional change in burnishing is of the order of 0.4 μm for interference up to 30 μm. The maximum value of the dimensional change increases with the increase in interference. Fig. 8 shows the dimensional change due to burnishing for brass and aluminium.

The dimensional change for an interference of 30 μm is 1.3 μm for aluminium and less than 0.075 μm for brass.

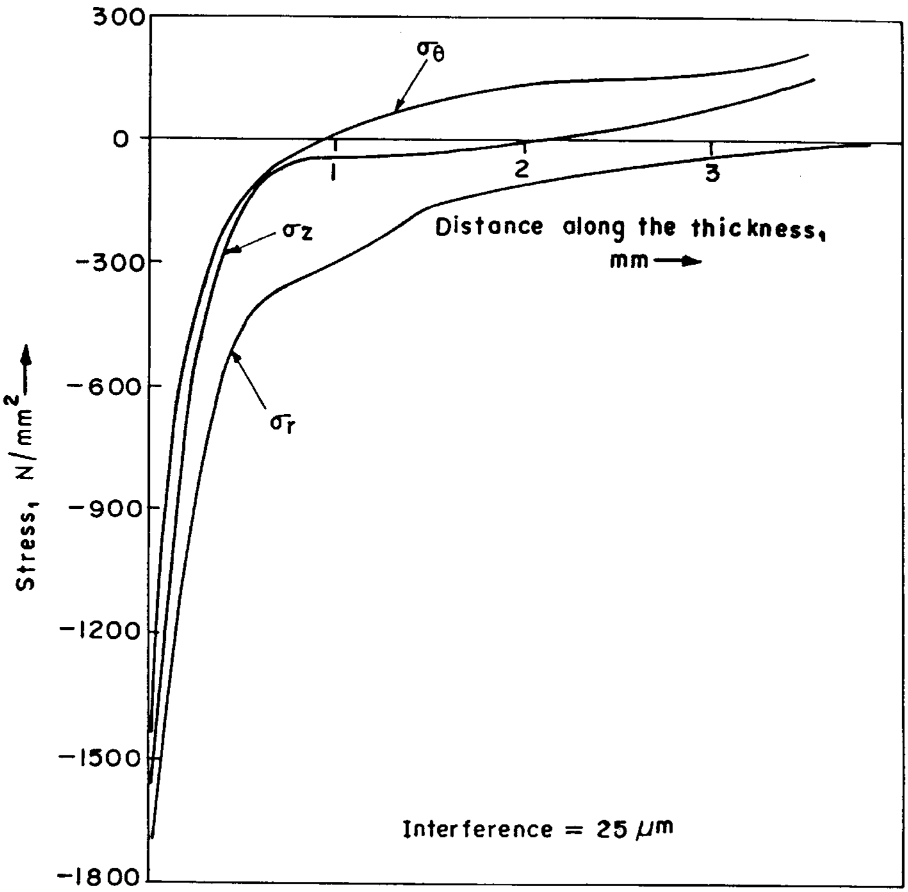

Fig. 6. Stresses along the thickness of the workpiece under the burnishing tooth.

2.4 Dimensional change in burnishing for different thicknesses of the workpiece for a given load

Dimensional change caused by burnishing is dependent on the thickness of workpiece (Fig. 9). The dimensional change due to burnishing decreases with the increase in thickness of the workpiece for a given load.

2.5 Dimensional change in burnishing for different thicknesses of the workpiece for same interference

The variation of the dimensional change in burnishing with interference, for different thicknesses of the workpiece, is shown in Fig. 10. For a given interference, there is a marginal increases in the dimensional change as the thickness of the workpiece increases.

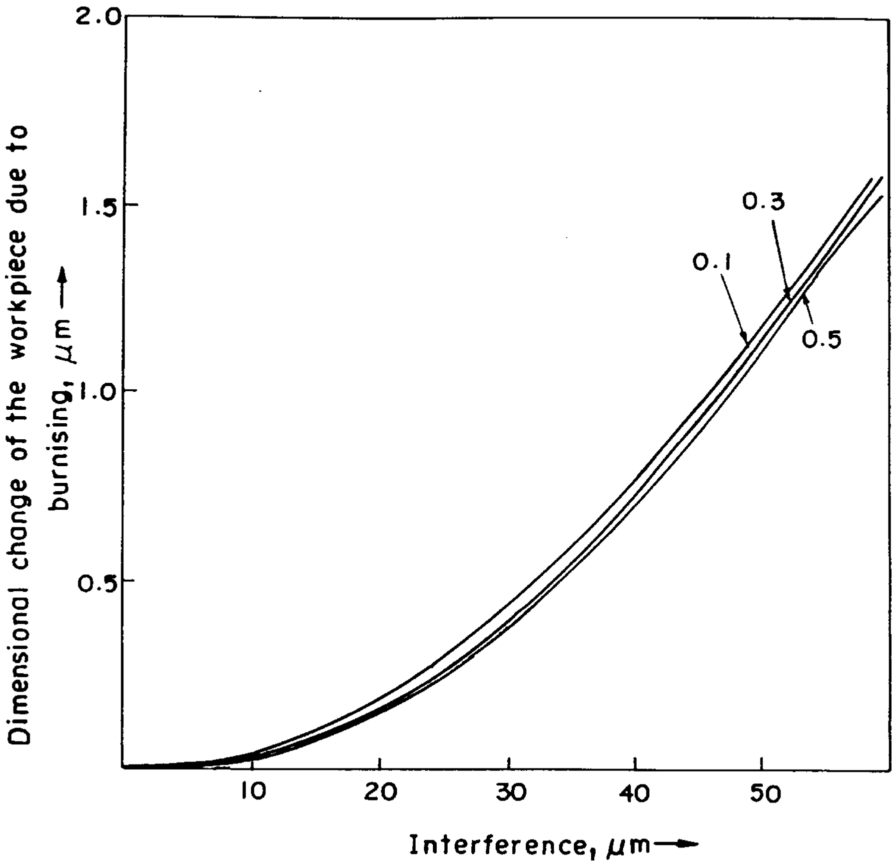

Fig. 7. Dimensional change due to burnishing for different interferences with different ratios of axial to radial forces while broaching low carbon steel.

2.6 Residual stresses along the length of the workpiece

Residual stress distribution along the length of the workpiece is shown in Fig. 11. The residual stresses were obtained by simulating the movement of the burnishing load of a single tooth near the inner wall (0.00677 mm away from the wall) are plotted.

2.7 Residual stresses along the thickness of the workpiece

Residual stress variations along the thickness of the workpiece at three different sections are shown in Fig. 12. Residual stresses are high near the inner diameter and drop to low values a short distance away.

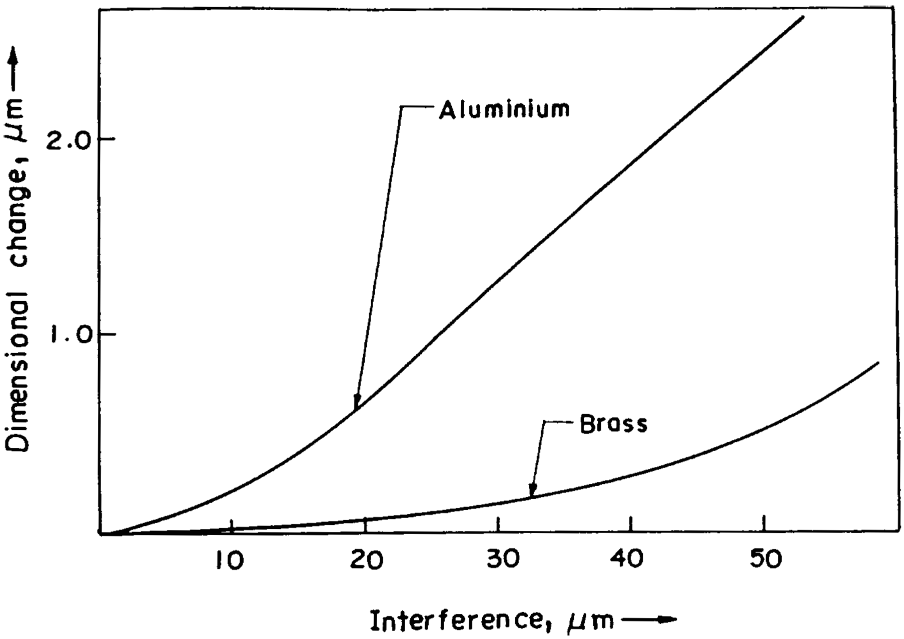

Fig. 8. Dimensional change due to burnishing for different interferences while broaching brass and aluminium.

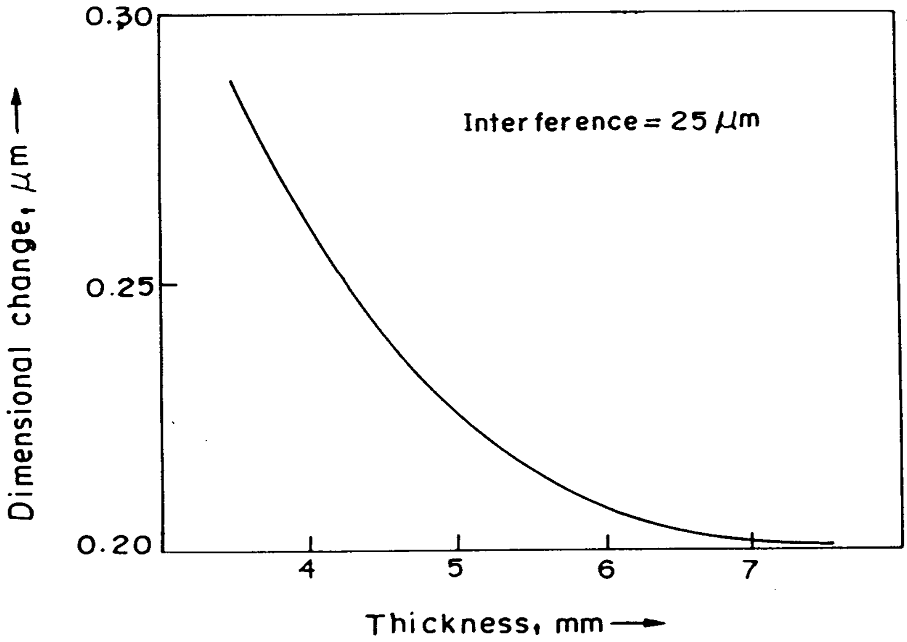

Fig. 9. Dimensional change due to burnishing for different thicknesses of the workpiece for a given load while broaching low carbon steel.

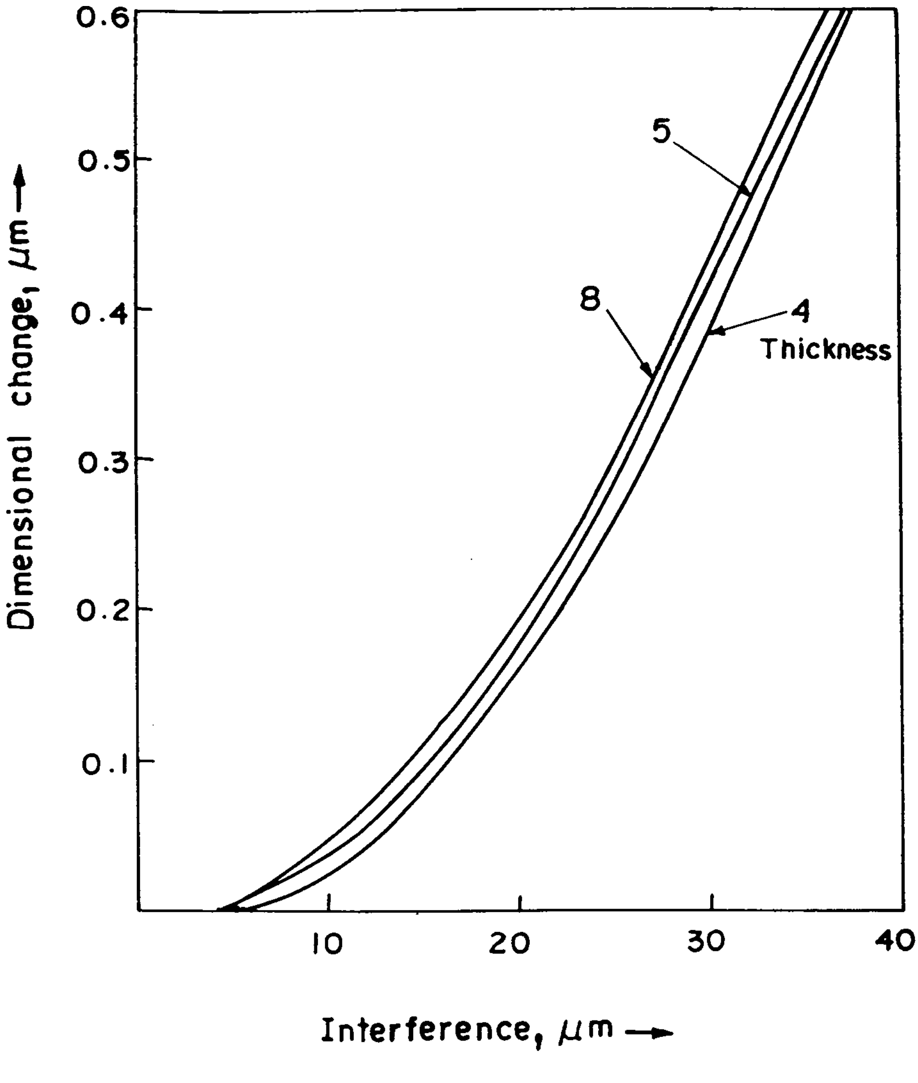

Fig. 10. Dimensional change due to burnishing for different values of interferences with different workpiece thicknesses while broaching low carbon steel.

3. CONCLUSIONS

Tool-work interfaces while burnishing have compressive stresses. Burnishing stresses on the tool and workpiece are very high at the tool-work interface and low at all other regions. Dimensional change in burnishing is proportional to the tool-work interface. The ratio of radial to axial force does not have much influence on the dimensional change due to burnishing. The dimensional change in burnishing is lower for brass and higher for aluminium than for steel for the same interference. The dimensional change in burnishing marginally increases with the thickness of the workpiece for a constant interference. The

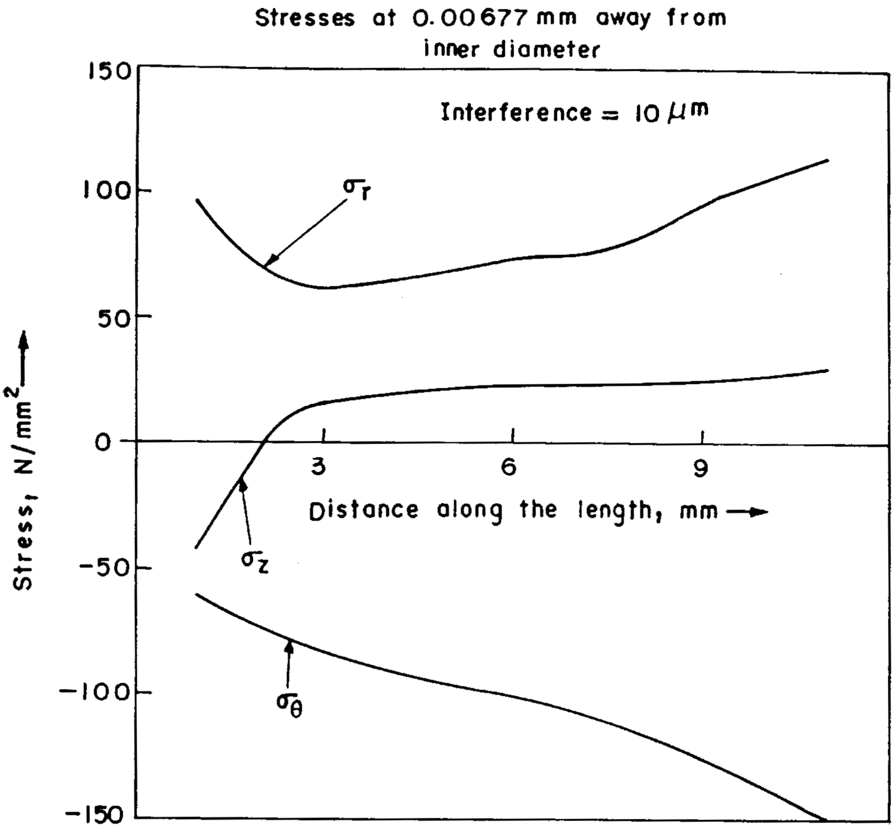

Fig. 11. Residual stresses along the length of the workpiece.

residual stresses along the length of the workpiece have positive values for σ_r and σ_z and negative values for σ_θ. The residual stresses are very high near the inner surface and drop to low values as the diameter increases.

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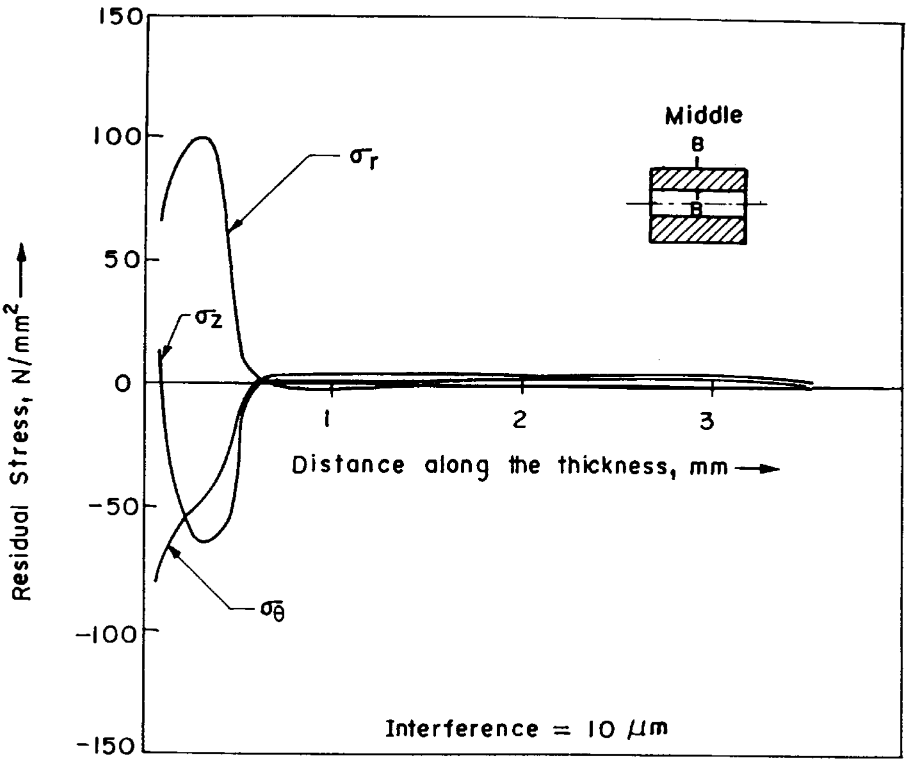

Fig. 12. Residual stresses along the thickness of the workpiece at section B–B.