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# DISTORTION OF LATTICE STRUCTURE OF METALS BY GRINDING

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We have studied the distortion of the structure of carbon steel U8 * caused by grinding on a large grinding machine under different conditions, with removal of 4, 10, 25, 37.5, 50 and 75$\mu$ by grinding at feeds of 2.1, 3.9, 7.8, 13, 24 and 49 mm (0.083, 0.15, 0.31, 0.51, 0.94, 1.93 in.)/revolution and cutting speeds of 30 m (98.5 ft) and 50 m (165 ft)/second.

Structural distortions were estimated from the changes in width and intensity of diffraction lines. The strain hardening of the metal surface after grinding was determined by microhardness measurements.

The X-ray study was made by the back-reflection method with cobalt radiation, and a special camera [1]. The diagrams were analyzed with an MF-2 microphotometer, by the defocussing method. Intensity curves were plotted in large magnification, 1 mm on the film corresponding to 50 mm on the microphotogram; the intensity heights were 0.1-100 mm.

In measuring the width and intensity of the (310) interference line, the K$\alpha$ doublet was resolved into its K$\alpha_1$ and K$\alpha_2$ components.

From a study of the surface of ground metals, it was established that production grinding is a hardening operation, for the microhardness increases 30-70%, depending on the grinding conditions. Presumably this hardening results from lattice distortions during plastic deformation of the surface. The occurrence of considerable distortion is also indicated by the 100-300% widening of the interference lines and by a 40-80% decrease in their intensity.

As the thickness of the layer removed by grinding increases from 5 to 75$\mu$, the width of the interference lines changes 18-100% depending on other grinding factors. The line width increased particularly strongly when the depth of grinding varied between 5 and 10 microns, pointing to considerable lattice distortion (Fig. 1). Under certain conditions, there was no increase in lattice distortion.

The elementary lattice distortions also increase with the grinding depth, as can be seen from the decrease in relative intensity (Fig. 2). The same sort of correlation is observed for the variation of the hardness with depth of cut (Fig. 3).

The effects of grinding conditions on lattice distortions amd microhardness can be explained on the basis of Maslov's [2] theoretical and experimental work. As the depth of cut increases, the thickness of the layer removed by the abrasive grains and the deforming forces increase, which results in greater breaking up and deformation of the blocks of crystallites and distortion of their elementary cells. Such changes increase the microhardness: the metal is strain hardened to an extent which increases with the magnitude of these distortions.

The dependence of distortion on the grinding depth is usually non-linear. Initially the distortions increase rapidly but beyond a certain depth the increase

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* 0.75-0.84% carbon, 0.20-0.40% manganese, 0.15-0.35% silicon; max 0.20% chromium, 0.25% nickel, 0.035% phosphorus, 0.030% sulfur).

slows down and sometimes ceases, because of softening by the high temperatures associated with deep cuts [3].

The results on iron specimens confirm that heat generation affects the degree of lattice distortion. In ground specimens of technical iron, the lattice distortions are stabilized at lower depths of grinding than in steel, since they are thermally less stable in the former and are relieved at lower temperatures [4].

Increase of the grinding speed from 30 to 50 m/sec. almost always lowers the crystallite and elementary lattice distortions (Fig. 1 and 2). The same is true for technical iron.

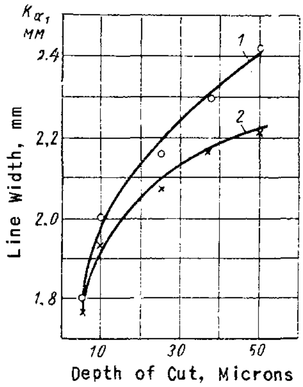


Fig. 1. Dependence of width of $K\alpha_1$ line on the depth of cut at (1) 30 m (100 ft)/second; (2) 50 m (165 ft)/sec. grinding speeds. [1 m/min; 77 rpm]*

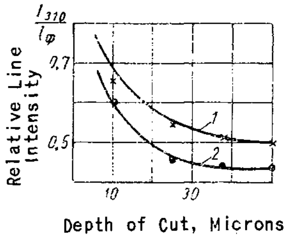


Fig. 2.

Fig. 2. Dependence of relative intensity of $K\alpha_1$ line on the depth of cut. 1 and 2: see Fig. 1. [1 m/min; 77 rpm].

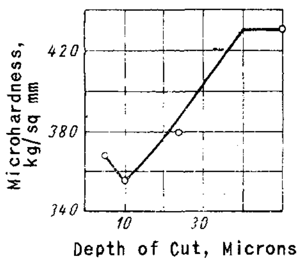


Fig. 3.

Fig. 3. Dependence of the microhardness on the depth of cut (1 m/min., 77 rpm).

The decrease of lattice distortions with increase of grinding speed can be explained as follows: at the higher speed, the cutting force and the thickness of the layer of metal (chip) removed by each abrasive grain are smaller [5]. This in turn causes less deformation and lattice distortion.

Table 1 (p. 20) shows width and relative intensities of the diffraction lines and the microhardness of steel and iron ground with different longitudinal feeds. There is very little change of line width: initially it rises, then becomes constant and at very great feeds decreases slightly. The latter can be attributed to thermal softening. It will also be seen that there is a small reduction of the distortions (relative intensity) as the longitudinal feed increases. This is true for steel U8 and technical iron alike.

The microhardness of ground steel and technical iron does not change when the longitudinal feed increases, whereas the lattice distortions change by 30-40%. This proves to some extent that lattice distortions are not always linearly related to the strain hardening.

Effect of Grinding Conditions on the Structural Distortion and Microhardness of the Metal Interior.

For this study, 6-8 layers of metal were etched away electrolytically. After

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* Translator's Note: Apparently feed and rpm of work, respectively.

each layer had been removed, the exposed metal was subjected to X-ray study and its microhardness was measured. From the resulting plots of width and intensity of the interference lines, and of the microhardness, against the thickness of the layer removed, we can make qualitative estimates of the degree of structural distortion and strain hardening under the ground surface.

Table 1. Width and Relative Intensities of Interference Lines for Different Longitudinal Feeds of Specimens

| Metal | Item | Feeds in mm/rev | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2.1 | 3.9 | 7.8 | 13 | 24 | 49 |
| Steel U8 | Line width in mm | 2.06 | 2.34 | 2.20 | 2.16 | 2.20 | 2.15 |
| | Relative intensity | 0.55 | 0.53 | 0.67 | - | 0.66 | 0.72 |
| | Microhardness* | 370 | 340 | 350 | 370 | 350 | 380 |
| Technical Iron | Line width, mm | 2.10 | 2.30 | 2.10 | 1.80 | - | 1.60 |
| | Relative intensity | 0.70 | 0.75 | 0.72 | 0.87 | - | 0.85 |
| | Microhardness * | 240 | 260 | 260 | 260 | 250 | - |

* kg/sq mm.

It was found that the thickness of the hardened layer, determined by microhardness measurement, was usually less than the thickness of the layer with a distorted structure, found by X-ray study. However, a determination of the maximum thickness of a distorted or strain-hardened layer is highly inaccurate. Because of the asymptotic character of the distribution curve, one cannot determine accurately the maximum thickness of the layer with a distorted structure. Hence, besides the maximum thickness of the distorted layer, we determined the thickness of the highly distorted layer, considering as 'highly distorted' layers which gave interference lines 50% wider than those from an annealed specimen. Because of the small errors in this method, we managed to establish the effect of technological factors on the depth of extensive strain hardening.

Figs. 4-6 show the variation of width and intensity of the interference lines, and also the microhardness of the layer, as a function of layer depth. As the

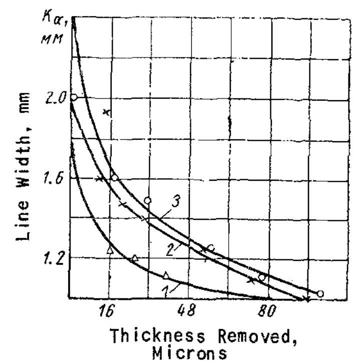


Fig. 4. Dependence of the $K\alpha_1$ line width on the thickness of the layer removed at different depths of cut: 1 = 5; 2 = 25, 3 = 50 $\mu$ (30 m/second, 1 m/minute, 300 rpm)

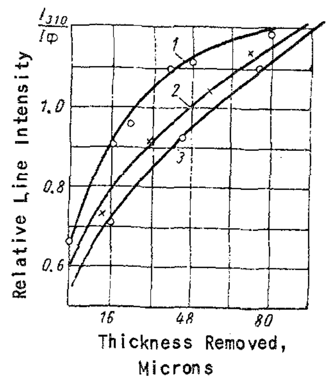


Fig. 5. Dependence of relative intensity of (310) line on the thickness of the layer removed, at depths of cut: 1 = 5, 2 = 25, 3 = 50 $\mu$

depth of cut increases, both the lattice distortions and the strain-hardening in the depth of the metal increase. Deeper cuts mean greater thickness of the strain-hardened and distorted layer; the depth of pronounced strain hardening always exceeds the depth of cut. These results contradict Marshall and Shaw's [6] finding that the depth of strain hardening is half the depth of cut. Since they estimated lattice distortions visually, the differences between their results and ours can be attributed to their experimental errors.

The considerable increase of depth and degree of strain-hardening with increase of grinding depth is due to the creation of deforming forces through increase of the chip thickness.

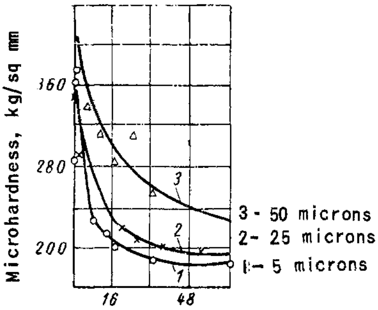


Fig. 6. Dependence of microhardness on thickness of layer removed at different depths of cut (1 m/minute, 30 m/second, 77 rpm).

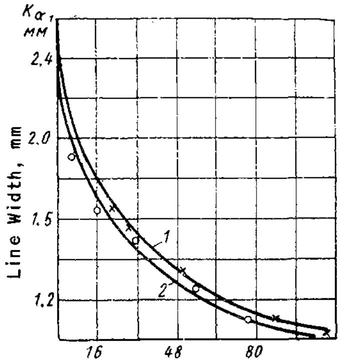


Fig. 7. Dependence of $K\alpha_1$ line width on the thickness of layer removed at: 1 - 30 m (100 ft), 2 = 50 m (165 ft)/second

The pattern of distribution of structural distortions and microhardness under the ground surface differs somewhat with the depth of grinding. At heavy cuts, there is smoother transition from the distorted surface layer to the undistorted. This is due to the relation between surface structural distortions and the depth to which they penetrate. With a greater surface distortion there is a greater thickness of distorted layer. This is true also for grinding at different speeds of the grinding wheel and table feeds.

When metal is ground at large longitudinal feeds, the thickness of the distorted layer is lower because of the heat generated under these conditions. This accounts for the smooth change-over from distorted to undistorted layer at fast feeds.

Great attention was paid to a study of the effect of grinding speed on the lattice distortion of the interior metal. Fig. 7 shows the distortion distribution for grinding at high (50 m (165 ft)/second) and ordinary speeds (30 m (100 ft)/second). The distribution of distortion within the metal is practically the same in both cases.

In high-speed grinding, cutting is facilitated by the thinner chips removed by the abrasive grains. This to some extent lowers the surface structural distortion. However, the pattern of distribution of distortion within the metal remains the same.

These results show that in high-speed grinding, the structural distortion in the surface layer is decreased not by thermal softening, but by lower cutting (deforming) forces. The grinding depth is therefore the main factor controlling the thickness of the distorted layer (from 10 to 100-120$\mu$).

Protuberances and the metal lying immediately below them, up to 10$\mu$ thick, are most strain hardened.

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