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Surface damage in machining red brass

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The effect of cutting speed, tool rake angle, and wearland length on the nature of the surface generated in machining annealed red brass under unlubricated and lubricated conditions is studied. The machined surfaces are examined using optical and scanning electron microscopy. The machined surfaces were observed to have defects such as microcracks and macrocracks perpendicular to the direction of relative work-tool motion, cavities and plastically deformed regions. The surface damage decreases with an increase in the cutting speed and/or the positive tool rake angle. The presence of lubricant in the cutting region results in a surface of high quality.

1. Introduction

Machining metals consists of the removal of layers of the material from the workpiece in the form of chips by the action of a wedge-shaped cutting tool. The chips are formed as the material is sheared in the deformation zone [1]. The type of chip produced has a controlling influence on the condition of the surface generated. The discontinuous formation of a chip, for example, results in a machined surface which contains severely deformed areas, microcracks and macrocracks, cavities, etc. Continuous chip formation, on the other hand, produces a smooth surface.

The process of machining metal is complex. The type of surface generated depends on several variables; the work and tool materials, tool geometry, cutting speed, feed, the presence or absence of a lubricant in the cutting region, etc. Previous investigations have shown that in the machining of metals a damaged surface region is produced that is different from the bulk of the material [2–8]. The damage in the surface region consists of plastic deformation, which is a result of the interaction between the nose region of the tool and the machined surface of the workpiece. The nose region includes the cutting edge and the land and rake face of the tool. The machined surface of the material contains residual stress, the magnitude and nature of which depends on the parameters mentioned above. The geometric defects in the surface consist of grooves parallel to the direction of relative tool motion, fine scale chatter marks, cavities, surface roughness and other stress risers. The presence of a lubricant in the cutting region usually results in a considerable reduction in the surface and subsurface damage [9, 10].

The failure of machined parts in service is invariably due to creep, fatigue and stress corrosion. Such failures start as a small crack at the surface of a component which propagates to the core and leads to sudden failure. These failures depend very sensitively on the quality of the surface [11–13]. Therefore, it is important that the impact of machining on the condition of the surface generated be understood so that remedial manufacturing procedures can be introduced to reduce service failures.

The object of the present investigation was to determine the effect of cutting speed and tool geometry on the nature of the surface generated for annealed red brass when machined orthogonally under dry unlubricated conditions.

2. Experimental work

The work material of red brass (85% copper and 15% zinc), which was received in the form of a tube, was cut into small rings of outside diameter, 3 in. (7.62 cm); inside diameter, 2.25 in.

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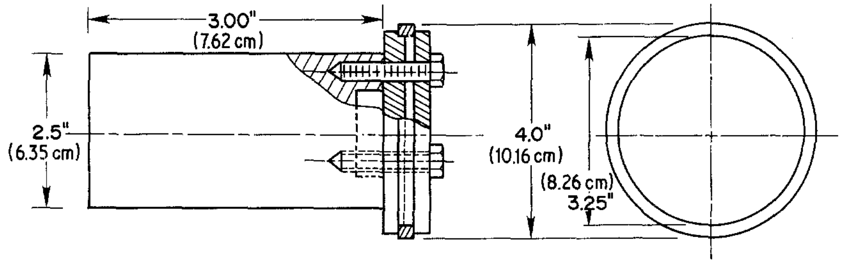

Figure 1 Work specimen and mandrel.

(5.71 cm); and width, 0.063 in. (0.16 cm). The workpiece geometry and the mandrel used for holding it while machining are shown in Fig. 1. The work material was used in the fully annealed condition in this study. The rings were heated to 1200° F (~649° C) and held for 0.5 h, then air cooled to room temperature.

The tool material, as recommended by the Metcut Research Associates [14] and the American Society for Metals for machining brass, was high speed steel. The tool tips were ground to rake angles of 15°, 20°, 25° and 30° and a common clearance angle of 5°. Artificial wearlands of 0.005, 0.010 and 0.020 in. (0.013, 0.254 and 0.050 cm) length were ground on the flank face of the tool. Tools with zero wearland length were also used. Fig. 2 shows the tool geometry and other details of the cutting region.

All the cutting tests were carried out on a Cincinnati 17 in. Hydroshift Lathe. The lathe is equipped with a tachometer generator and a variable speed adjuster. A wide range of spindle speeds from 5 to 1500 rev min^{-1} and the feed rates in the range from 0.001 to 0.060 in. rev^{-1} (0.003 to 0.15 cm rev^{-1}) can be obtained. The tests were conducted for both lubricated and unlubricated conditions. A highly chlorinated water soluble oil (Key-cut-Keystone) was used as the cutting fluid. A constant feed rate of 0.010 in. rev^{-1} (0.025 cm rev^{-1}) was used throughout the work. This feed rate gave a ratio of the width to the depth of cut of 12:1, which should be sufficient to ensure plane strain deformation.

Table I shows a summary of cutting conditions which were used during the investigation.

The workpieces were machined under steady orthogonal cutting conditions. The cutting action was suddenly stopped, leaving the chip attached to the workpiece. Small pieces measuring approximately 1 in. (2.54 cm) long were cut from the machined workpiece, and the surfaces were prepared for examination with optical and scanning electron microscopes.

3. Results and discussion

Figs. 3 and 4 show the surfaces produced when machining annealed material with a sharp tool having rake angles of 15° and 25°, respectively, and no wearland under dry cutting conditions at a feed rate of 0.010 in. (0.025 cm) and cutting speed of 25 ft min^{-1} (12.7 cm sec^{-1}). Figs. 4 and 5 show the effect of artificially ground flank

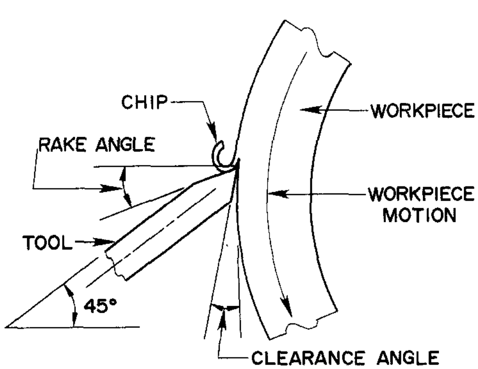

Figure 2 Orthogonal cutting.

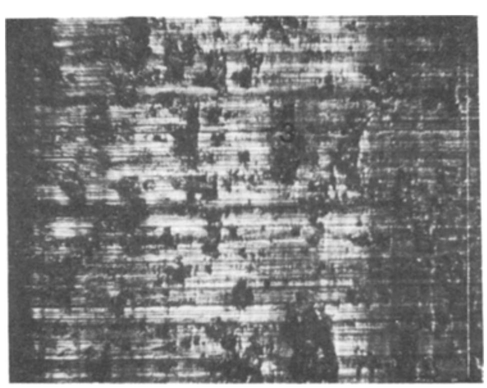

Figure 3 Optical micrograph of machined surface. Cutting speed 25 ft min^{-1} (12.7 cm sec^{-1}); wearland length 0.000 in.; rake angle 15°; dry cutting. ×25

TABLE I Summary of test conditions*

Rake angle (deg)	Combinations tested for the following cutting speeds				Tool wearland (in.) (cm)
	12.5 ft min^{-1} (6.35 cm sec^{-1})	18.5 ft min^{-1} (9.4 cm sec^{-1})	25.0 ft min^{-1} (12.7 cm sec^{-1})	30.0 ft min^{-1} (15.24 cm sec^{-1})	
15	●	●	●	●	0.000
			●		0.005 (0.013)
			●		0.010 (0.025)
			●		0.020 (0.051)
20	●	●	●	●	0.000
			●		0.005 (0.013)
			●		0.010 (0.025)
			●		0.020 (0.051)
25	●	●	●	●	0.000
	●	●	●	●	0.005 (0.013)
	●	●	●	●	0.010 (0.025)
	●	●	●	●	0.020 (0.051)
30	●	●	●	●	0.000
			●		0.005 (0.013)
			●		0.010 (0.025)
			●		0.020 (0.051)

*●, combinations tested; material, red brass; feed, 0.010 in. rev^{-1} (0.025 cm rev^{-1}); width of cut, 0.125 in. (0.32 cm); tool material, high speed steel; clearance angle, 5°; heat treatment, annealed to a hardness of 102 HV; lubricant, oil.

wearland on macrostructure of surfaces machined with a sharp tool having a rake angle of 25° at a cutting speed of 25 ft min^{-1} (12.7 cm sec^{-1}). Figs. 4 and 6 show the effect of cutting speed on the surface generated when machined with a sharp tool having a rake angle of 25° and wearland length of 0.000 in.

It is observed that the surfaces consist of chatter marks, perpendicular to the direction of relative work-tool motion, long straight grooves, parallel to the direction of relative work-tool motion, areas of microcracks and macrocracks, etc. Surface damage at various cutting conditions depends upon the type of chip produced and the flow of material. There are mainly two kinds of chip formation, namely continuous chip formation and discontinuous chip formation, and sometimes a combination of them which depend on change in a selected cutting parameter. A wide variety of surface damage can be generated with a change in one of the parameters. It is seen that the surface generated with continuous chip formation in the absence of built-up edge is of a better quality (smooth and regular in appearance) than that generated with discontinuous chip formation. The amount

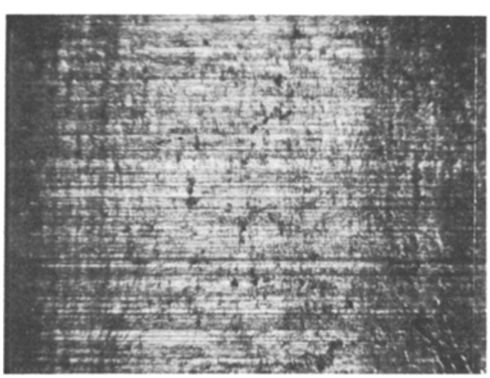

Figure 4 Optical micrograph of machined surface. Cutting speed 25 ft min^{-1} (12.7 cm sec^{-1}); wearland length 0.000 in.; rake angle 25°; dry cutting. ×25

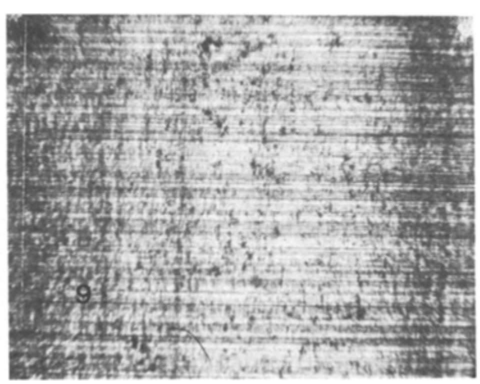

Figure 5 Optical micrograph of machined surface. Cutting speed 25 ft min^{-1} (12.7 cm sec^{-1}); wearland length 0.020 in. (0.051 cm.); rake angle 25°; dry cutting. ×25

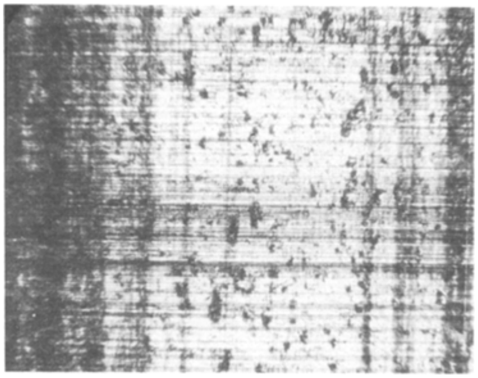

Figure 6 Optical micrograph of machined surface. Cutting speed 12.5 ft min^{-1} (6.35 cm sec^{-1}); wearland length 0.000 in.; rake angle 25°; dry cutting. × 25

of side spread, in spite of orthogonal cutting conditions maintained in machining, affects the quality of machined surface and shows the generated surface with rough and irregular finish.

The macrostructure inspection of the machined surface reveals that the surface generated with a sharp tool having a rake angle of 25° at a cutting speed of 25 ft min^{-1} (12.7 cm sec^{-1}) has a better quality with less surface damage than that produced with tools of various other rake angles.

The general growth of wearland in the cutting tool shows evidence of unsteady cutting conditions in metal surface deformation. A high quality surface generated under a sharp tool having a wearland of 0.020 in. (0.51 cm) and

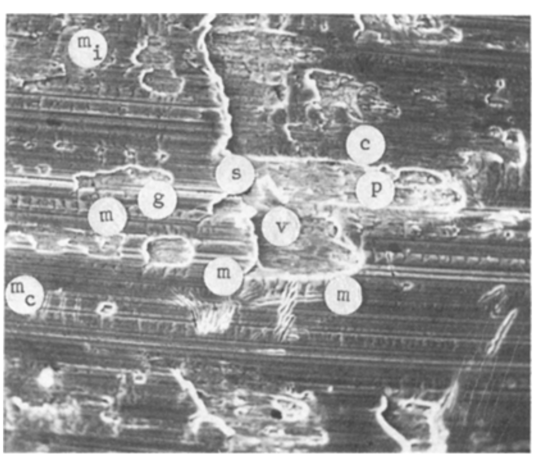

Figure 7 Scanning electron micrograph of machined surface. Cutting speed 25 ft min^{-1} (12.7 cm sec^{-1}); wearland length 0.000 in.; rake angle 15°; dry cutting. × 3000

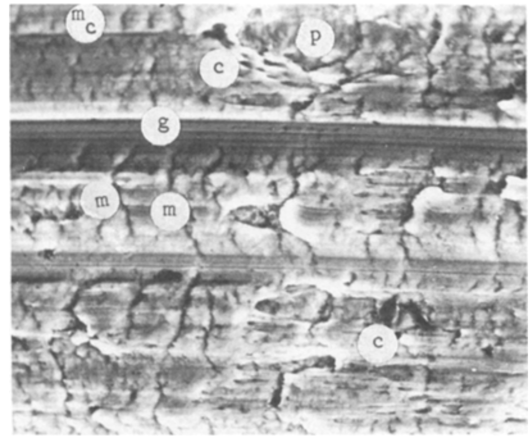

Figure 8 Scanning electron micrograph of machined surface. Cutting speed 25 ft min^{-1} (12.7 cm sec^{-1}); wearland length 0.000 in.; rake angle 20°; dry cutting. × 1000

rake angle of 25° at a cutting speed of 25 ft min^{-1} (12.7 cm sec^{-1}) can be seen in Fig. 5. This is because of the existence of constant friction between the tool and the machined surface in the primary zone.

Cutting speed is one of the most influential parameters in the generation of high quality surfaces. The results of this investigation show that the surfaces generated at the various cutting speeds selected in this work are similar in appearance, with grooves in the direction parallel to the relative work-tool motion, a small number of chatter marks in the direction perpendicular to tool motion, and micro and macro coarse scale cracks and fine scale cracks. It is very difficult to make any conclusion on the macrostructure of a surface machined in a small range of cutting speeds.

The surfaces generated at various cutting conditions were examined under the scanning electron microscope for studying the effect of tool geometry and cutting speed on surface appearance and variation in the structure of machined surfaces. Figs. 7 to 10 show a selection of surfaces generated with sharp tools having various rake angles and no wearland length at a cutting speed of 25 ft min^{-1} (12.7 cm sec^{-1}) under dry cutting conditions. It can be seen that the surface consists of well-defined long, straight, deep grooves (g) parallel to the direction of relative work-tool motion and small cavities (c) where small segments of the workpiece have been removed from below the general level of the surface. Several microcracks (m) can also be

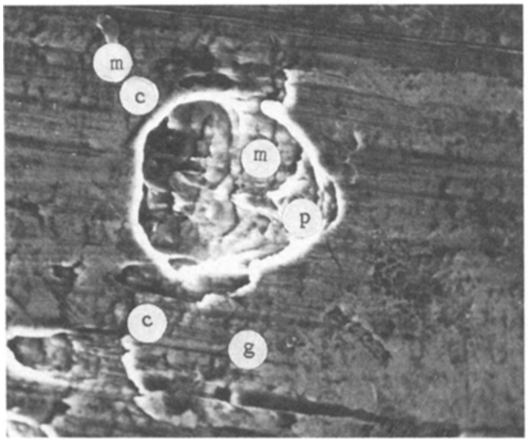

Figure 9 Scanning electron micrograph of machined surface. Cutting speed 25 ft min^{-1} (12.7 cm sec^{-1}); wearland length 0.000 in.; rake angle 25°; dry cutting. × 1000

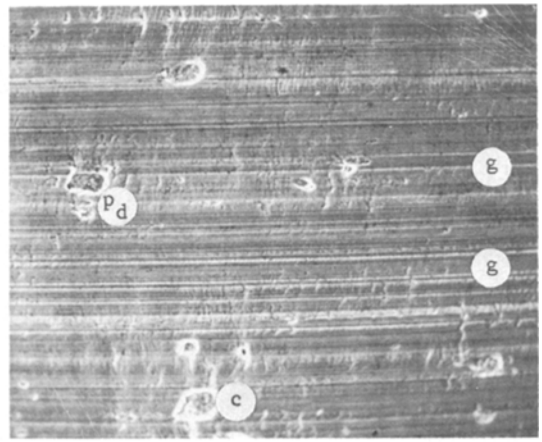

Figure 11 Scanning electron micrograph of machined surface. Cutting speed 25 ft min^{-1} (12.7 cm sec^{-1}); wearland length 0.000 in.; rake angle 25°; dry cutting. × 300

seen in the direction perpendicular to the relative work-tool motion.

Fig. 7 shows a cavity (c) generated in the surface. It can be seen that the cavity is severely plastically deformed with steps irregularly terraced. It also shows that voids (v) are formed in the cavity. The micro chatter cracks (m_i) can be identified in isolated areas in the surface. Fig. 8 shows that an increase in positive rake angle from 15° to 20° produces a surface which possesses microcracks in the direction perpendicular to the relative work-tool motion. The severity of microcracks is seen in the region where the surface grooves deeply penetrate below the general level of the surface. It is also seen that the crack generally initiates at the side

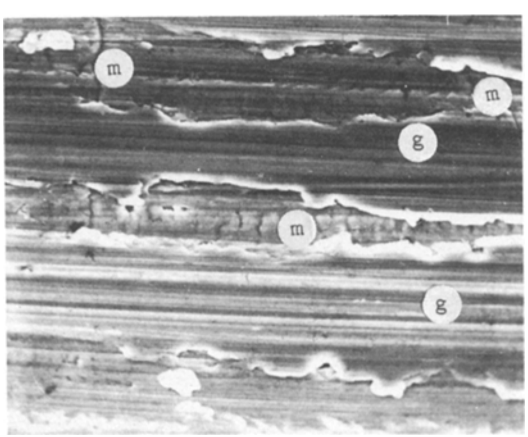

Figure 10 Scanning electron micrograph of machined surface cutting speed 25 ft min^{-1} (12.7 cm sec^{-1}); wearland length 0.000 in.; rake angle 30°; dry cutting. × 3000

surface of grooves. The surface shows the evidence of cracks, cavities and micro chatter marks.

In Fig. 9 it can be seen that the nature of the cavity is severely plastically deformed (p). The surface of the cavity shows that the surface consists of severe cracks which are very similar to the cracks exposed in the free level of the surface. In Fig. 10 it can be seen that the surface shows evidence of microcracks which are less severe in nature. This is due to less deformation of the machined surface under a sharp tool having a larger positive rake angle. It can also be seen that the grooves are poorly defined.

In general, the machined surface generated with a sharp tool having a reduced positive rake angle shows a severe deformation of surface with well-defined grooves, cavities and coarse and fine scale surface damage. An examination of the surface of material machined with a sharp tool having a high positive rake angle shows a reduction in the amount of cavities, grooves and cracks. The surface appears to be better in quality with less deformed surface layer. The examination of surfaces machined for various cutting conditions shows the evidence of severe side spread in the surface at all rake angles of cutting tools selected in this investigation, in spite of orthogonal plane strain cutting maintained in machining.

Severe changes in the characteristics of the fine and coarse scale surface damage were seen with changes in tool wearland length at a given cutting speed. Figs. 11 and 12 show the effect of

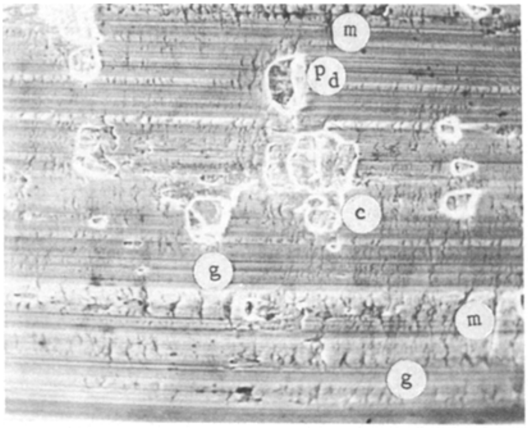

Figure 12 Scanning electron micrograph of machined surface. Cutting speed 25 ft min^{-1} (12.7 cm sec^{-1}); wearland length 0.020 in. (0.051 cm) rake angle 25°; dry cutting. × 300

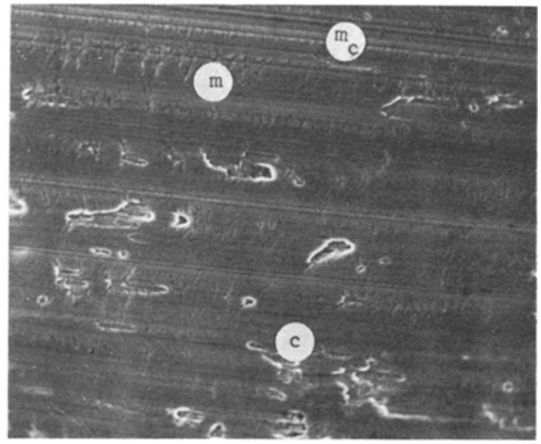

Figure 13 Scanning electron micrograph of machined surface. Cutting speed 12.5 ft min^{-1} (6.35 cm sec^{-1}); wearland length 0.000 in.; rake angle 25°; dry cutting. × 300

tool wearland length on the surface damage. It can be seen that the damage in the machined surface increases as the wearland length is increased.

In general, it was found that an increase in the cutting speed produced a decrease in the amount of fine scale surface damage in terms of both intensity and the area affected. Figs. 9 and 13 to 15 show the effect of cutting speed on the quality and nature of the surface generated. Fig. 14b shows an enlarged photograph of a cavity shown in Fig. 14a. Severe cracks can be seen at a cutting speed of 18.5 ft min^{-1} (9.4 cm sec^{-1}). It can be concluded that grooves are very well defined and that the cavities and cracks are small at all cutting speeds. The surface damage decreases as the cutting speed is increased.

Cutting tests were conducted using the lubricant over the range of the cutting conditions stated in Table I. The machined surfaces were in general very smooth with little evidence of grooves, cracks, and cavities. The presence of lubricant in the cutting region results in a condition of sliding friction between the tool and the workpiece surface. The formation of chips is continuous. Consequently, the damage in the surface region is minimal.

4. Conclusions

The following conclusions are drawn from the results of the investigation.

(a) In the machining of red brass, a variety of surface defects such as microcracks and macro-

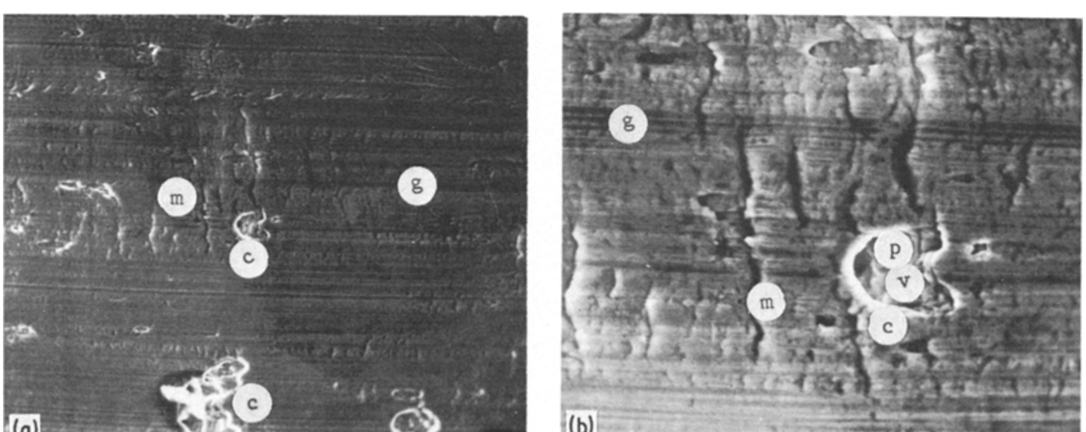

Figure 14 Scanning electron micrographs of machined surface. Cutting speed 18.5 ft min^{-1} (9.4 cm sec^{-1}); wearland length 0.000 in.; rate angle 25°; dry cutting. (a) × 300; (b) × 1000.

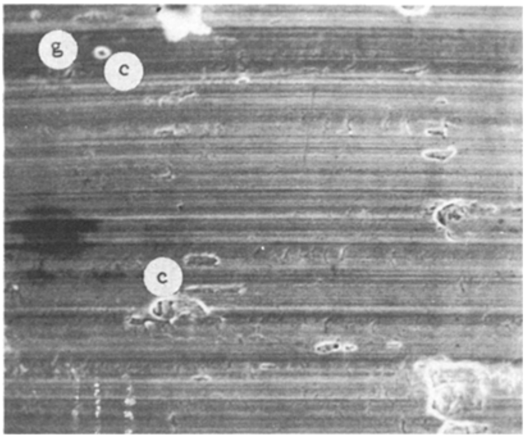

Figure 15 Scanning electron micrograph of machined surface. Cutting speed 30 ft min^{-1} (15.24 cm sec^{-1}); wearland length 0.000 in.; rake angle 25°; dry cutting. × 300

cracks perpendicular to the direction of relative work tool motion, long straight grooves parallel to the direction of work tool motion, large cavities, and plastically deformed areas are generated.

(b) When machining at a given cutting speed with the tool at various rake angles it was observed that the surface damage is large at low rake angles and decreases as the rake angle is increased.

(c) When machining at various cutting speeds with a tool of given geometry, it was observed that the surface damage was high at low cutting speed and decreased as the cutting speed is increased.

(d) The surfaces generated using a lubricant while machining are in general very smooth with poorly defined cracks, grooves, and cavities.

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