

Machining Properties of Platinum

SUPERIOR PROCESS RESULTS FROM WEAR INVESTIGATIONS

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Platinum is usually considered to be a ductile workable metal readily fabricated by all the usual processes; it is therefore somewhat surprising to discover that the machining of platinum by conventional techniques results in rapid and extensive tool wear, with consequent deterioration of the surface finish imparted to the platinum article. This paper reports the results of an investigation into the behaviour of platinum during machining and the mechanisms by which the tool becomes worn. In addition the techniques devised to alleviate these phenomena, such as preferred tool materials and configurations, are described.

To the platinum fabricator his material presents an enigmatic mixture of characteristics; its strength and ductility coupled with its high melting point and tarnish resistance makes many operations such as forming and soldering straightforward. However, others such as wire drawing can result in extensive, and often rapid, tool or die wear. These characteristics of platinum and high platinum alloys have been highlighted recently as, in anticipation of an increasing demand for platinum jewellery, attempts have been made to apply the techniques normally used by manufacturing jewellers for carat golds and silver to these platinum materials. One such technique, using a specifically shaped diamond tool on a small lathe, enables many thousands of gold and silver items to be gloss turned to an excellent surface appearance, superior in both topography and finish to that produced by traditional hand polishing techniques, Figure 1. This high quality finish is imparted to the surface of less than ten platinum items before wear of the diamond tool causes surface deterioration to the extent that the product is no longer acceptable to either the manufacturer or the customer. In addition there is considerable evidence from our own workshops that any turning of

platinum with either tool steel or cobalt bonded tungsten carbide tools results in severe tool wear problems.

To attempt to explain this apparent incompatibility between tool and platinum during machining and to establish improved techniques for platinum, a wide ranging investigation has been made of platinum machining and the properties related to it. In conjunction with the particular experimental techniques described, extensive use has been made of optical-, interference- and scanning electron-microscopy for the examination of cutting tools and of the machined surfaces and swarf produced. In addition Talysurf measurements have enabled an assessment of surface finish to be made. Some of the findings of this investigation are reviewed in this paper.

It is perhaps hardly necessary to mention that the machining of a metal by turning in a lathe is fundamentally an extremely complex process embracing many varied phenomena. Frequently small adjustments in one particular machining parameter can change the tool wear rate by an order of magnitude. Further, although tool wear can be caused by mechanical processes such as abrasion, adhesion or fretting, there are examples of

Fig. 1 One of the more obvious applications for the improved machining techniques which have been developed is in jewellery manufacture. These gloss turned and diamond milled rings show the high quality of the finish which can be imparted to the platinum surface by a diamond tool



such wear occurring through chemical interaction between the workpiece and the tool. When considering the machining of platinum, however, four factors emerge as probable prominent contributors to tool wear. These are:

1. The promotion of a transition reaction, for example, diamond \rightarrow graphite, tungsten carbide \rightarrow tungsten + carbon
2. The affinity of platinum for carbon
3. The physical and mechanical properties of platinum
4. The generation of high temperatures at the tool/workpiece interface.

Platinum Carbon Interactions

An obvious link between diamond, tungsten carbide and tool steel, the three tool materials initially examined, is the presence of carbon in each; therefore when the metastable nature of diamond under ambient conditions and the well-documented catalytic properties of platinum were also taken into account it appeared that chemical factors could have a significant influence on tool wear.

However, these theories were not supported by the results of several experiments where platinum-diamond powder mixes were heated to temperatures in excess of 700°C in air or in vacuum. Neither was there any evidence from these tests to suggest that platinum promoted the diamond oxidation reaction.

While the solubility of carbon in solid platinum is very low, considerable amounts dissolve in liquid platinum, suggesting that the carbon affinity of platinum is higher than that of gold. It was thought feasible that carbon could diffuse from the tool into the platinum workpiece, thus causing the severe tool wear which was observed. However, when a platinum bar containing a saturated solution of carbon was diamond machined the wear on the tool was not reduced by the presence of carbon in the workpiece. Furthermore, an evaluation of the wear characteristics of carbon-free materials such as alumina, sapphire and boron nitride when employed for the machining of platinum supported these results and indicated that the wear mechanisms were unlikely to be directly influenced by the presence of carbon, in any form, in the tool material. These results are discussed in more detail later in this paper.

Friction and Wear Studies

There is clearly a link between the physical and mechanical properties of platinum and the generation of high temperatures at the tool/workpiece interface. Heat production during a machining operation is a well known phenomenon and in fact most of the work done appears as heat, generated mainly in the shear zone of the chip as it separates from the workpiece (1). Additional heat is also produced by friction during the interactions

Table I
Coefficient of Friction Determinations for Diamond on Platinum
and Diamond on Gold

Couple	Finish on Test Surface	Lubricant	Speed mm/s	Coefficient of Friction
Diamond on Platinum	Unpolished	None	0.5	0.13
	Unpolished	None	2.0	0.15
	Unpolished	Gelatine	2.0	0.14
	Polished	None	0.5	0.14
	Polished	None	2.0	0.17
	Polished	Paraffin-based Cutting Oil	0.5	0.15
Diamond on Gold	Unpolished	None	0.5	0.14
	Unpolished	None	2.0	0.13

which take place between the workpiece and the front face of the tool and between the chip and the top face, Figure 2. Some further basic studies were therefore completed prior to examining the basic parameters of the machining process in detail.

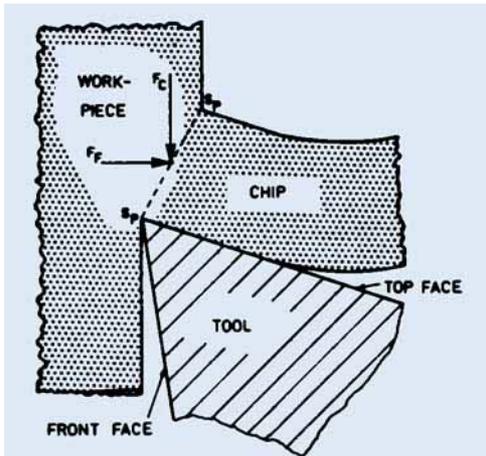
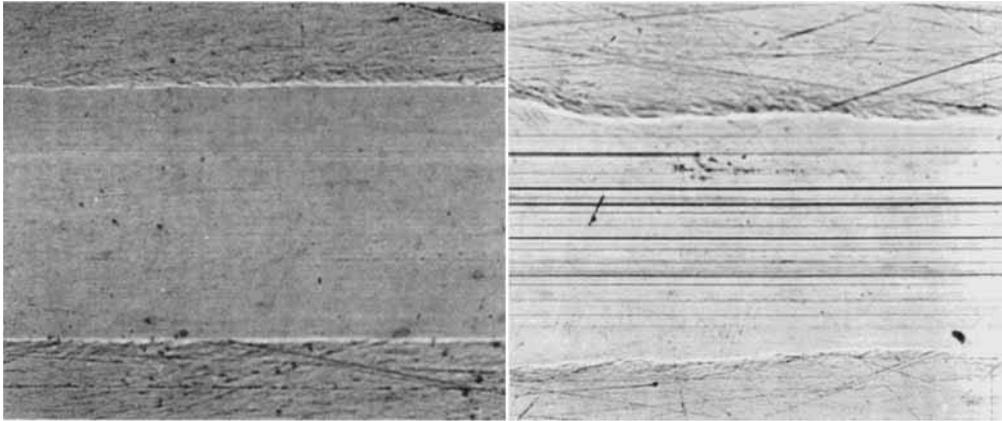


Fig. 2 Schematic diagram of the tool/workpiece interface showing the shear planes of the chip and the two main forces acting on the tool
 F_C - Cutting force; F_F - Feed force;
 S_P - Shear Plane

The coefficient of friction between the material and the cutting tool can affect the cutting process, and hence an abnormally high coefficient between diamond and platinum could contribute to machining problems. Measurements were therefore made with diamond/platinum and, for comparative purposes, diamond/gold couples. The frictional forces were determined as a hemispherical diamond, of 1 mm radius, was drawn across the degreased metal surface under a series of applied loads in the range 50 to 1500 grams. The results obtained are summarised in Table I. Clearly, the differences in coefficient of friction are small and insufficient to account for any marked difference in machining characteristics.

The platinum and gold used for these friction determinations were both relatively soft with low yield points and under the heavier applied loads grooving of the surface occurred. Examination of these grooves showed that those formed on gold were smooth with straight parallel edges, Figure 3(a), while those formed in the platinum had irregular edges and scouring in the grooves, with the score marks sharply defined, Figure 3(b). Occasionally these score marks



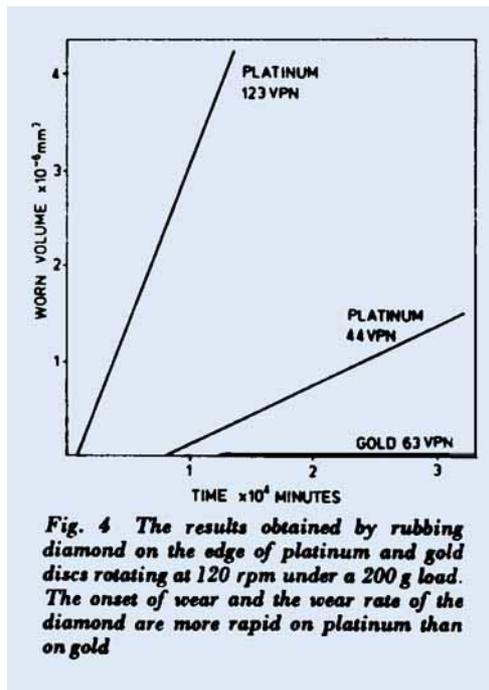
Figs. 3 (a) and (b) Grooves produced on gold (left) and platinum (right) surfaces during the coefficient of friction evaluations. The specific nature of the differences produced in these simple friction tests is typical of the behaviour patterns of the two metals in subsequent wear and machining trials × 350

would terminate in a small pile of debris. Electron probe microanalysis of this debris detected no element other than platinum and it is therefore concluded that the score marks are evidence of localised platinum to diamond adhesion.

In a second study, the wear of diamond when rubbed with platinum or gold was measured directly by the technique described by Hirst et al (2). In these tests a diamond with a flat face, 2 mm square, was pressed against the rounded edge of a platinum or gold 21 mm diameter disc rotating at 120 rpm. Then, using interferometry, the dimensions of the wear scar and hence the volume of material removed were determined.

The relationship between the volume of the wear scar and time of rubbing for both work-hardened and for annealed platinum is shown graphically in Figure 4. Initially no wear takes place, and this is believed to be due to the build-up of internal stress in the surface of the diamond, but after this induction period wear progresses linearly. Clearly, annealed platinum has a longer induction period and slower wear rate than the work-hardened metal. The very low wear rate for gold, in spite of this sample being harder than annealed platinum, is well illustrated, the

steady state wear rate being about two orders of magnitude less than for platinum. Under the conditions of this wear test, temperature effects are likely to be small compared with those of the machining operation, so the heavy wear of the diamond which takes place



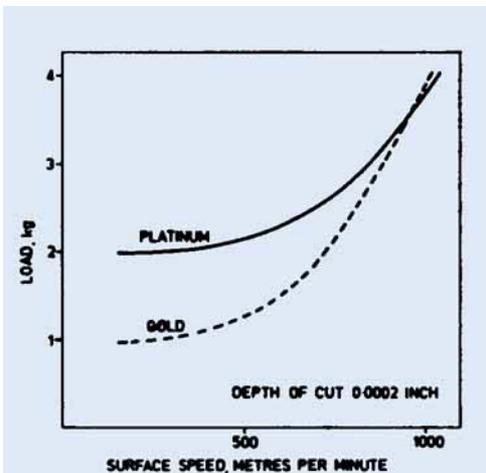


Fig. 5 The effect of workpiece surface speed on the cutting force acting on the tool. The heat generated at high speeds caused the surface of the gold test piece to smear and resulted in extremely high tool loadings

when it is rubbed against platinum suggests that factors other than temperature are responsible.

Effect of Machining Parameters

Considering now the basic machining process, it is clear that the forces acting on the tool are related to the work done in machining, thus minimising these forces would be expected to reduce tool wear. Measurement of the tool forces gives a quantitative parameter which enables the effect of numerous variables in the machining process to be assessed rapidly and conveniently.

The forces operating on the tool may be resolved into three orthogonal components. The radial force acting at right angles to the surface being machined is generally accepted as being of little significance; therefore in the present work only two of the component forces were measured: the tangential or cutting force which operates in the direction of motion of the workpiece and the feed force which opposes the motion of the tool as it traverses the workpiece.

The sensors and associated equipment for the requisite force measurements were mounted on a small precision lathe. High quality crystal pick-up heads were used for sensing the tool deflection and the output was fed through suitable amplifiers to a cathode-ray oscilloscope or to chart recording equipment. The units were calibrated for each tool used by applying a range of known loads both in the vertical (cutting) and horizontal (feed) directions and noting the corresponding trace on the oscilloscope or chart recorder.

Using this equipment, cutting force measurements were made for a variety of tool materials, lubricants and tool geometries. The feed force, although also recorded, proved to be a less sensitive indicator of machining conditions than the tangential cutting force, and hence only the latter has been considered in detail in this paper. Large differences were observed in the behaviour of platinum and gold and much of the work has involved a comparison of the behaviour of these two metals.

Initially the effect of various machining parameters, such as cutting depth and surface speed, on tool forces was examined for both annealed gold and platinum, using a tungsten carbide tool of standardised configuration. For the test with platinum it was found necessary to regrind the tool several times. Changing the depth of cut from 0.005 mm to 0.05 mm resulted in a four-fold increase in the cutting force for both platinum and gold.

There are well established optimum cutting speeds for many of the metals and alloys that are machined; these offer the considerable advantages of minimising tool wear and improving surface finish without inducing unnecessarily high tool forces into the machining operation. Trials made with a tungsten carbide tool taking small depths of cut from workpieces rotating at all the surface speeds available showed that the forces increase with speed for both platinum and gold, Figure 5. At the higher speeds the forces generated during the machining of gold were greater than those associated with

platinum, and this is thought to be due to the tendency of gold to smear at the tool/workpiece interface under these conditions. Evidence of adhesion between platinum and the tool was obtained during these trials; Figure 6 shows a tungsten carbide tool to which the platinum chip was adhering despite the pressure of swarf build-up behind it.

These results indicate that both increased cutting depth and surface speed result in higher rates of tool wear and higher tool forces without improving the surface finish of the workpiece.

In further studies the effects of turning fine gold and annealed platinum bars using a cobalt-bonded tungsten carbide tool without a lubricant were investigated. After twelve cuts of 0.005 mm over a 19 mm length of 11.7 mm diameter platinum bar, the tungsten carbide tool had worn severely and the associated deterioration in surface finish indicated that the tool was no longer cutting the platinum. The tool forces were found to increase significantly as the cutting operation proceeded. A similar trial on a gold bar showed negligible tool wear, a good surface finish and no increase in cutting forces.

This machining resulted in an increase in the hardness of the platinum surface from 45 to 180 VPN, while gold only hardened from 25 to 56 VPN. Metallographic examination of a section of the platinum bar showed a severely fragmented layer adjacent to the surface with a microhardness of 210 Hv, Figure 7, and the deformed zone beneath this layer gave values between 130 and 190 Hv. These hardness values are extremely high for platinum—for example the hardness of 90 per cent cold worked platinum is only 130 Hv—and indicate the degree of strain that may occur in the surface layers during machining.

Scanning electron-microscope examination of the platinum swarf produced during these tests showed that severe chip compression had occurred, Figure 8(a). This may be compared with the gold swarf where the compression is much less, Figure 8(b). Such compression results from a stick/slip reaction

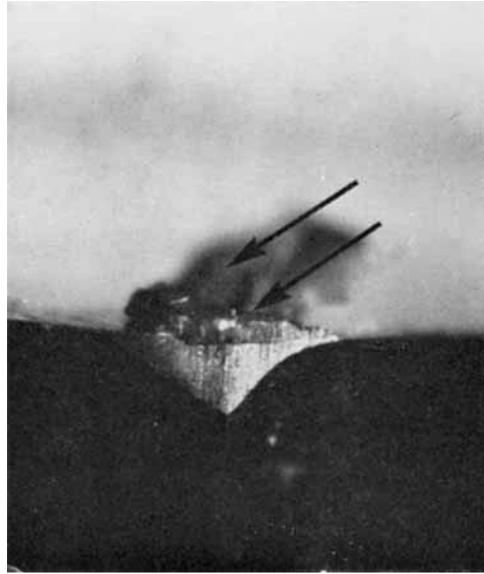


Fig. 6 An extreme instance of the adhesion of a massive chip of platinum (indicated) to the tungsten carbide tool at high workpiece surface speeds $\times 25$

created by the chip initially adhering to the top face of the tool but then being sheared from the surface of the tool by the pressure of the oncoming chip. In severe instances particles of tool material can be removed as the adhering chip is sheared away and this results in adhesive wear of the tool.

Similar tests using high-speed steel tools also supplied evidence of this wear mechanism. A scanning electron microscope examination of such a tool used for machining platinum showed the basic features of fine grooving down the front face and a swarf scar on the top rake. Further investigation of the scar on the top face showed that particles had been pulled out of the steel by the platinum chip and then had dragged across the surface of the tool, Figure 9. The wear scar on the front face was grooved, and during machining had grown downwards from the top edge of the tool. Such grooving could be caused by fine particles of tool material being dragged down from the cutting edge across the front face of the tool. Further, microprobe



Fig. 7 The surface deformation which occurred when an annealed platinum bar was machined with a progressively wearing tungsten carbide tool. Even a single cut with a sharp tool introduces a high degree of strain into the surface of the platinum and results in a large increase in hardness
 ×200

examination of the top face of the tool confirmed the presence of platinum either adhering to or embedded in the surface.

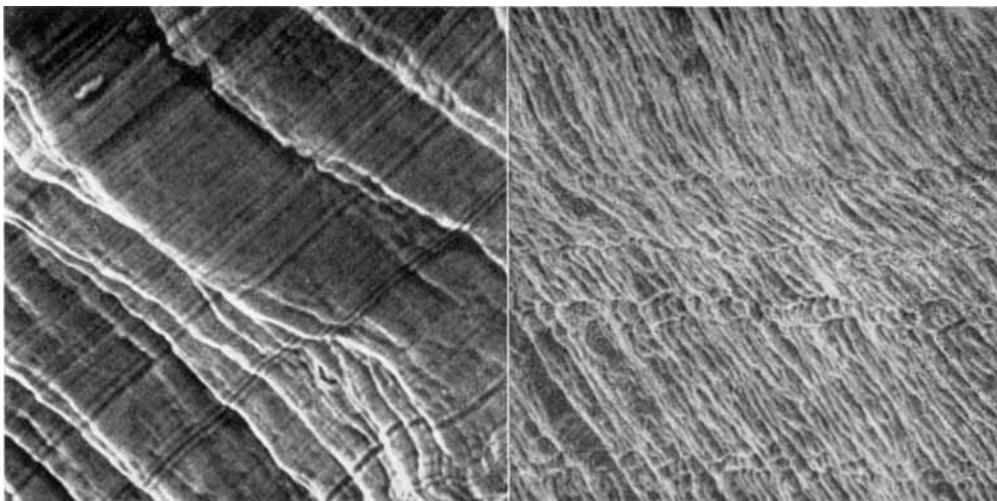
Examination of a diamond tool worn by machining platinum revealed a similar scar configuration to the steel, although the size is inherently smaller. Once again microprobe analysis established the presence of platinum on the top surface of the tool although it was impossible to distinguish between platinum adhering to the tool and platinum embedded in the irregular worn top surface.

A number of other cutting tool materials are commercially available and further turning trials were conducted using cubic boron nitride and two tools based on aluminium oxide, namely synthetic sapphire and Sintox, a sintered alumina. In fact boron nitride performed in a similar manner to Sintox and is not therefore individually identified. Compared to tungsten carbide, the cutting forces remained low and throughout the trials both these tools continued to cut platinum to a fine turned finish, Figure 10. Examination of the Sintox tool revealed that wear of the original cutting edge occurred by removal of grains; however, this exposed new alumina grains which continued to cut the

platinum without large increases in the forces acting on the tool or affecting the surface finish. The high quality of the machined finish is shown in Table II, in which the results of Talysurf scans across the surface are given.

In this initial evaluation the performance of the sapphire tool was comparable to that of diamond but during further trials chipping occurred at the cutting edge resulting in a very poor surface finish on the workpiece. The performances of polycrystalline Sintox and cubic boron nitride tools were confirmed by further tests and for the fine turning of

Table II Talysurf Measurements of the Surface Finish Produced on Platinum by Various Cutting Materials	
Tool Material	Surface Finish, microns
Tungsten carbide	Surface severely damaged, no measurements made
Sintox	2.0
Sapphire	0.2
Diamond	0.1



Figs. 8(a) and (b) Scanning electron photomicrographs illustrate the types of swarf produced during the machining of platinum (right) and gold (left) bars. The highly compressed platinum swarf is typical of a stick/slip tool-chip interaction × 6000

platinum and high platinum bearing alloys these materials are clearly superior to carbide and steel tools.

However, only two tool materials, diamond and sapphire, both of which are single crystal, appear capable of producing the high gloss finish on platinum which is required by the jeweller. Of these only diamond has the

mechanical toughness to withstand consistently the rigours of platinum machining without edge chipping.

Alternative Configurations

A considerable amount of evidence of the adhesion of platinum to the tool during machining had now been accumulated.

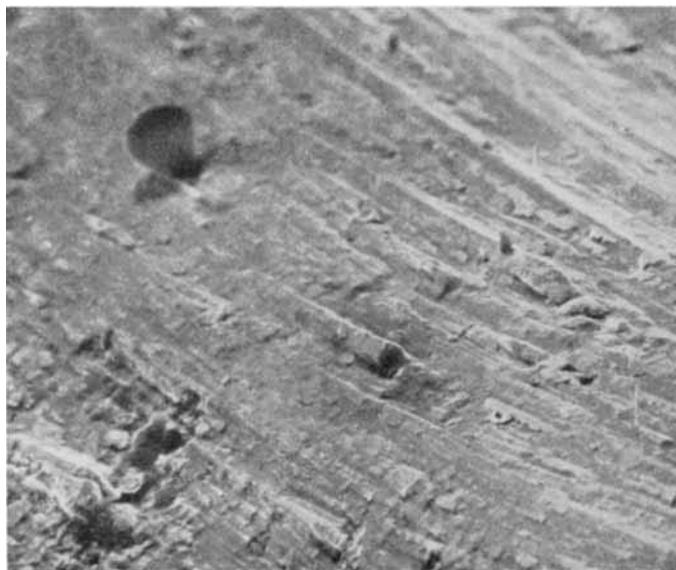
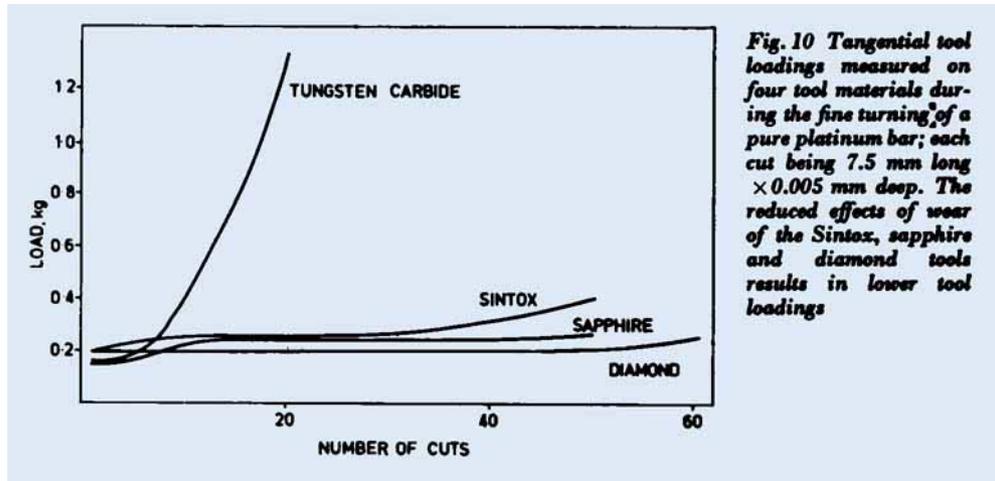


Fig. 9 The top face of a high-speed steel tool showing the results of severe stick/slip interaction with the platinum chip. The continual shearing of the adhering chip and the consequent removal of particles of tool material produce a worn and scored surface on the tool



It seemed logical to suppose that improvements in diamond tool life would result if any reduction in the interaction between the cutting tool and the platinum could be achieved, by improvements in tool configuration or more effective lubrication.

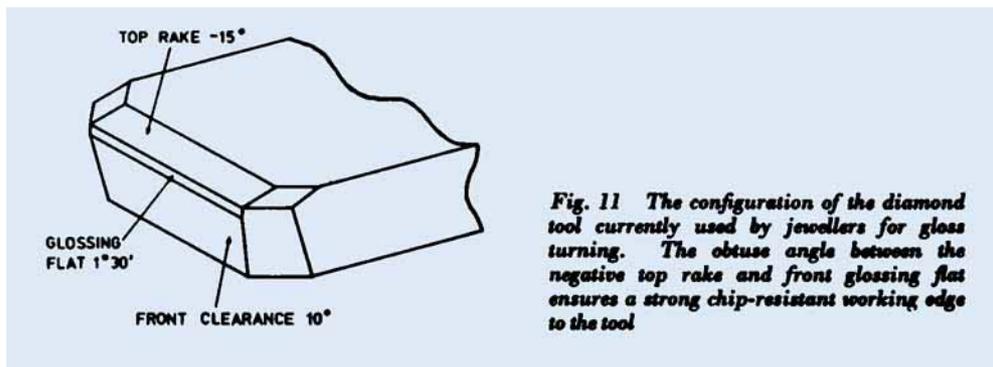
The jeweller's standard diamond lathe tool for gloss turning is shown in Figure 11. This tool has a relatively obtuse cutting edge with 15° negative top rake and a narrow glossing flat immediately below the edge. The purpose of this flat is to burnish the material after cutting and so produce a gloss surface finish. Some preliminary trials using tungsten carbide tools with a more positive top face demonstrated the advantages of such configurations for machining platinum. When

the top rake is changed to zero the cutting force is reduced by almost an order of magnitude and even after significant tool wear has occurred this advantage remains, as is shown in Figure 12.

Further trials were undertaken, using a proprietary lubricant, to enable a direct comparison to be made of specially prepared diamond tools with the following configurations:

- (a) 15° negative top rake with narrow glossing flat
- (b) Zero top rake with 10° front face clearance
- (c) 5° top rake with 5° front face clearance.

After 60 cuts, each 10.2 mm long and 0.005 mm deep, had been made on an annealed



pure platinum bar the negative rake tool was oscillating severely during each cut and the initial gloss-turned mirror finish had been replaced by a very poor surface topography. In addition the tool forces had increased substantially due to the large wear scar on the front face of the tool.

Both the zero and 5° positive top rake tools completed 150 cuts along the platinum bar with only slight tool oscillation occurring and only minor deterioration in the surface finish. The tool forces and wear scars were both smaller than those found for the negative rake diamond.

Comparison of the negative rake configuration used by the jeweller and the zero rake diamond tools evaluated in these tests revealed a significant difference between their ability to fully utilise the lubricant applied to the platinum workpieces, Figure 13. This must make a considerable contribution to the large reduction in tool forces noted with the zero rake tools.

One further advantage of these geometric variations was demonstrated by a simplified cutting technique, in which a high-speed steel tool was traversed slowly along a flat surface

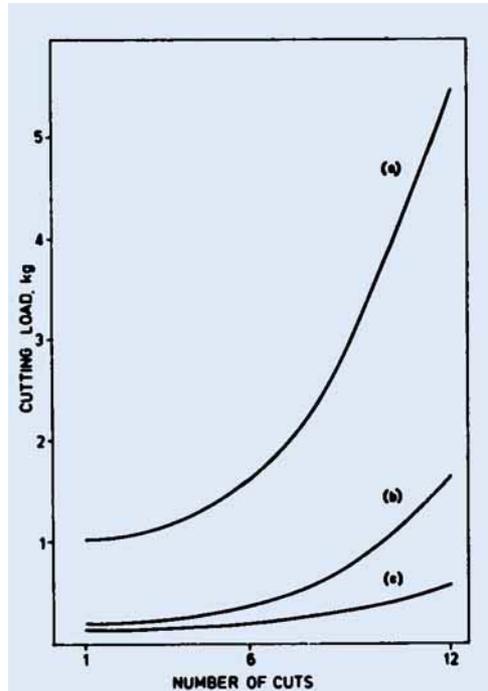


Fig. 12 Tangential loadings on tungsten carbide tools showing the reducing effect of more positive top rake, and lubrication. (a) 15° negative top rake, machined dry; (b) zero top rake, machined dry; (c) zero top rake, lubricated during machining

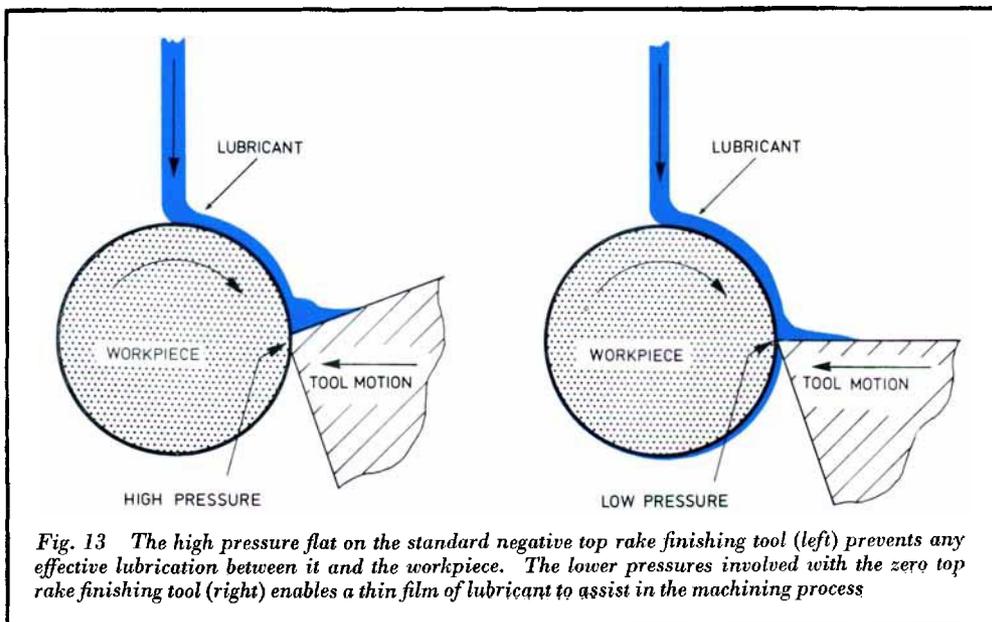
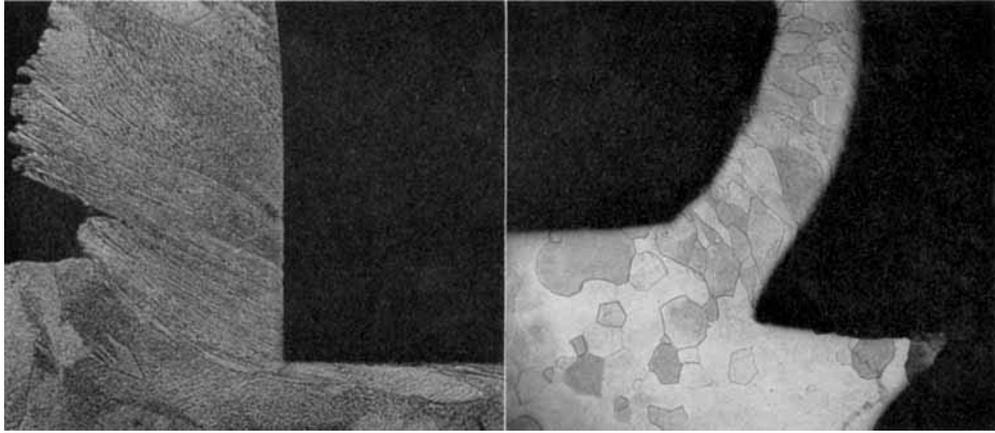


Fig. 13 The high pressure flat on the standard negative top rake finishing tool (left) prevents any effective lubrication between it and the workpiece. The lower pressures involved with the zero top rake finishing tool (right) enables a thin film of lubricant to assist in the machining process



Figs. 14(a) and (b) Microsections of two annealed platinum samples subjected to an interrupted cut with a high-speed steel tool of zero rake (left) and of 40° positive top rake (right). Surface distortion and chip compression are clearly reduced by the use of more positive top rake tool configurations

with the tool perpendicular to the direction of the cut.

A section through an annealed platinum sample subjected to an interrupted cut of 0.13 mm by this technique with a zero top rake tool is shown in Figure 14(a). Flow lines were visible along the cut edge and there was no evidence of crack propagation ahead of the tool. The chip was compressed, having been pushed ahead of the tool, with fracture occurring by shear; microhardness values showed that very high hardnesses were generated even after a single cutting operation. However, a similar experiment involving a tool with 40° positive top rake showed that a highly compressed discontinuous chip was not produced. In this instance the chip was in the form of a continuous ribbon with only slight distortion of the original grain structure, Figure 14(b).

Conclusions

The various parameters measured in this investigation indicate that adhesion of platinum to the tool is the most likely source of excessive tool wear during the machining of platinum. A possible contributing factor is the abnormally high hardness values observed in swarf produced by platinum machining

operations, and it would appear that the behaviour of platinum at high strains and high rates of strain could be a fruitful area for further research.

During this work no evidence was obtained to support the idea of an abnormally high coefficient of friction between platinum and diamond, neither could the platinum promoted decomposition of diamond to graphite at the tool tip be substantiated.

The use of more positive tool geometries has resulted in increasing tool life while retaining surface finish; Sintox or cubic boron nitride tool materials, when combined with such configurations, give a better, more efficient process for platinum machining.

This preliminary work therefore suggests that improvements in the platinum gloss turning process can be brought about by changing the configuration of the diamond tool and using specific lubricants. The optimisation of this process, together with its implications for other platinum fabricating operations, will be discussed in a later article.

References

- 1 E. M. Trent, "Metal Cutting", Butterworths, London, 1977
- 2 D. Crompton, W. Hirst and M. G. Howse, *Proc. Roy. Soc., A*, 1973, 333, 435-454