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[54] **CRYOGENIC GRINDING OF COPPER**

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[51] **Int. Cl.**..... **B24b 1/00;** B24b 55/02

[58] **Field of Search**..... 51/2 F, 266, 267, 322, 51/284; 241/DIG. 13, DIG. 22, 3, 15, 17, 18, 23; 82/1 C, 47; 83/15, 16, 170, 171

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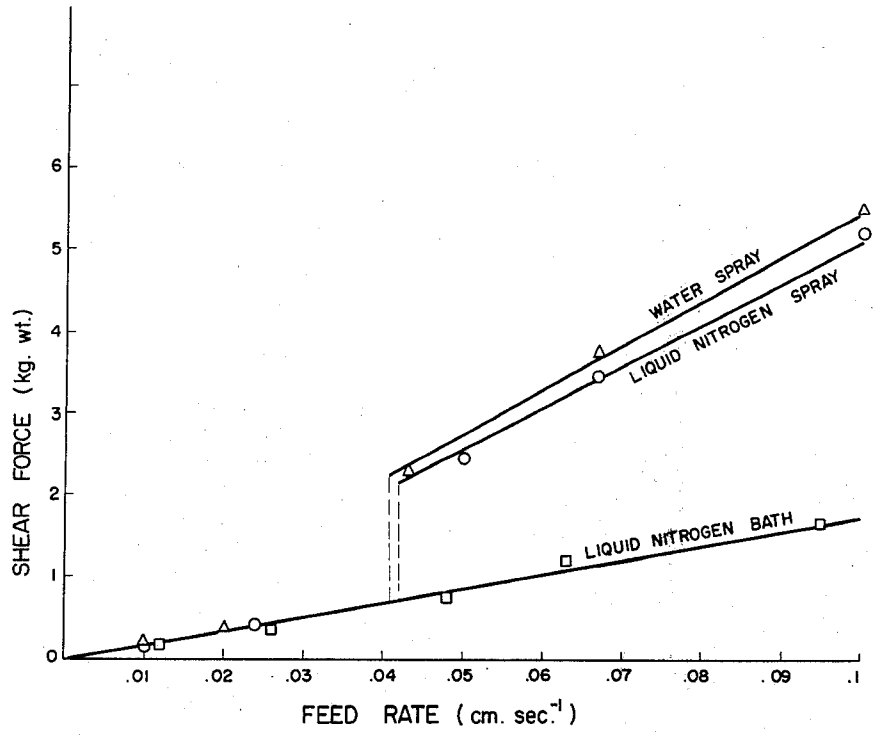
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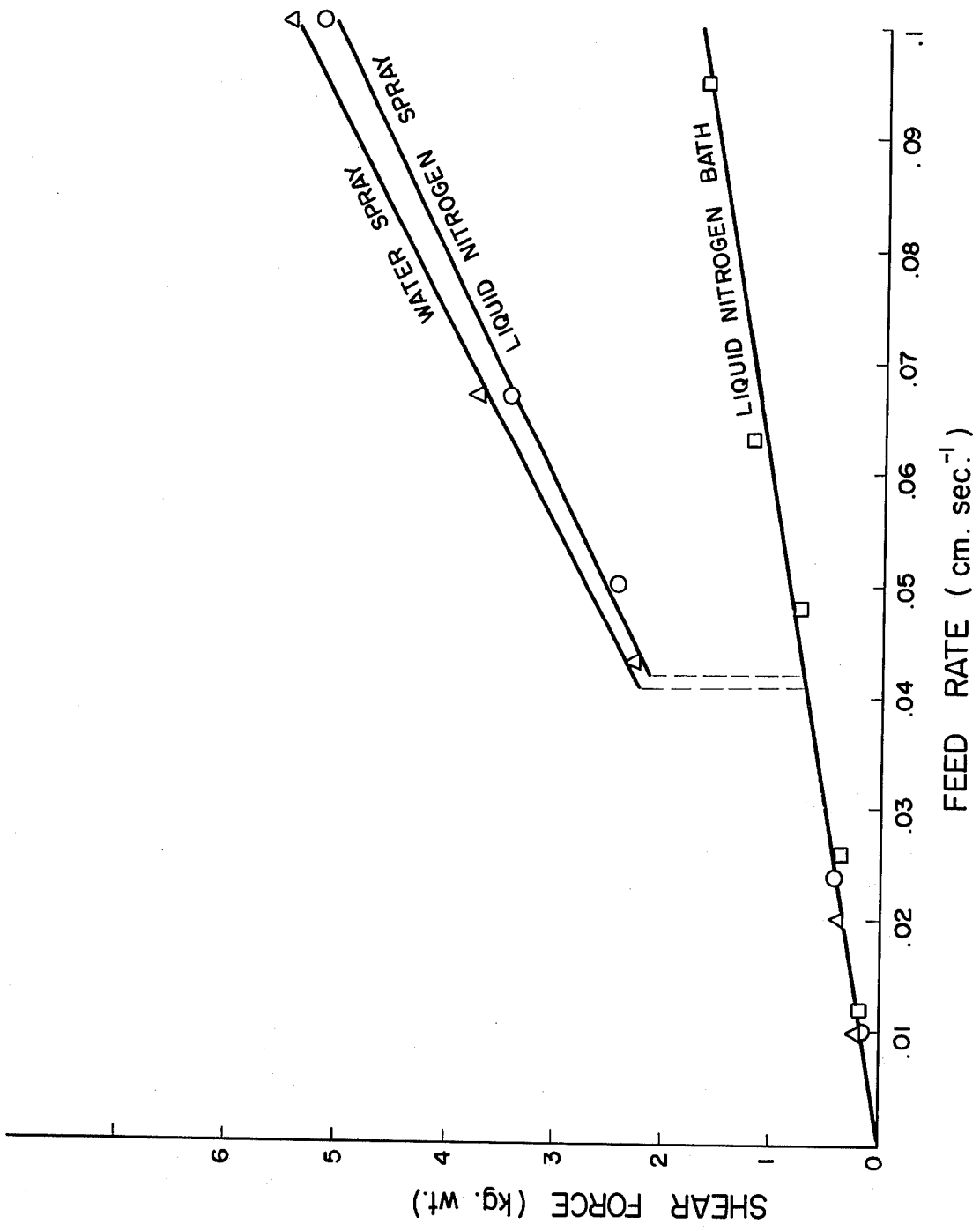
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[57] **ABSTRACT**

A process for abrasively grinding copper comprising (1) cooling the entire copper workpiece to a cryogenic temperature and (2) abrasively grinding the copper workpiece while it is at said cryogenic temperature. The workpiece is preferably immersed in liquid N_2 during the abrasive grinding thereby preventing adhesive wear from occurring at relatively high metal removal rates.

3 Claims, 1 Drawing Figure




WATER SPRAY
LIQUID NITROGEN SPRAY
LIQUID NITROGEN BATH
SHEAR FORCE (kg. wt.)
FEED RATE (cm. sec.$^{-1}$)
0
1
2
3
4
5
6
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1

CRYOGENIC GRINDING OF COPPER

BACKGROUND

This invention relates, in general, to abrasive processes, and more particularly, to an improved method for abrasively grinding copper metal.

The abrasive grinding of metal is an operation in which hard, sharp and friable abrasive particles are used as cutting tools. The abrasive particles are generally embedded in a wheel which is power driven as it contacts the workpiece. In general, abrasive processes yield fine surface textures and precise workpiece dimensions and are considered, for the most part, finishing operations. Among the abrasive processes in common use are grinding, honing, lapping, superfinishing, abrasive machining and abrasive cutting.

Grinding is the best known and most common abrasive process. In contradistinction to most other metal cutting operations, grinding is a self-sharpening process. That is, as the abrasive particles wear during cutting they either fracture or are torn from the bonding material exposing new and sharp cutting edges. In order for the abrasive particles to maintain their sharp cutting edge, it is essential that they wear abrasively during normal operation. Abrasive wear occurs when a rough hard surface, such as an abrasive grit, contacts a softer surface (i.e. the workpiece) and cuts a series of grooves therein; the removed workpiece material taking the form of long helicoidal chips which are generally thrown clear of the abrasion contact zone.

Adhesive wear is an undesirable type of wear which may occur during abrasive processing depending upon the rate of metal removal and the composition of the workpiece. It is basically a form of material removal which occurs when the fragments of the workpiece surface which are removed by the abrasive particles adhere to such particles rather than forming loose chips of metal. Microscopic observation reveals that during adhesive wear small elements of the workpiece come into contact with the abrasive particles, adhere to said particles and when contact is broken, the break occurs not at the original interface but rather within the individual elements of the workpiece. As a result, the grinding surface becomes progressively loaded with the material being abraded to the point where the abrasive particles are unable to cut the workpiece efficiently. Consequently, adhesive wear results in a very unsmooth workpiece surface and a marked increase in the shearing force required for abrasion.

High purity copper is considered an extremely difficult material to grind because of its tendency to wear adhesively during abrasion. That is, when copper is abrasively machined it readily loads the grinding wheel, even at relatively low speeds corresponding to metal removal rates far lower than conventionally used for metals such as steel. Consequently, copper grinding is a relatively lengthy and expensive machining operation. In an effort to prolong tool life and prevent localized welding or adhesive wear during the machining of copper, coolants have been used to lower the temperature at the cut surface of the workpiece. Thus, coolants such as water and liquid CO_2 have been directed at the grinding wheel and the work surface in attempts to conduct heat away from the tool-work interface. These techniques, however, have proven only partially successful because the resulting metal removal rates are only slightly improved beyond those practical at room

temperature in the absence of a coolant spray. Consequently, copper abrading operations are presently incapable of being performed at metal removal rates comparable to those for iron and steel.

OBJECTS

Accordingly, it is an object of the present invention to provide a process for abrading copper at relatively high rates of metal removal.

It is a further object of the invention to provide a relatively rapid process for abrading copper while preventing the abrading surface from wearing adhesively.

SUMMARY OF THE INVENTION

These and other objects which will become apparent from the detailed disclosure and claims to follow are achieved by the present invention, one aspect of which comprises:

a process for abrasively grinding copper comprising the steps of:

1. cooling the copper workpiece to be ground to a cryogenic temperature such that substantially the entire workpiece is at said cryogenic temperature, and
2. abrasively grinding said copper workpiece while at said cryogenic temperature, thereby minimizing the tendency of the copper chips removed during abrasion to weld to the grinding surface.

In a preferred embodiment of the present invention the copper workpiece is cooled by immersing substantially the entire workpiece in liquid nitrogen. The cooled workpiece is thereafter abraded while remaining immersed in the cryogenic liquid.

The term "abrasively grinding" as used herein is intended to encompass abrasive processes such as surface grinding, honing, lapping, superfinishing, abrasive cutting and abrasive machining. Surface grinding, honing, lapping and superfinishing are finishing operations intended to produce uniform high accuracy and fine finish on a surface. Abrasive machining is an abrasive process in which the primary aim is metal removal while abrasive cutting is an abrasive process intended to sever metal parts.

The term "copper" as used herein refers to pure copper metal as well as to copper alloys having either less than two weight percent of alloying elements or copper alloys having a hardness below Rockwell B25 irrespective of the percentage of alloying elements. Thus, the term "copper" includes such alloys as the aluminum bronzes and beryllium copper.

The term "cryogenic temperature" as used herein is intended to encompass the range of temperatures corresponding to conventional cryogenic fluids such as liquid N_2 and liquid CO_2. Accordingly, cooling of the workpiece to a "cryogenic temperature" refers to temperatures below −70°C with liquid N_2 being the preferred cryogen.

The invention is predicated on the discovery that the tendency of copper to wear adhesively during abrasive grinding can be substantially reduced or eliminated at relatively high rates of metal removal if the copper workpiece is maintained at a sufficiently low temperature during the grinding operation. Heretofore, it had been believed that cooling of the workpiece was beneficial — but only if it occurred at the grinding interface, namely, within the zone of contact between the abrasive particles and the workpiece. It has now been dis-

covered that by sufficiently reducing the temperature of substantially the entire workpiece, a heat-sink effect is created which allows the frictional heat generated at the work surface to be rapidly dissipated throughout the entire workpiece, thereby avoiding the transition from an abrasive wear process to an adhesive wear process at commercially practical metal removal rates. Thus, the fact that a copper workpiece cooled with liquid nitrogen spray directed at the tool-work interface will experience an adhesion wear mechanism at relatively low metal removal rates, while a similar workpiece immersed in liquid nitrogen will remain in the abrasive wear region at metal removal rates normally associated with iron or steel, is truly unexpected. Moreover, the surprising nature of the result is underscored by the fact that similar type experiments conducted with materials such as aluminum and iron showed no improvement whatever when comparing the grinding of specimens immersed in liquid nitrogen with specimens which were cooled by directing a liquid coolant spray at the grinding wheel. Indeed, in tests conducted with iron, immersing the workpiece in liquid nitrogen proved to be a less preferred mode of cooling because grinding of the immersed workpiece was accompanied by a marked increase in the shearing force at the grinding surface relative to that required when the grinding wheel was cooled with a liquid spray.

DRAWINGS

The FIGURE is a plot of shear force vs. feed rate during the abrasive cutting of copper for three different modes of cooling the workpiece.

DETAILED DESCRIPTION OF THE INVENTION

The grinding operations contemplated by the present invention include all of the types in common use such as surface, cylindrical, internal, centerless and off-hand grinding. The first four types of operations are used primarily to obtain accurate dimensions and good surface finishes. The material to be ground is generally fed against the grinding wheel which is rotated at a velocity sufficient to attain a surface speed of from about **3000–5000** ft/min. Finishing operations, such as honing, lapping and superfinishing are characterized by the extreme fineness of the abrasive particles. Off-hand grinding is used mainly where metal removal is of prime importance and dimensions are not critical. In abrasive cutting, a cut-off wheel is used to sever metal parts such as risers, sprues and flushing from castings. In abrasive machining, the primary aim is metal removal, not surface finish.

Adhesive wear is a problem common to all abrasive grinding operations, but particularly, when the workpiece is a soft and ductile metal such as copper. The presence of adhesive wear during copper grinding can be visually detected by numerous methods. First, the abrasive surface can be examined to determine the extent of copper loading thereon; second, the surface of the workpiece can be examined to determine whether the resulting finish is characteristic of abrasive or adhesive wear; and finally, the chips of metal ejected from the tool-work contact area can be examined to determine whether they are nodular or helicoidal in shape, the former being characteristic of adhesive wear and the latter indicating abrasive wear.

Cooling of the copper workpiece to cryogenic temperatures is accomplished by immersing substantially the entire workpiece in a cryogenic fluid such as liquid nitrogen such that substantially the entire mass of copper is cooled to and maintained at a cryogenic temperature; not merely the area of contact between the workpiece and the abrasive surface as in conventional practice. By cooling the entire workpiece in the manner disclosed, it is believed that a heat-sink effect is created which prevents a rapid temperature rise at the work-tool interface and the concomittant loading of the abrasive wheel with copper chips.

EXAMPLE

A series of experiments were conducted with annealed, electrolytic tough pitch copper to determine the effect of various modes of cooling the workpiece on the grinding operation. An abrasive cut-off machine was modified to permit measurement of the shear force exerted by the grinding wheel as copper bars were severed at varying rates of feed. A **10** inch diameter x **1/16** inch TC **120** HRR wheel manufactured by the Carborundum Company was used in all the experiments. The wheel speed was kept constant at **2100** rpm.

Three sets of experiments were performed corresponding to three modes of cooling the workpiece. In the first set of experiments, water was sprayed on to the cut-off wheel; in the second set, liquid nitrogen was sprayed on to the wheel; and in the third set the copper workpiece was immersed in a dewar flask containing liquid nitrogen such that the work surface was about 1 inch below the level of liquid nitrogen. The results are shown in FIG. **1.**

When cooling was accomplished by spraying water or liquid nitrogen on to the wheel, the cutting mechanism is seen to be dependent on feed rate. At low feed rates, below **0.24** cm sec.$^{-1}$, the shear force is described by the equation:

$$(1)\ S = 17.2\ f$$

where: S is the shear force in kg. wt. and f is the feed rate in cm. sec.$^{-1}$. At higher feed rates, i.e. above **0.043** cm. sec.$^{-1}$, there is an abrupt increase in the shear force to a value approximately three times the shear force measured at the same feed rate when the copper specimen was immersed in a bath of liquid nitrogen. This discontinuity in the curve indicates a transition from an abrasive wear mechanism to an adhesive wear mechanism. The shear force of the specimen immersed in liquid nitrogen, on the other hand, was invariant with feed rate and is described by equation (1) throughout the range of feed rates studied. In other words, the workpiece immersed in liquid nitrogen remained in an abrasive wear region at feed rates up to three times that ordinarily associated with copper grinding in commercial practice.

What is claimed is:

1. A process for abrasively grinding copper comprising the steps of:

1. cooling the intended copper workpiece to a cryogenic temperature such that substantially the entire workpiece is at said cryogenic temperature, and
2. abrasively grinding said copper workpiece while at said cryogenic temperature thereby minimizing the tendency of the copper chips removed during abrasion to weld to the grinding surface.

2. The process as in claim **1** wherein said workpiece is cooled by immersing substantially the entire workpiece in a cryogenic fluid.

3. The process as in claim **1** wherein said cryogenic fluid is liquid N_2.

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