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EROSION BEHAVIOR OF HARD SURFACE COATINGS/INSERTS

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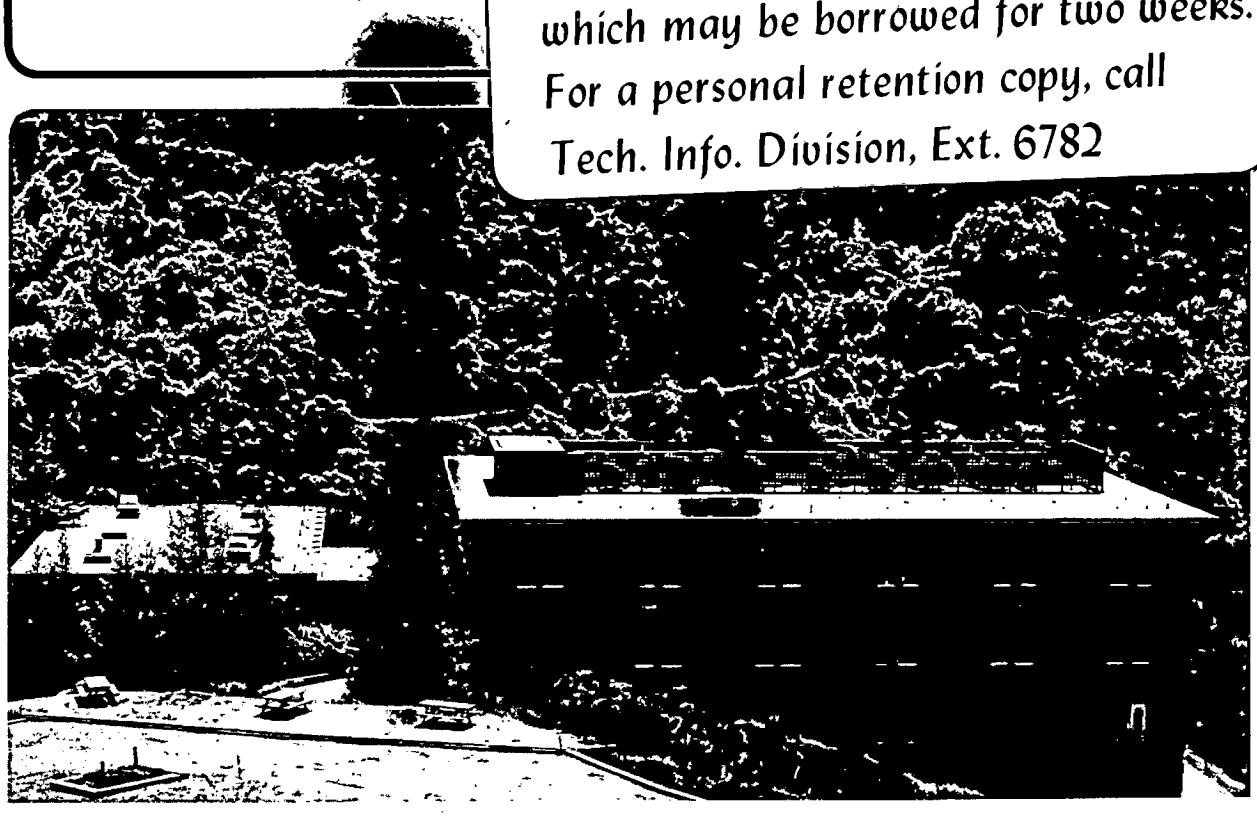

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INTRODUCTION

The wear resistance requirements of some of the components in the emerging energy systems necessitates the use of hard materials of the refractory hard metal family i.e., carbides, nitrides, borides, silicides, to serve at the wear surface. They are used either as deposited coatings on structural metal surfaces or as separately fabricated inserts that are assembled into a structural metal retaining area. There has been considerable study of the wear behavior of carbides, nitrides and borides in rubbing and sliding wear and in abrasive wear. However, there has been very little research conducted to determine their resistance to wear by erosive particles directed at the surface by a gas stream. In several of the newer energy conversion and utilization systems, particularly those that use coal, the mechanism of erosive wear is an active one that must be addressed.

The purpose of this was to determine the basic erosion behavior of several of the most promising refractory hard metal coatings and bodies that are currently either in development or commercial use. A representative group of materials was obtained from a few of the suppliers of hard surface materials and tested at room temperature in an air blast tester. The materials selected were meant to be a sample and not a definitive representation of all of this type of material available. The tests were done at room temperature only to establish an initial basis for understanding the nature of the erosion process and not to attempt to simulate any regime of service conditions. With this screening work completed, the continuing effort will incorporate

additional materials and test conditions more nearly simulating service conditions.

EXPERIMENTAL CONDITIONS

Flat, rectangular specimens of the order of 3cm x 2cm x 1/2cm were used. Table 1 lists the materials tested. Since several of the materials tested are still in development or initial production applications, their proprietary nature precludes a detailed description of their composition, structure or method of processing.

The specimens were placed in an air blast tester[1] are eroded incrementally with up to 280gm of 200μm, angular SiC particles, carried in an air stream at 100fps at room temperature. The velocity was determined using a rotating disc method.[2] The angle of impingement between the direction of the particles out of the nozzle and the flat target surface was 30°, 60° or 90°. Total test time ranged from 8 min. to 15 min. (approximately 5 sec/gram) depending upon when a steady state erosion rate was reached. A steady state erosion rate is defined as that condition of the target surface where each succeeding batch of particles causes the same amount of weight loss of the specimen as the previous batch.

The specimens were blasted with small amounts of particles in each erosion increment that were increased as the steady state of production was approached, as can be seen by the weight loss curves. Weighing was done on a balance accurate to 10.1 milligram.

RESULTS

The steady state erosion rate of each material tested at 30° and 90° impingement angles is shown in Fig. 1. A wide range of performance occurred for the group of test materials. In all instances the materials eroded more at 90° angle than at 30°, which is typical of brittle type materials. Some materials showed relatively little difference in erosion between the two impingement angles, especially the hard CNTD silicon carbide material. However, others showed three to four times greater erosion at 90° than at 30°. There was a wide variation in the erosion behavior of silicon carbide depending on its type, fabrication method and source. The two tungsten carbide materials behaved in a similar manner, especially at the 90° impingement angle.

Table 2 compares the performance of the materials at an impingement angle of 90° by normalizing them with respect to the performance of the CNTD hard silicon carbide. The rather wide spread in their performance can be easily seen. Since all of the materials were procured for testing because of their reported excellent wear resistance, the extent of the differences in performance that were measured were not expected.

Figure 2 shows the pattern of the incremental erosion of the hard and soft CNTD silicon carbide that was chemically vapor deposited on graphite. It can be seen that both materials rapidly reached an erosion rate peak after the initiation of erosion and then rapidly decreased to a low steady state erosion rate. The soft SiC peak is lower than that of the hard SiC and its rise could be measured while the rate of the hard SiC was at a peak at the first increment of one

gram of particles. The hard SiC reached a considerably lower steady state rate which accounted for its lower overall steady state of erosion. The hard SiC took somewhat longer to reach a steady state condition.

Figures 3 and 4 show the incremental erosion curves of the LW-5 and LW-15 detonation gun sprayed tungsten carbide coatings on a stainless steel substrate. The curves are similar in shape to that of the CNTD hard SiC, but have a more gradual slope down to their steady state erosion rate. The LW-5 requires 35 grams of particles to reach steady state while the LW-15 material reaches steady state in only 15 gm. The CNTD hard SiC took only 10 gm to reach steady state erosion and the CNTD soft SiC reached it in 5 gm of particles. The time to reach steady state is a characteristic erosion behavior property of materials. It appears to relate to the level of steady state erosion, the longer it takes to reach steady state erosion, the lower is the final erosion rate in the case of the CNTD SiC and the sprayed WC.

The hot pressed NC-132 silicon nitride and Ni-203 hot pressed silicon carbide had low rates of erosion at steady state and incremental erosion rate curves that were different from those of the deposited materials. Figures 5 and 6 show that the nature of the erosion was one of an increasing erosion rate up to a steady state rate, similar to that which occurs in ductile metals.

A comparison of the incremental erosion curves for the several types of materials is shown in Fig. 7. The initial behavior varies somewhat, but each material reaches a steady state condition in a rel-

atively few grams of impacting particles. The negative initial readings for the hot pressed silicon carbide and nitride materials probably are due to embedded particles of erodent in the surface. The very high initial erosion rate readings relate more to the mechanism of initial erosion then in steady state erosion behaving in the reduced peak material, the CNTD hard SiC has the lowest steady state erosion rate.

METALLOGRAPHIC ANALYSIS

The scanning electron microscope (SEM) was used to study the nature of the physical deformation that occurred on each material as the result of the erosion process. Figure 8 shows scanning electron microscope (SEM) photos of the CNTD silicon carbide coatings eroded surfaces after steady state conditions were reached. The uneroded surfaces of the two coatings were essentially alike. After erosion there is a great difference in the appearance of the surface at both lower and high magnifications. The hard SiC appears to be eroding by the loss of fine chips of materials, representative of a very fine grain size. The soft SiC on the right hand side of Fig. 8 is eroding by a mechanism of combined cleavage of crystallites of a considerably larger grain size than that of the hard SiC and some plastic determination of material that appears to have some small degree of ductility.

Figure 9 shows the appearance of the eroded surfaces of the hard and soft CNTD silicon carbide at the time of the peak erosion rate as shown in Fig. 2. It can be seen that considerably more surface has been affected in the soft SiC than in the hard SiC even though the peak erosion rate of the hard SiC is higher at this early point in the erosion of the two surfaces.

Figure 10 shows a phenomenon which occurred only the hard CNTD silicon carbide near the coating substrate interface. The coating preferentially eroded in areas which appear as grooves in the left side photo. At high magnification on the right side, the grain size at the root of the cracks can be seen to be considerably larger than that of the major part of the coating. This resulted in a preferential erosion pattern along the paths of the larger grains. There may even have been some porosity present in the regions of the apparent cracks to further reduce the erosion resistance of the area. The chipping away of small grains that were typical of the hard SiC material can be seen in the regions on either side of the large grained area.

Figure 11 shows the steady state erosion surface of the LW-5 tungsten-carbon coating. The appearance of the material at the surface indicates that considerable plastic deformation had occurred along with some lesser amount of brittle fracture or chipping. The degree of plastic deformation is considerably more than was seen on most of the metal binder content. The nature of the platelets formed is similar to those formed when ductile metals are eroded.

DISCUSSION

The erosion behavior of the hard materials tested varied over a relatively wide range as is shown in the bar graph, Fig. 1. The variation in hardness of the various refractory had metals tested was too small to relate to the differences in measured erosion rate. Therefore, the erosion rates must be attributed to a combination of characteristics such as composition, amount and type of binder material,

grain size, and other factors which combine to absorb and distribute the kinetic energy of the impacting particles. All of the materials tested had the characteristic erosion behavior of brittle materials, i.e., the erosion rate was greater at the 90° impingement angle than at the more shallow 30° impingement angle. The role of such binder materials as silicon metal in the material systems does not modify the basic mode of erosion although it does modify the sensitivity of the material to erosion with the more intimately mixed silicon-silicon carbide or nitride materials having the best erosion resistance. Since several of the materials tested are highly proprietary and their grain structures very fine, the distribution of silicon in them is not known without further analysis or information from the supplier.

The very low erosion rate of the CNTD SiC (hard) from San Fernando Laboratories and its insensitivity to the impingement angle is due to the fineness of the distribution of the binder phase and the small grain size of the material. This resulted in material loss by chipping away of very small pieces. A modification of this material, the CNTD SiC (soft) has considerably different grain structure and a marked difference in the erosion mechanism as can be seen in Figs. 8 and 9. This resulted in a considerably higher erosion rate as can be seen in Fig. 1. Scanning Auger Microscopy (SAM) analysis of the two CNTD materials indicated that the soft, higher erosion rate material had a considerably higher oxygen content which could also have affected its erosion rate.

The relatively low erosion rates of the hot pressed silicon carbide and silicon nitride from the Norton Co. also relates to the fine grain size and binder distribution that can be achieved by this type of processing. Hot pressing is generally limited to producing wear resistant bodies or inserts. The ability of the chemical vapor deposition process to deposit the coating of CNTD SiC on large surfaces with such a fine structure and low erosion rate shows the promise of this method of developing wear resistant material systems.

The erosion rate peaks that some of the materials experienced, as shown in Fig. 2 for the CNTD SiC, is typical of the erosion of some brittle materials. In the work of Zambelli and Levy[3] to determine the erosion behavior of NiO formed on CP nickel, the same type of peaks were observed. They are due to the initial loss of material in the outer layers of the brittle material after the surface area has been thoroughly cracked by the impacting particles without pieces being removed. After the initial loss, cracks penetrating into the material separate out pieces of material for removal at a considerably lower rate, sharply reducing the erosion rate to a much lower value.

This cracking mechanism accounts for the difference in the shape and peak height of the erosion rate curves for the hard and soft CNTD SiC. The smaller grained, more strongly bonded hard material would undergo considerably more initial surface cracking without loss of material than the soft material. Hence, when the crack pattern has been completed in the surface layers, an initial high rate of loss occurs in the hard SiC and a lower initial rate in the soft material. The

much lower steady state loss of the hard material compared to the soft can be seen in the curves.

The normalized erosion rate loss of the material tested in Table 2 indicates the superiority of the CNTD SiC (hard) in the type of erosion test carried out. At other test conditions of velocity and particle size, shape, and composition other relative behaviors could occur among the materials tested.

The erosion rate curves of the detonation gun applied tungsten-carbon coatings LW-5 and LW-15 is similar to that for the CNTD SiC (hard), but the curves fall off much more gradually to a higher steady state condition because of their different structure and composition. Within the same composition, the more gradual the slope of the curve to steady state erosion, the lower is the steady state erosion rate. However, the comparison does not appear to apply between different materials. The CNTD SiC materials' erosion rates fall off to steady state considerably faster than do the tungsten-carbon coatings; yet are considerably lower. The difference in the erosion mechanism between the CNTD SiC and the LW-5 materials appears to undergo considerably more plastic deformation at the eroding surface than does the CNTD SiC material.

The hot pressed bodies of silicon carbide, NC-203, and silicon nitride, NC-132, have erosion rate curves that are considerably different from the previously discussed materials. They do reach a peak erosion rate after the initiation of erosion, but undergo a lower but measurable erosion rate prior to reaching the peak rate. In the case

of the silicon nitride, the peak rate is very near the steady state erosion rate. A comparison of several of the curves of materials tested is shown in Fig. 7. The reasons for these differences in the shapes of the curves have still to be determined.

CONCLUSIONS

1. All of the material tested eroded in a brittle manner, undergoing more erosion at a 90° impingement angle than a 30° angle.
2. The CNTD SiC (hard) had the best erosion resistance, apparently due to the fine grained microstructure of the carbide phase and the fine distribution of the silicon rich phase.
3. The coating materials had a peak erosion rate at the beginning of the erosion process, which has been observed for other brittle coatings on substrates. The hot pressed bodies had an increasing erosion rate up to a steady state value, which is typical of metals.
4. The amount of apparent plastic deformation that occurred in some of the materials can be related in the amount and condition of the metallic phases in the materials, but more work is required to establish this relationship.
5. The large grain size near the coating-substrate interface of the CNTD SiC (hard) that eroded preferentially could be related to an instability in the deposition processes that occurred near the initiation of deposition.

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Selection and procurement of the materials that were tested were made by Donald Boone.

Pauline Chik prepared the metallographic specimens.

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1. Levy, A.; "The Solid Particle Erosion Behavior of Steel as a Function of Microstructure"; Wear 68, P. 269-283, 1981.

2. Buff, A. and Ives, L.; "Measurement of Solid Particle Velocity in Erosive Wear", Wear 35, P. 195, 1975.

3. Zambelli, G. and Levy, A.; "Particulate Erosion of NiO Scales"; Wear 68, P. 305-332, 1981.

Table 1

Material Designation	Composition	Substrate	Fabrication Method	Surface Condition	Source
CNTD SiC (Hard)	Silicon Carbide	Graphite	Chemical vapor deposited	as deposited	San Fernando Laboratories
CNTD SiC (Soft)	Silicon Carbide	Graphite	Chemical vapor deposited	as deposited	San Fernando Laboratories
LW-5	Tungsten Carbide	Stainless Steel	Detonation Gun sprayed	ground	Union Carbide Linde
LW-15	Tungsten Carbide	Stainless Steel	Detonation Gun sprayed	ground	Union Carbide Linde
ROKIDE C	Chromium Oxide	Black iron	Oxy-acetylene sprayed	as sprayed	Norton Co.
NC-132	Silicon Nitride	None	Hot pressed	as pressed	Norton Co.
NC-203	Silicon Carbide	None	Hot pressed	as pressed	Norton Co.
NC-403	High purity silicon carbide + silicon	None	Reaction sintering + densification of slip cast material	as sintered	Norton Co.

Table 2

Material	Steady State Erosion Rate in g/g x 10^4	Normalized Rate
CNTD SiC (Hard)	0.17	1
CNTD SiC (Soft)	3.0	17
LW-5 WC	3.4	20
LW-15 WC	4.5	26
ROKIDE C	6.0	35
NC-132	0.65	3.8
NC-203	0.9	5
NC-430	2.2	13

FIGURES CAPTIONS

Fig. 1. Bar chart of steady state erosion rate of each material.

Fig. 2. Incremental erosion rate of CNTD SiC, hard and soft.

Fig. 3. Incremental erosion rate of LW-5 sprayed WC.

Fig. 4. Incremental erosion rate of LW-15 sprayed WC.

Fig. 5. Incremental erosion rate of NC-132 hot pressed silicon nitride.

Fig. 6 Incremental erosion rate of NC-203 hot pressed silicon carbide.

Fig. 7. Incremental erosion rate of several materials.

Fig. 8. CNTD silicon carbide eroded surfaces at steady state.

Fig. 9. CNTD silicon carbide eroded surfaces at peak erosion rate.

Fig. 10. Large grained areas of hard CNTD silicon carbide near coating-substrate interface.

Fig. 11. Steady state erosion surface of LW-5 tungsten-carbon coating.

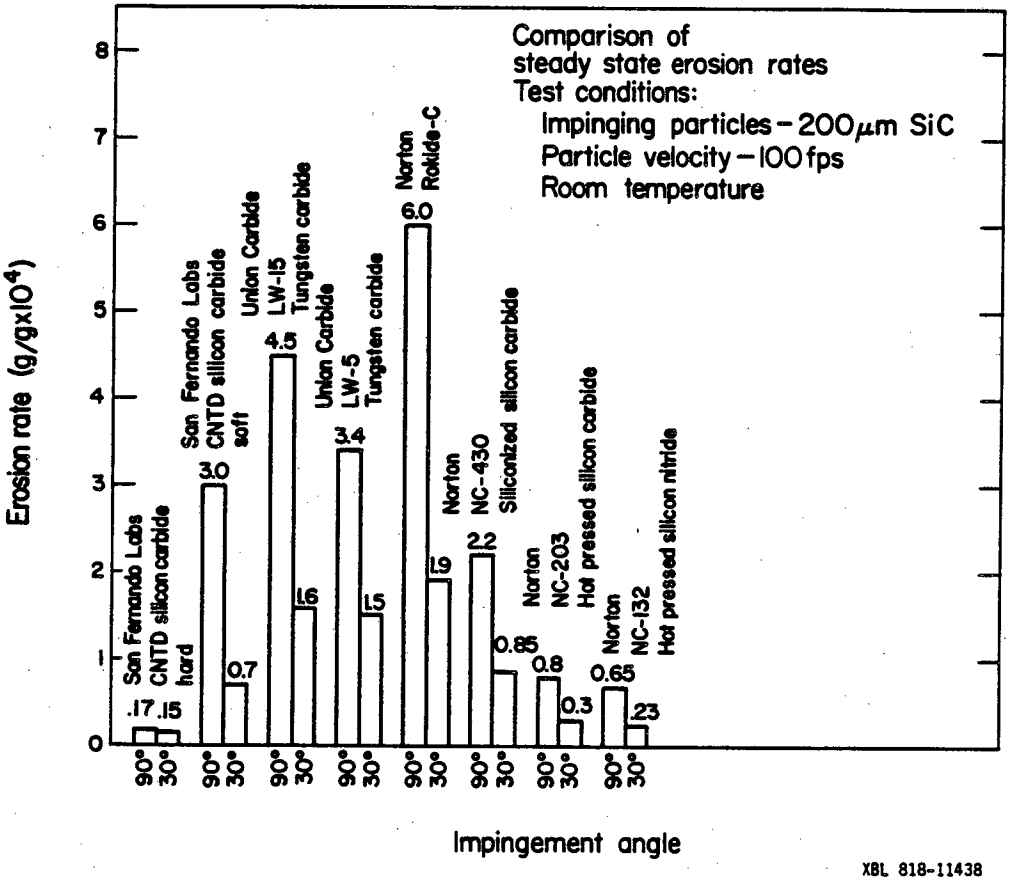

Fig. 1. Bar chart of steady state erosion rate of each material.

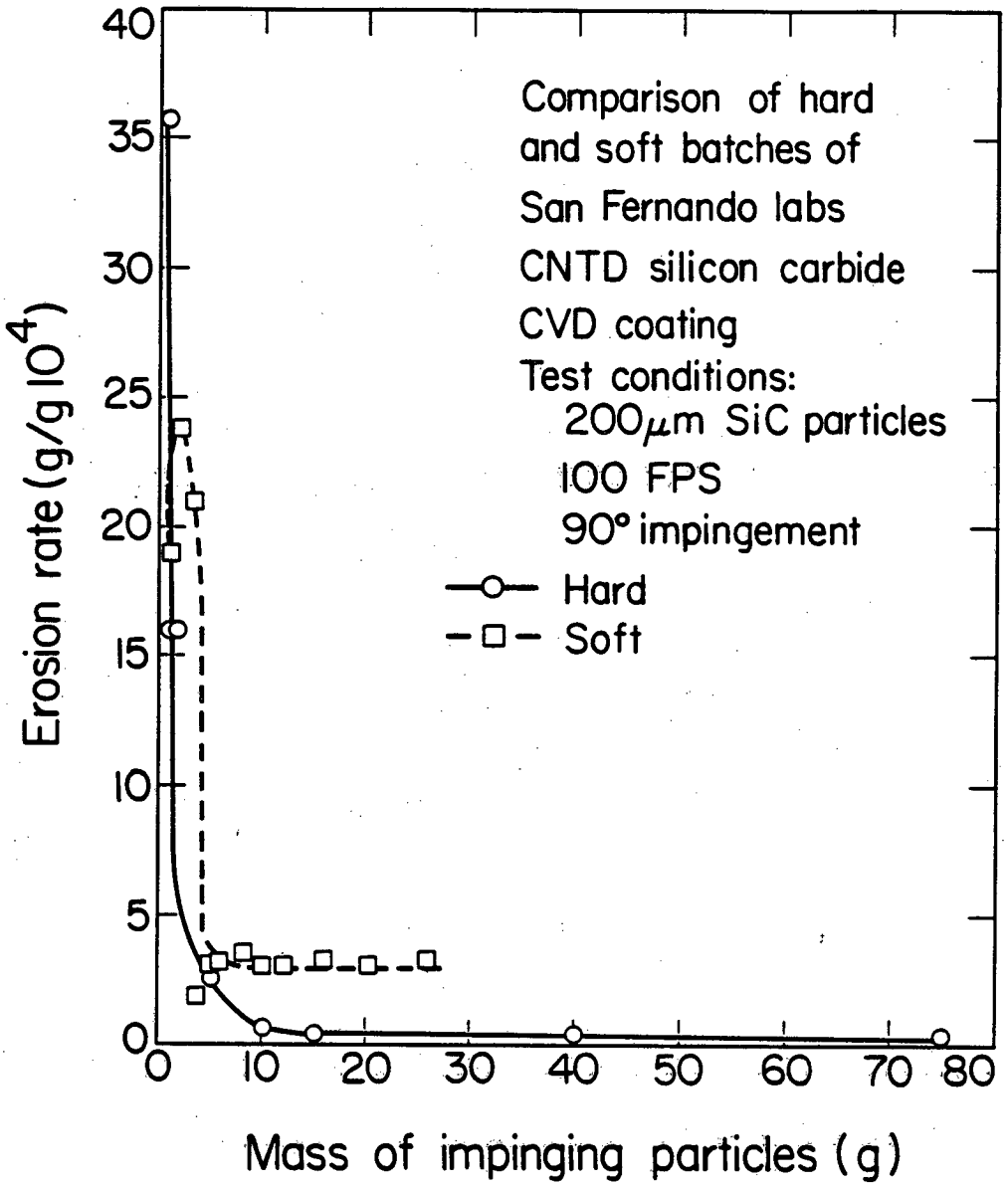

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Fig. 2. Incremental erosion rate of CNTD SiC, hard and soft.

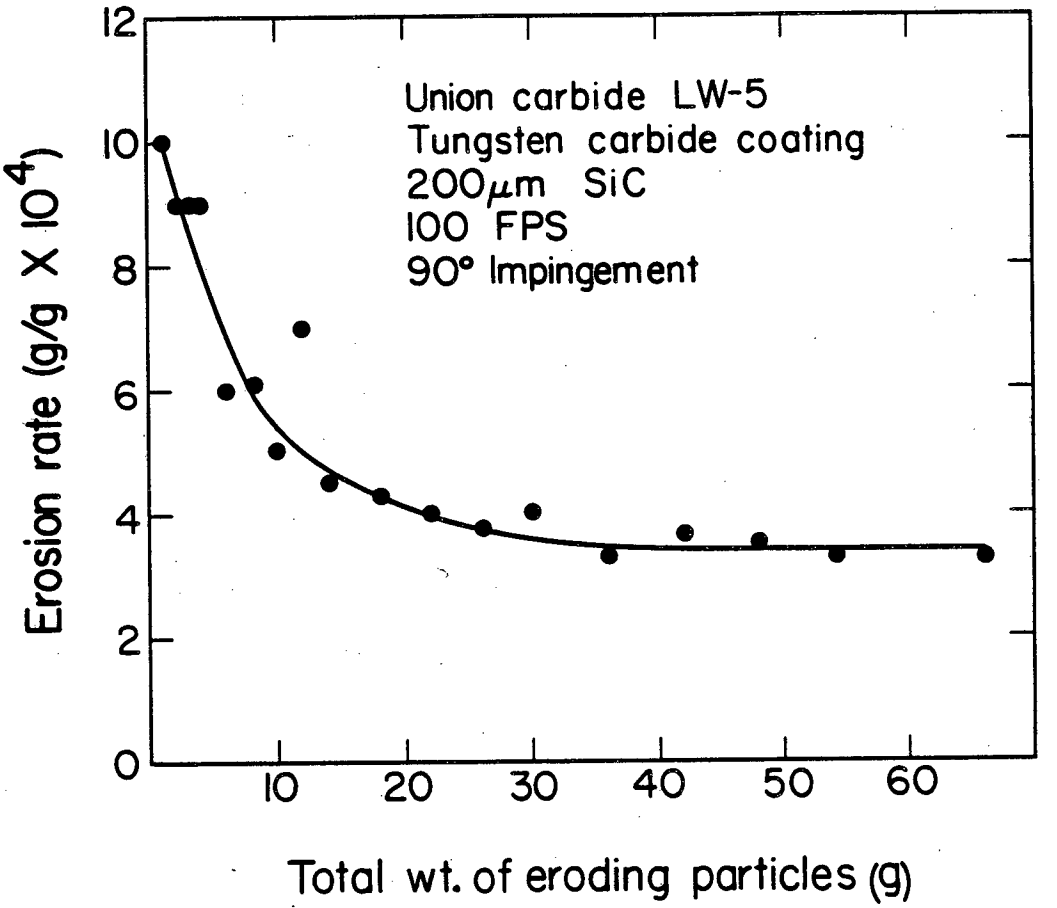

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Fig. 3. Incremental erosion rate of LW-5 sprayed WC.

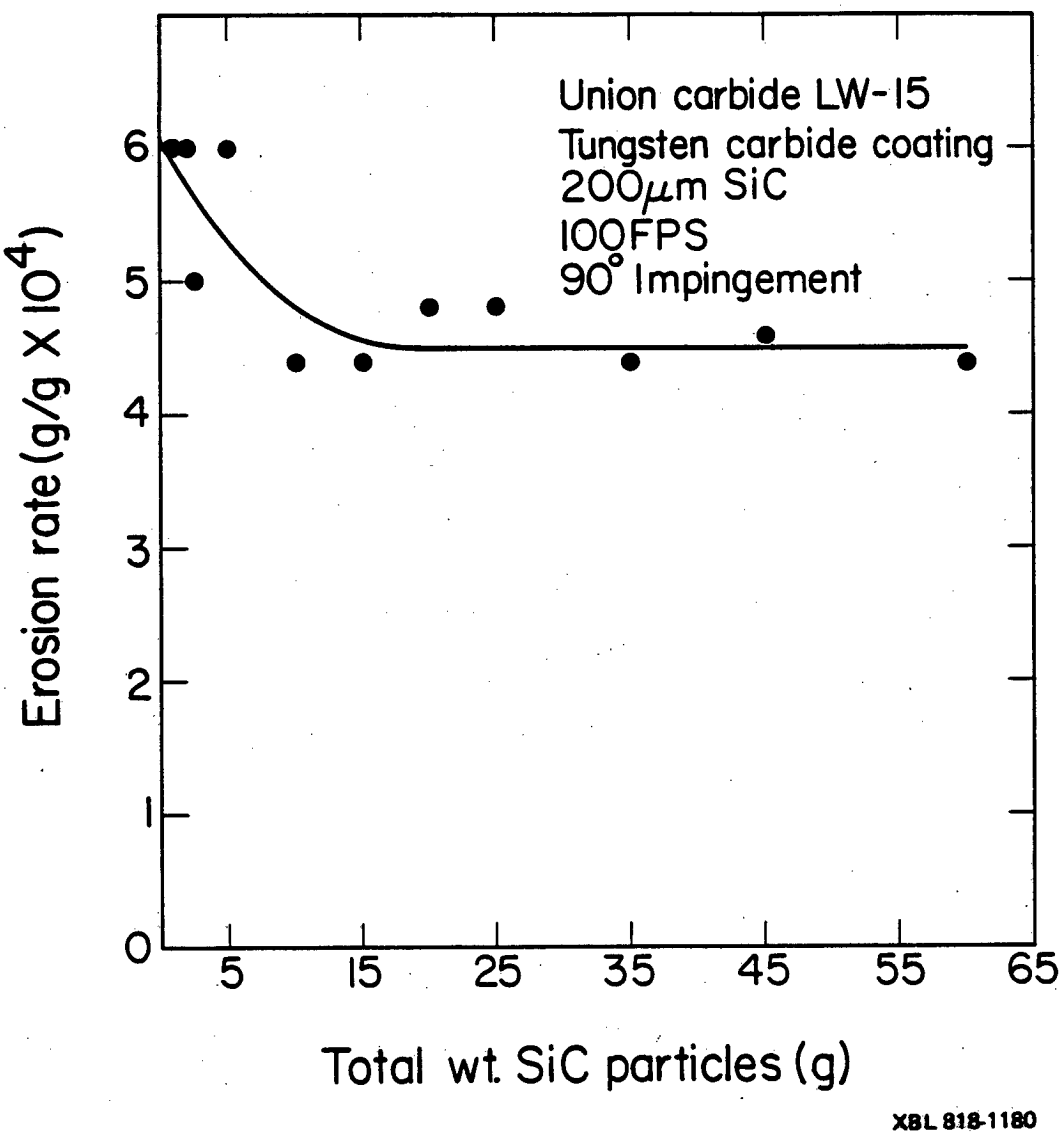

Fig. 4. Incremental erosion rate of LW-15 sprayed WC.

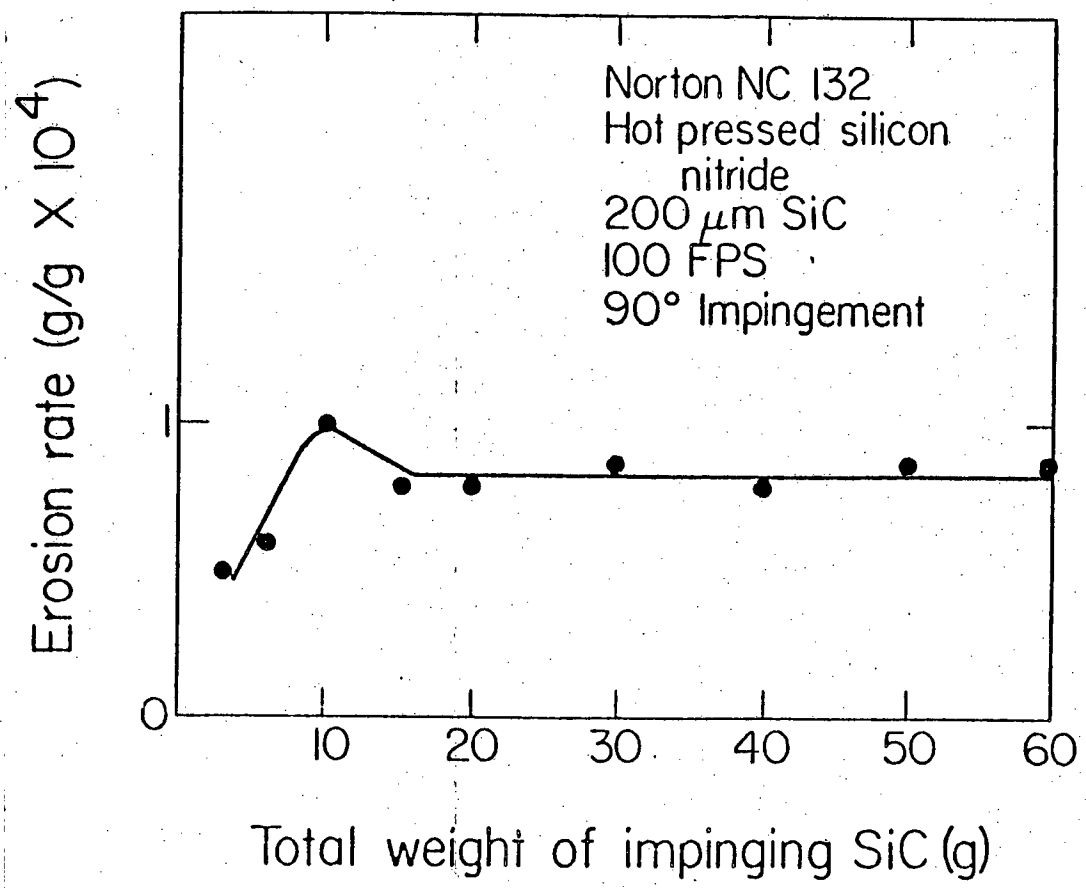

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Fig. 5. Incremental erosion rate of NC-132 hot pressed silicon nitride.

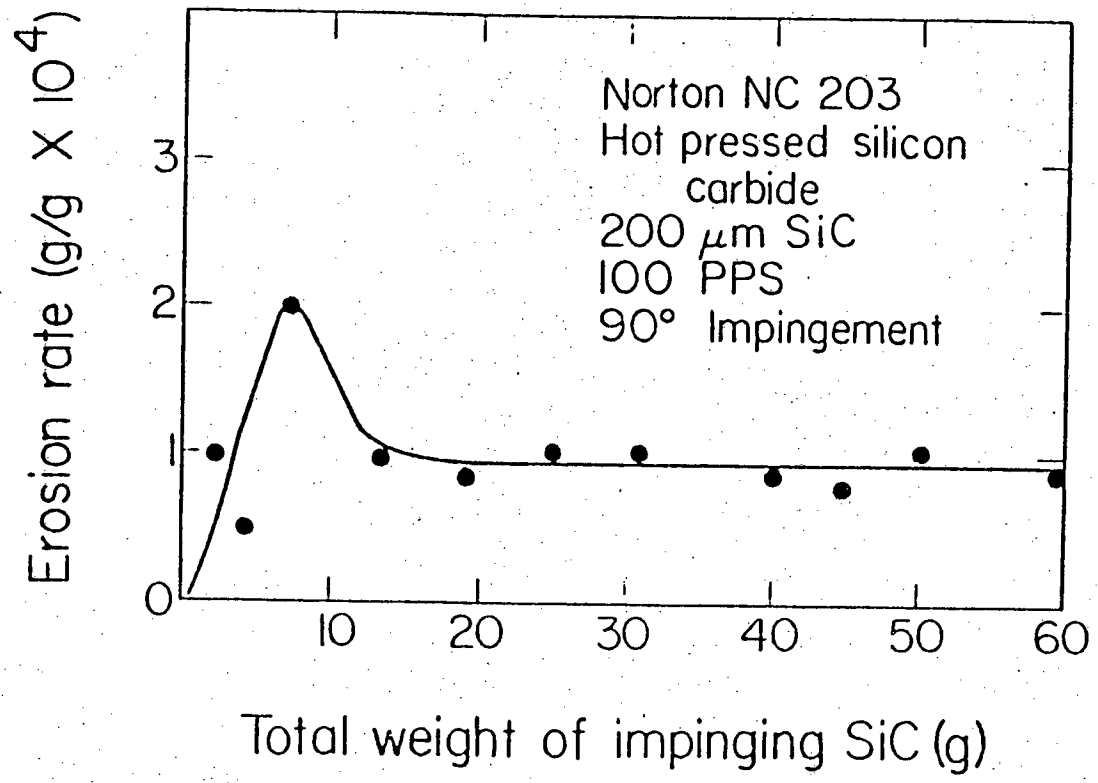

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Fig. 6. Incremental erosion rate of NC-203 hot pressed silicon carbide.

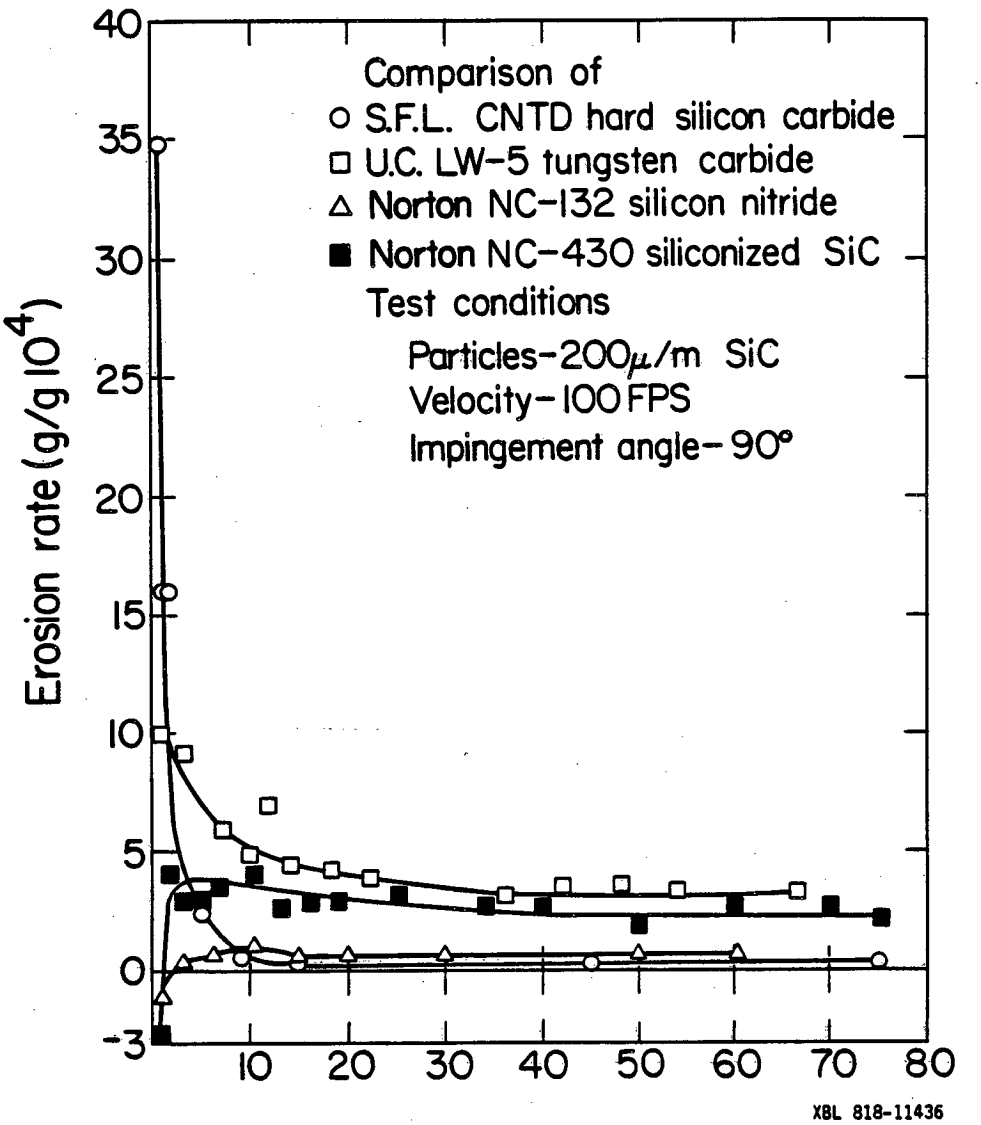

Fig. 7. Incremental erosion rate of several materials.

CNTD SILICON CARBIDE

Steady State Erosion

HARD SOFT

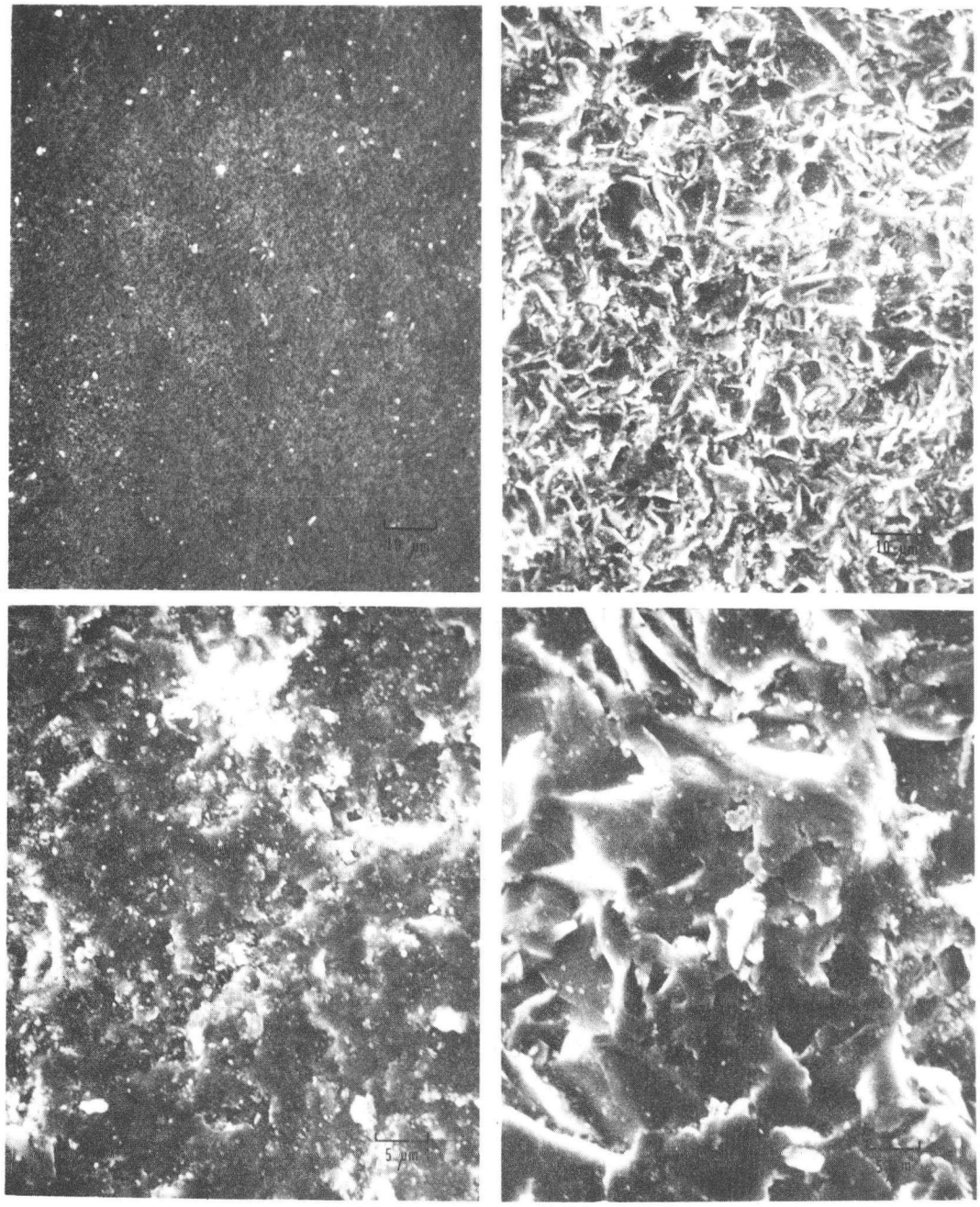

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Fig. 8. CNTD silicon carbide eroded surfaces at steady state.

CNTD SILICON CARBIDE

Peak Erosion

HARD SOFT

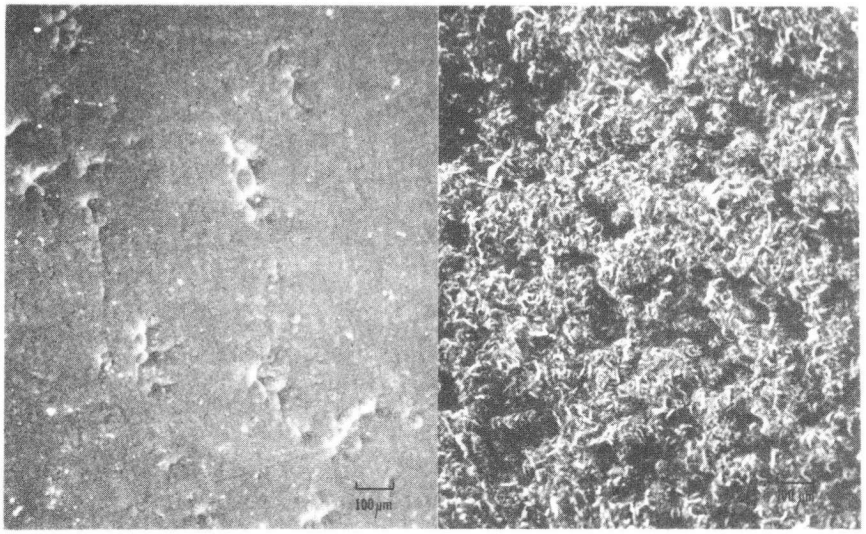

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Fig. 9. CNTD silicon carbide eroded surfaces at peak erosion rate.

CNTD SILICON CARBIDE-HARD

Crack near coating-Graphite Interface

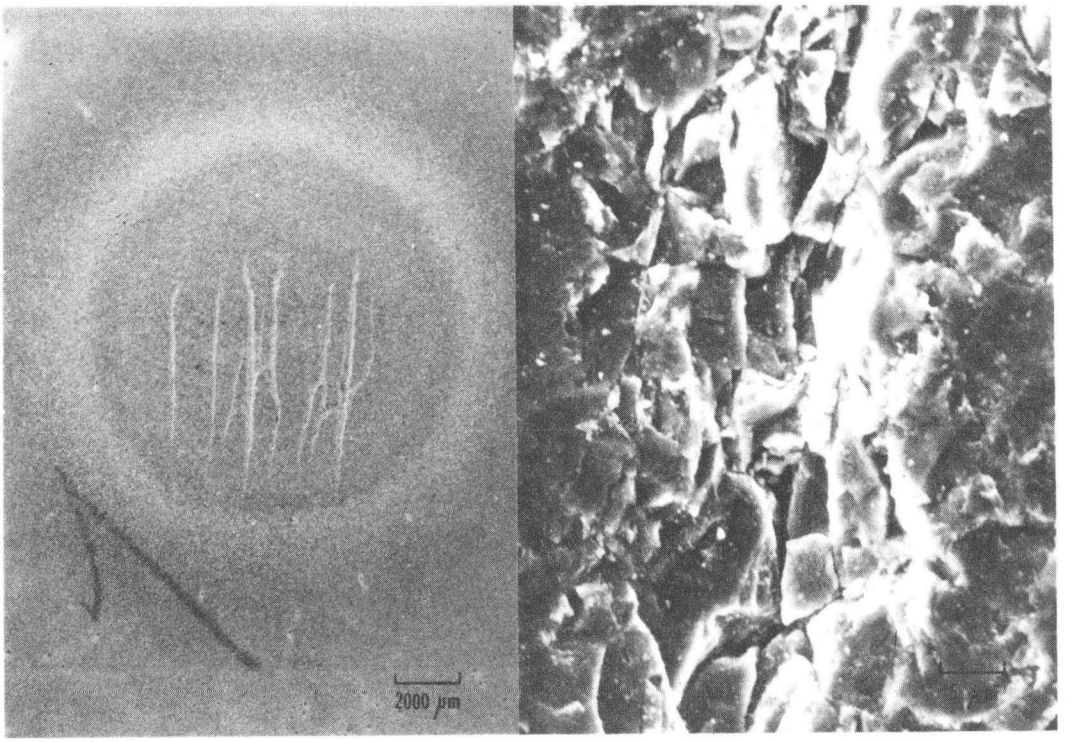

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Fig. 10. Large grained areas of hard CNTD silicon carbide near coating-substrate interface.

LW-5

STEADY STATE ERODED SURFACE

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Fig. 11. Steady state erosion surface of LW-5 tungsten-carbon coating.

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