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Technical Progress Report No.13

Analysis/Control of In-Bed Tube Erosion Phenomena in the Fluidized Bed Combustion (FBC) System

to

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by

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SUMMARY

This technical report summarizes the research work performed and progress achieved during the period of October 1, 1995 to December 31, 1995.

A series of material wastage tests was carried out on cooled AISI 1018 steel and three thermal-sprayed coating specimens at an elevated environmental temperature (300 °C) using a nozzle type erosion tester. Test conditions simulated the erosion conditions at the in-bed tubes of fluidized combustors (FBCs).

Angular silica quartz particles of average size 742 µm were used for erodent particles for tests at an impact angle of 30°, at a particle velocity of 2.5 m/s for exposure periods up to 96 hours. The specimens were water-cooled on backside. Material wastage rates were determined from thickness loss measurements of specimens.

Test results were compared with material wastage test results from testing isothermal specimens. The morphology of specimens was examined by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). It was found that the cooled specimens had greater material wastage than that of the isothermal specimens. The material wastage rate of cooling specimen for AISI 1018 was greater than that for thermal-sprayed coatings. The success in reduction of erosion wastage by cooled-coating specimens was related to the coatings' composition and morphology.

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SECTION 1

EFFECT OF COOLED THERMAL-SPRAYED COATINGS ON IN-BED TUBE EROSION IN FLUIDIZED BED COMBUSTOR

The need to reduce the material wastage which occurs in in-bed tubes in fluidized bed combustors (FBCs) is an important aspect of the development of fossil fuel power generation equipment. Protective surface treatments and coatings have shown to be effective in combating material wastage of in-bed tubes in FBC [1]. In our previous work [2,3], the erosion behavior of AISI 1018 steel and several thermal sprayed coatings was studied. In other investigations [4,5], the isothermal specimens were used. However, in service heat exchanger tubes are usually cooled by water or steam being heated. The tubing is subjected not only to gas-particle mixture, but also has both a temperature gradient across the thickness of the tube wall, and a positive heat flux during operation. Therefore, material wastage and mechanism in actual in-bed tubing could be quite different from those determined from isothermal specimens. In this work, tests were carried out using cooled specimens, which could investigate the effects of the temperature difference between the gas-particle mixture and the surface of specimens on material wastage rate and mechanisms of thermal sprayed coatings at low velocity erosion conditions.

1.1 EXPERIMENTAL TEST CONDITIONS

(A) Test Specimens and Materials

Target materials for the test were three thermal sprayed coatings and AISI 1018 steel, which are commonly used in-bed tubes of FBCs. The characteristics of each target material are listed in Table 1. The microstructures of three coatings are shown in Figure 1. Angular silica quartz particles were used for the erodent material. Their mean particle size was approximately 742 μm with a mean particle density of 2556 kg/m^3. These particles are mainly consisted of silica with a little amount of aluminum.

(B) Test Conditions

Laboratory tests on material wastage were carried out in the elevated temperature blast nozzle type of tester [6]. The surface of the specimen was exposed directly to the environmental temperature while the backside of specimen was water-cooled. The environmental temperature is defined as the temperature of the gas-particle mixture, which affected the surface of cooled specimen. The low particle velocity (2.5 m/s) and low elevated temperature (300°C) simulated the material wastage conditions at the in-bed tube of FBC [6,7]. In our previous work [2], it was found that all tested coatings exhibited "ductile behavior" as demonstrated by higher wastage rates at shallow impact angle than that of steep impact angle. Thus, this work focused on material wastage at a shallow impact angle (30°). Test conditions were summarized in Table 2. Material wastage rates were determined from thickness loss measurements of the specimens.

Material designation	Coating process	Nominal composition	Thickness (μm)	Hardness HVN_{300}	Porosity %
DS-200	HVOF	$75Cr_3C_2$-25NiCr	589	614-810	<2
DS-105	HVOF	Cr_3C_2	495	804-990	<2
Rokide C	Flame spray	$90Cr_2O_36SiO_24Al_2O_3$	548	1900	4

Table 1 Characteristics of Target Materials

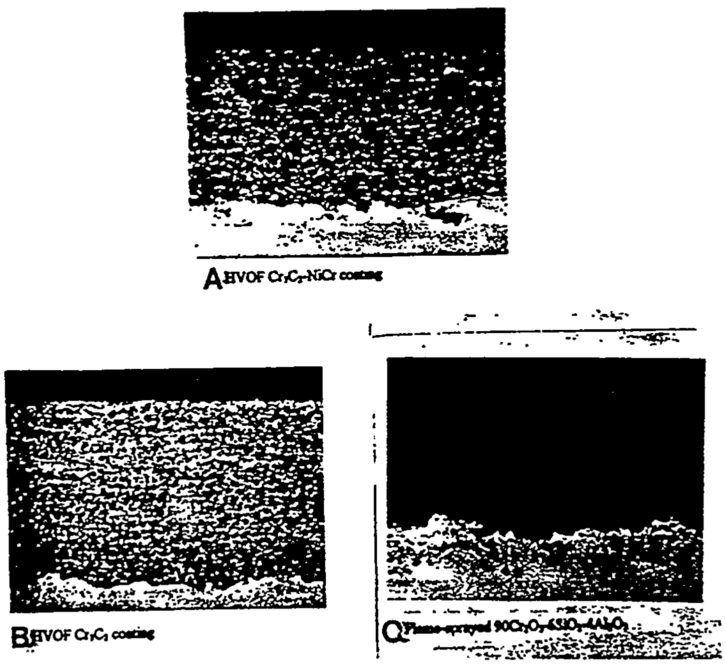


Figure 1 The microstructures of coating specimens: a) HVOF Cr_3C_2-25NiCr coating; b) HVOF Cr_3C_2 coating; c) Flame-sprayed $90Cr_2O_3$-$6SiO_2$-$4Al_2O_3$ coating.

SECTION 2

RESULTS AND DISCUSSIONS

Test results compared with the data of isothermal specimens (uncooled specimens) as shown in Figure 2. It is found that the cooled specimens had greater material wastage than that of the uncooled specimens. Test results indicated that the cooled 1018 steel specimen lost two times as large thickness as that of the uncooled specimen. The thickness loss of the cooled coating specimens had less increase comparing with the results of the uncooled coating specimens.

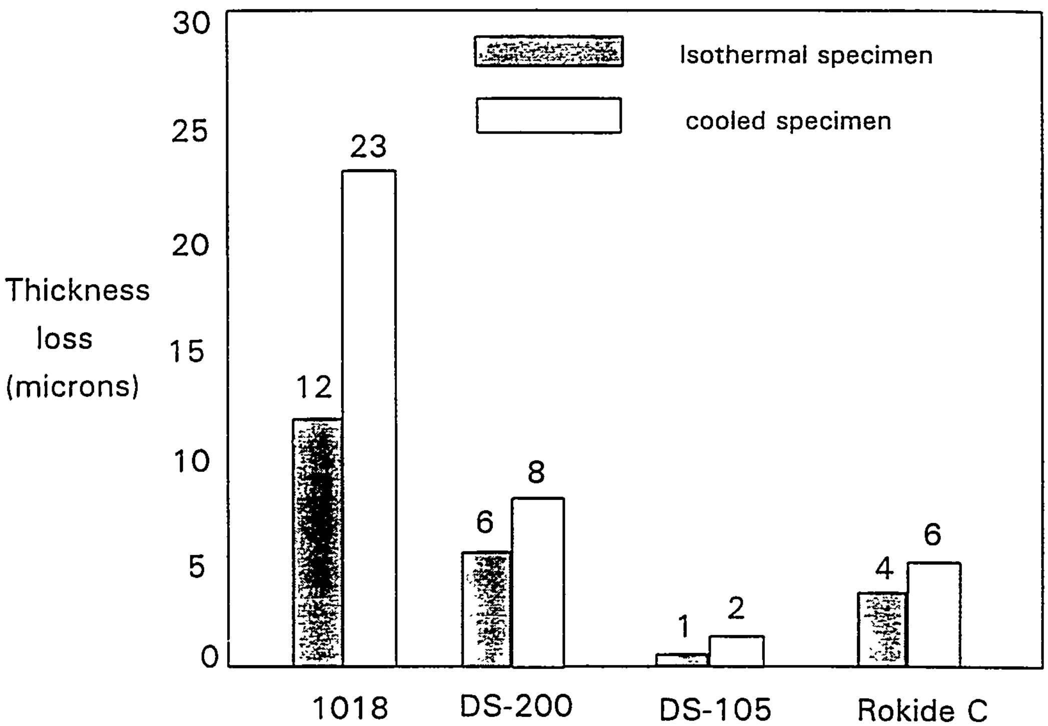
Figures 3 to 6 show the eroded surfaces with EDS analyses and cross sections of the cooled specimens. Some counterparts of the uncooled specimens are shown in Figures 7 to 9. It is found that a thin, continuous scale layer formed on the surface of the uncooled 1018 specimen while no scale layer formed on the surface of the cooled 1018 specimen as shown in Figures 7-c and 3-c. A great amount of erodent particles deposited on the eroded surface of uncooled specimen as proven by EDS analysis as shown in Figure 7-b.

By contrast, less amount of erodent particles deposited on the eroded surface of the cooled 1018 specimen as shown in Figure 3-b. The continuous scale and the depositions of erodent particles contributed to the reduction of material wastage by the protecting the surface [8]. From EDS analyses of the eroded surfaces of thermal sprayed coatings, it was also found that the amounts of deposited erodent particles on the surfaces of cooled-thermal sprayed coating specimens were less than those on the surfaces of uncooled specimens.

The surface of uncooled specimens was more receptive to retaining erodent particles. Since a combination of increased oxide formation trapped the depositions of the fine particles and a general softening of the material surface. The surface temperature increase of the uncooled specimens was immediately occurred as the result of the localized plastic deformation by impact particles. The continuous observation showed less increase of temperature in the cooled specimens than that of in the uncooled or isothermal ones. In addition, the part of heat was drawn away by the cooling water through conduction. Thus, the lower surface temperature resulted in less ductility of the surface and higher erosion wastage rate.

It is found that both surface morphology of cooled specimens and that of uncooled specimens were similar. At relatively low impact velocity, the load carried by each particle was below the threshold, which is needed to cause cracking for "brittle materials" [9]. So, the brittle fracture could be suppressed and the material wastage is believed to be occurred by plastic processes. As shown in Figures 4 to 6, the eroded surface of thermal sprayed coatings displayed the evidence of deformation, such as narrow gouges, striations and small craters. Comparing with the cross section of DS-200 coating specimen and that of DS-105, DS-105 coating specimen had fine structure and smaller splat size than that of DS-200 coating specimen. Thus, DS-105 coating specimen exhibited lowest erosion wastage due to its favorable composition and morphology.

Target material	Material Wastage (thickness loss)			
	Cooled specimens		Isothermal specimens	
	μm	Rate(μm/g)	μm	Rate(μm/g)
1018	23	0.00256	12	0.00133
DS-200	8	0.00089	6	0.00067
DS-105	2	0.00022	1	0.00011
Rokide C	6	0.00067	4	0.00044



Cooled specimen: V=2.5 m /s, T1/T2=750deg.C/300deg.C, 9000g quartz,96 hrs.
Isothermal specimen:V=2.5 m/s,T1/T2=300deg.C/300deg.C, 9000g quartz,96 hrs.

Figure 2 Erosion wastage for four target materials eroded at different test conditions.

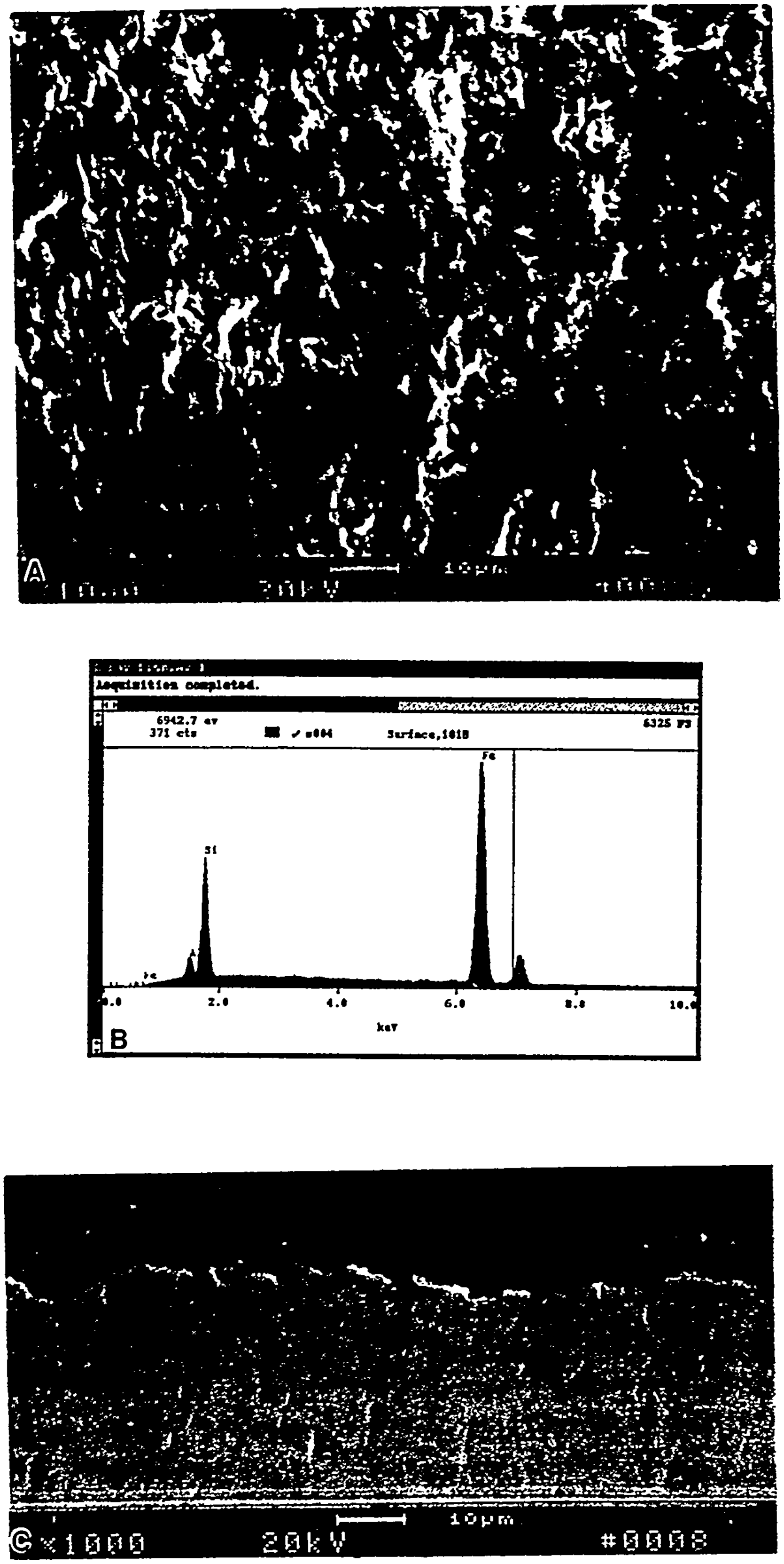


Figure 3 Cooled 1018 specimen,(A) Eroded surface; (B) ESD from surface; (C) Cross-section.

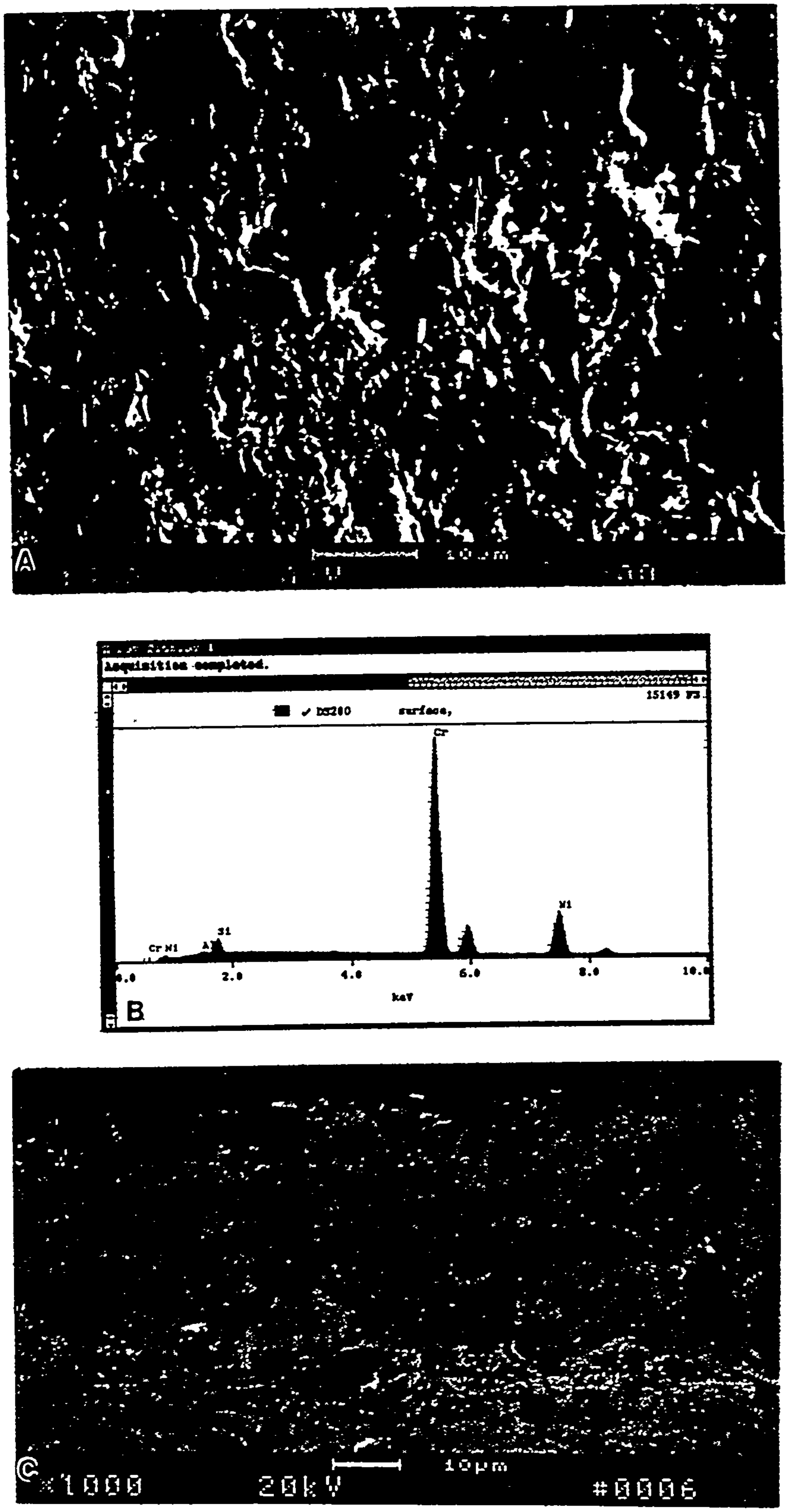


Figure 4 Cooled DS-200 coating specimen, (A) Eroded surface; (B) EDS from surface; (C) Cross-section.

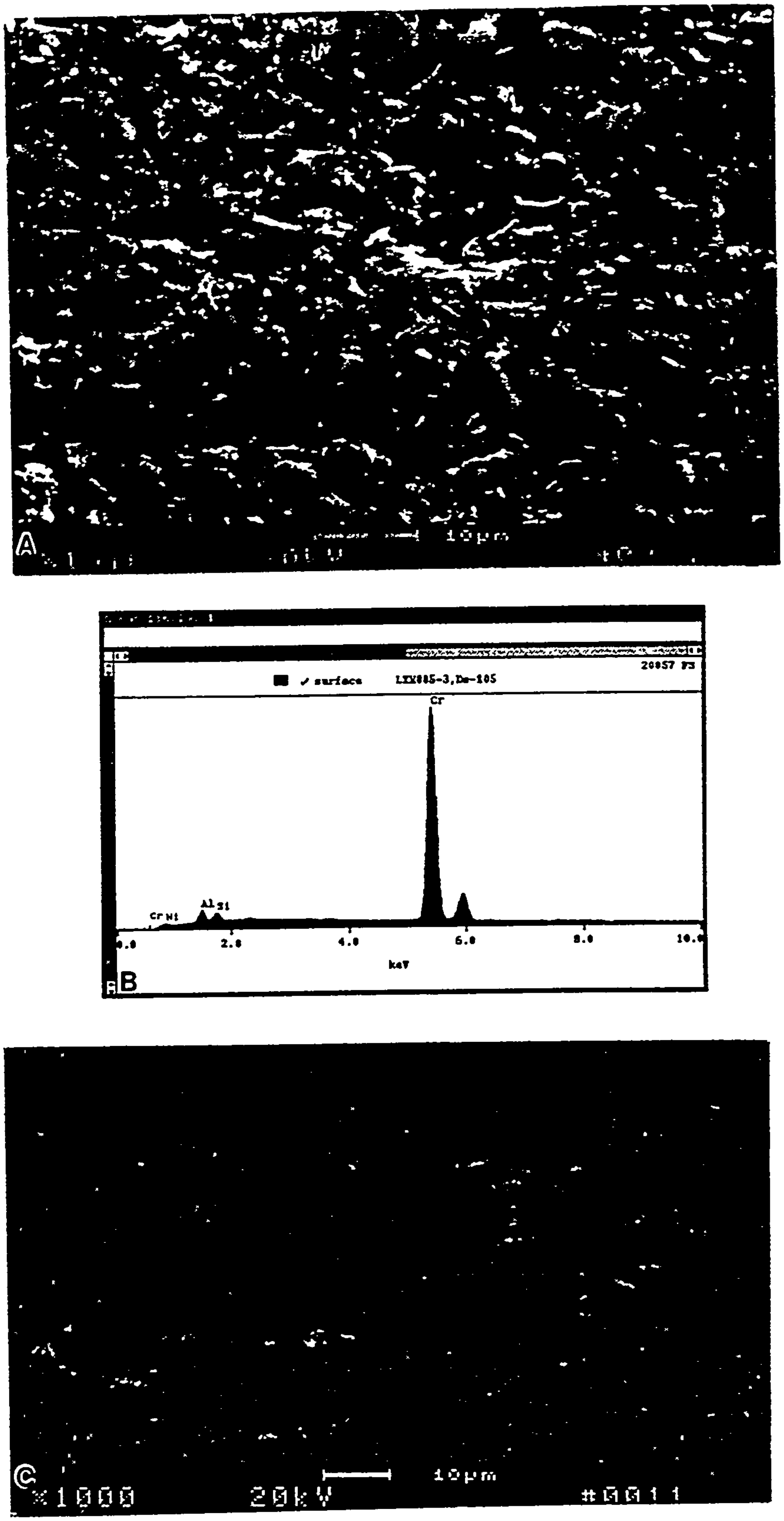


Figure 5 Cooled DS-105 coating specimen, (A) Eroded surface; (B) EDS from surface; (C) Cross-section.

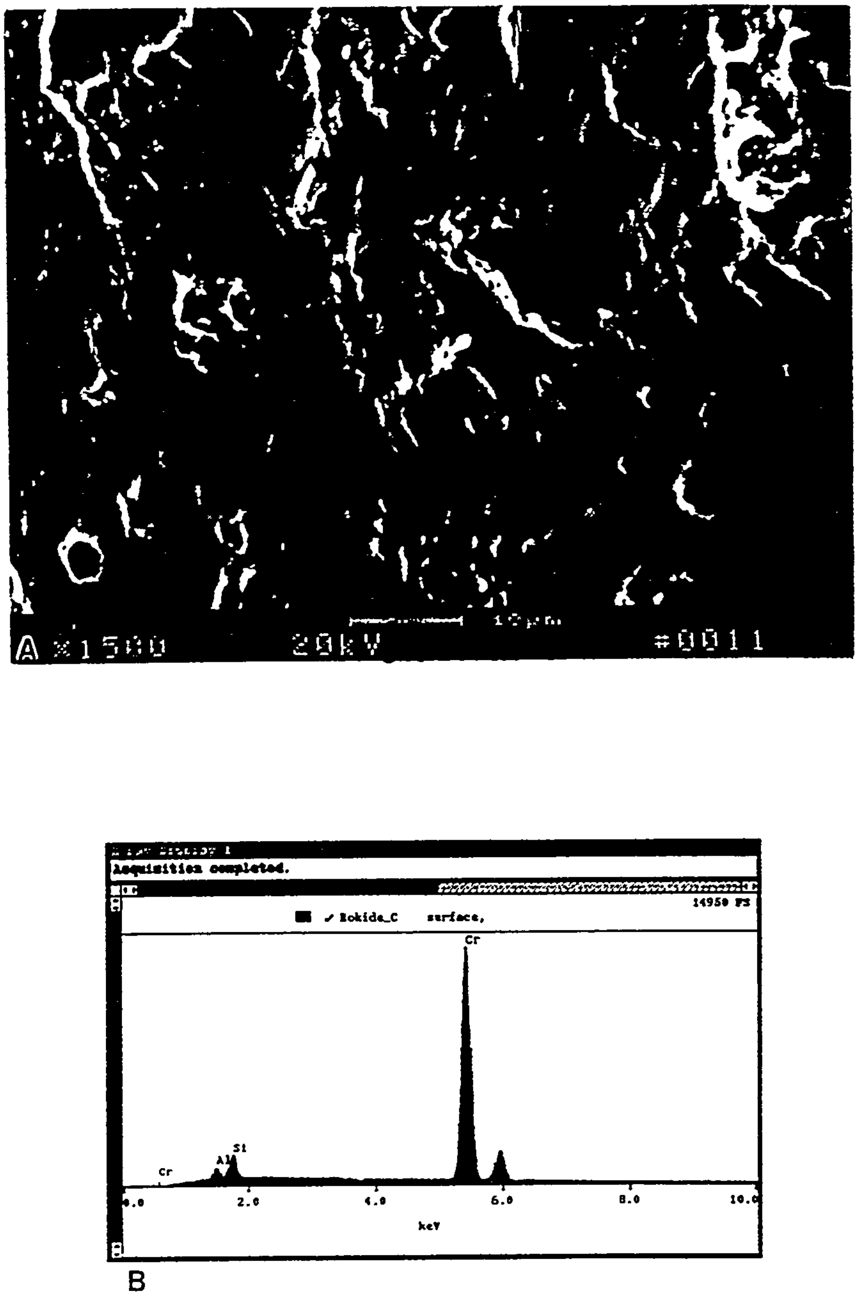


Figure 6 Cooled Rokide C coating, (A) Eroded surface; (B) EDS from surface.

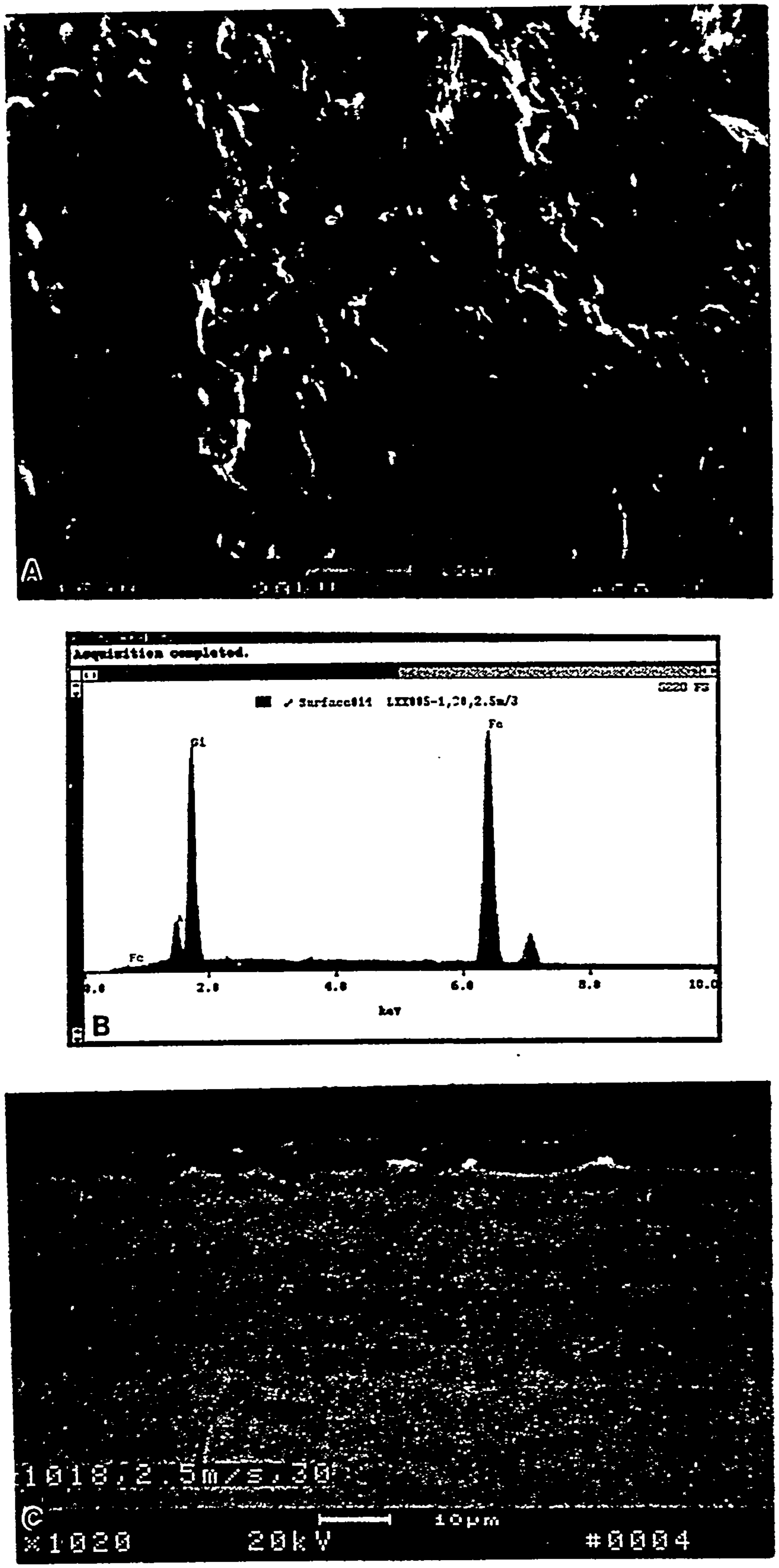


Figure 7 Uncooled 1018 specimen (A) Eroded surface;(B) EDS from surface; (C) Cross-section.

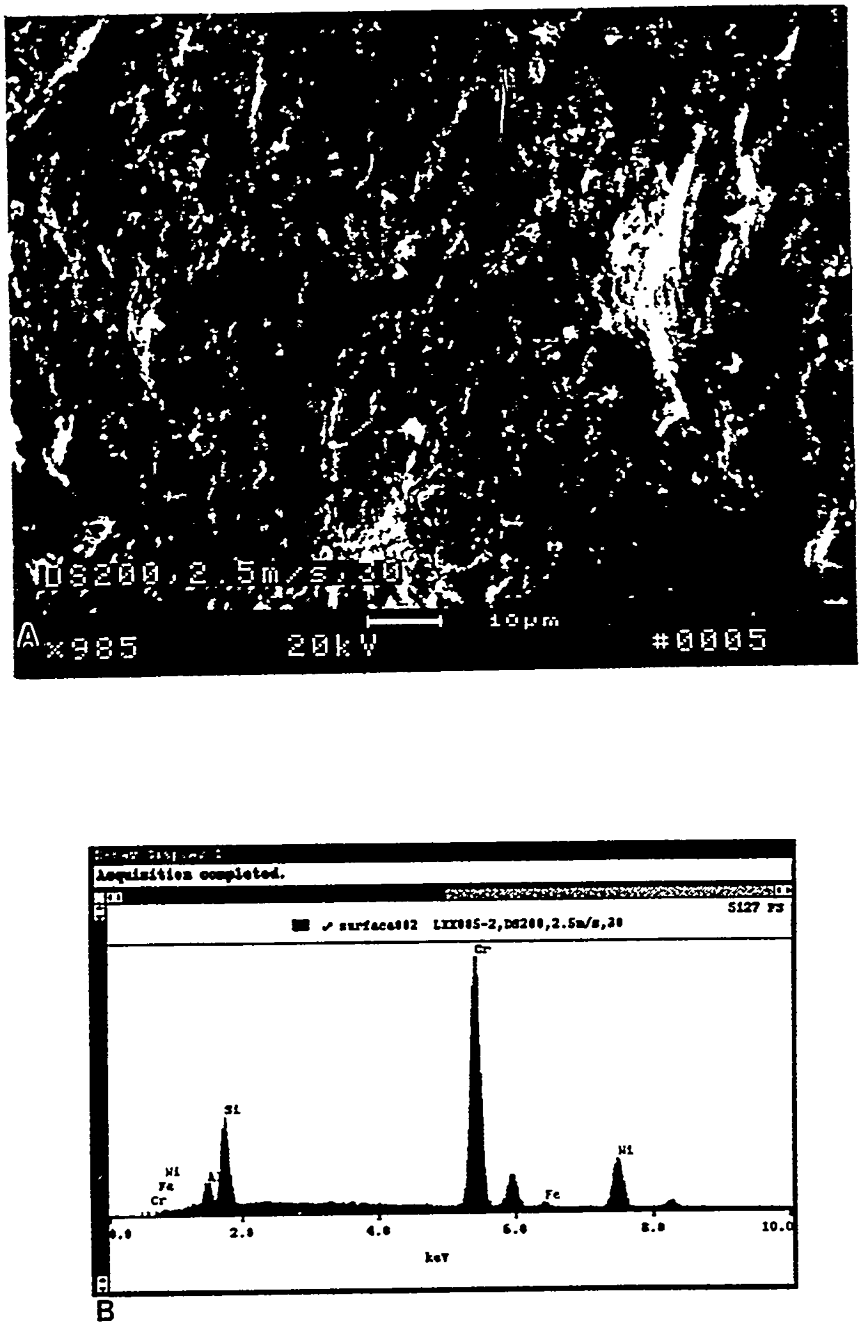
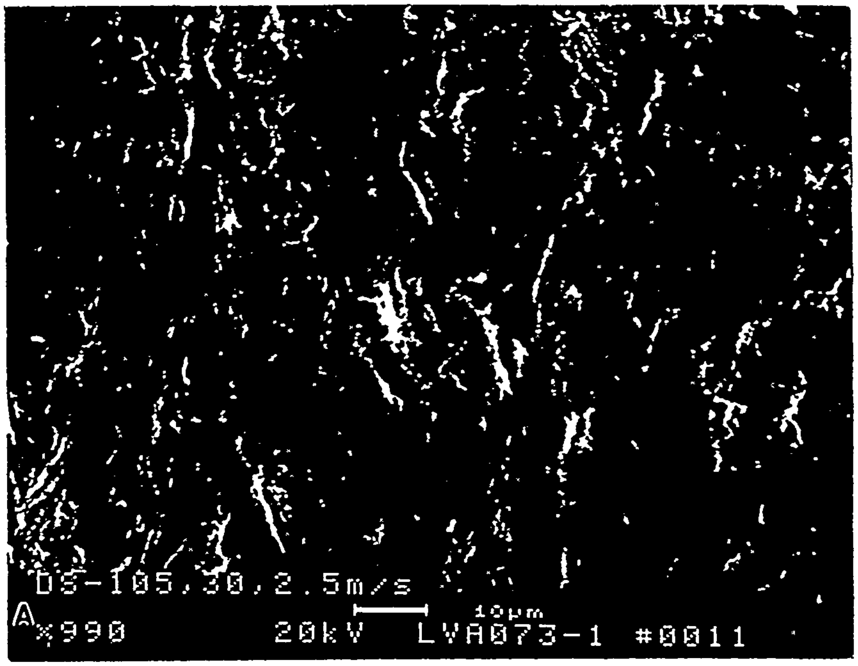


Figure 8 Uncooled DS-200 specimen. (A) Eroded surface.
(B) EDS from surface



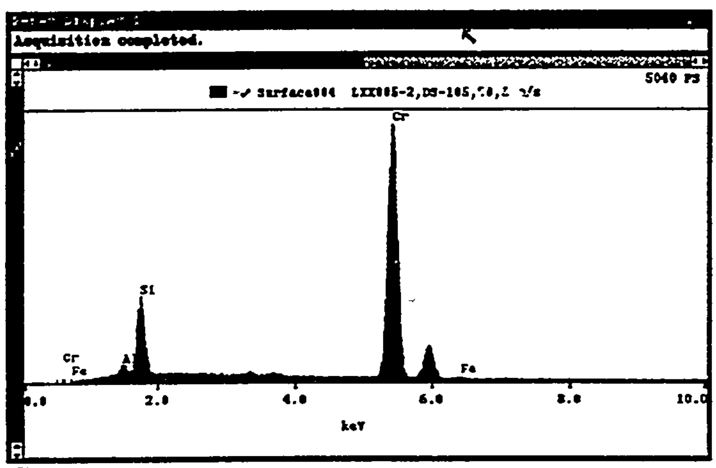


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Figure 9 Uncooled DS-105 specimen, (A) Eroded surface.
(B) EDS from surface.

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