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ABSTRACT

There is significant industrial interest in methods to improve the surface properties of cast iron. This paper describes investigations of laser treatments to enhance cast iron surfaces by alloying with the elements chromium, nickel or cobalt, or a cobalt/chromium mixture. The coatings achieved are of high integrity, low porosity and uniform in composition, microstructure and hardness. Alloyed surfaces have been subjected to corrosion testing in a range of acids and to wear and cavitation erosion in distilled and salt waters. The data show substantial improvements over those obtained from unalloyed material. Results are presented and discussed including the response of the microstructure to the testing environments.

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1. INTRODUCTION

Cast iron finds widespread use in industry owing to its low cost, ease of casting and relatively good wear resistance. These properties, together with acceptable strength and good damping properties, make it invaluable for use in items such as machine castings, engine blocks, agricultural equipment, gears and pumps. However, in certain situations the resistance of flake graphite cast iron to wear and corrosion is often inadequate. In many cases enhancement is required only on the surface; lasers provide an effective and precise technique of selectively heat treating the surface and also (by means of suitable additives) of selectively alloying the surface. Laser surface alloying has been investigated as a means to enhance the wear and corrosion resistance of cast iron in only a limited number of cases[1-3] where the main alloying elements have been chromium and nickel.

The present work concerns the investigation of the alloying of grey cast iron with substantial amounts of chromium, nickel, cobalt and cobalt-chromium mixtures and it is shown that it is possible to form coatings of high integrity that increase considerably the resistance of the cast iron to wear, corrosion and cavitation erosion.

2. EXPERIMENTAL

The substrate material chosen for the alloying was commercial grade 17 Meehanite GC grey cast iron[4] (BS1452, Grade 260) of nominal composition (wt %): C 2.9-3.2, Si 1.7-2.1, Mn 0.5-0.8, P 0.1Max and S 0.06-0.11. Alloying powders used were ≤250μm diameter and contained not more than 0.1% of impurities. Surfaces were alloyed by preplacing powders to a predetermined thickness on cleaned blocks of cast iron and carrying out melting under a protective helium shield using a 5kW CO_2 laser to produce tracks about 0.5mm deep and 4mm wide. Greater widths were produced by laying down overlapped adjacent tracks. After process optimisation[5], alloyed surfaces were subjected to wear, corrosion and cavitation erosion testing.

For wear testing a reciprocating machine was employed in which a loaded SiC pin was rubbed along the test surface with a frequency of 0.33Hz and stroke length 50mm. The testing was performed in a dry environment or with immersion in either distilled or 3% salt water. Evaluation was by weight loss. Corrosion testing was by immersion. Test coupons were hung vertically in various acids at room temperature, all but the alloyed regions being coated with stopping-off laquer. Evaluation was again by weight loss. Cavitation erosion testing employed an ultrasonic facility operating at 20kHz and peak to peak amplitude of 15μm. Testing was performed in distilled and 3% salt water with evaluation being by weight loss and Talysurf profiling. A more detailed account of the tests is given elsewhere[6].

3. RESULTS AND DISCUSSIONS

3.1 Microstructural

Typical microstructures for surfaces alloyed with Cr, Ni, Co and Co-Cr are shown in Figure 1. The related microhardness and EDAX surveys show good mixing and uniformity[5,6]. Table 1 shows results of x-ray diffraction phase analysis and in each case the high temperature phases have been retained to room temperature due to the rapid cooling of the melt.

3.2 Wear Testing

Alloyed cast iron coupons containing either ~20wt%Cr or ~15wt%Ni were assessed and compared with as-received cast iron using the sliding wear test in dry, distilled and 3% salt water environments. Table 2 summarizes the results. Under dry conditions the as-received surface performs better than the alloyed surfaces possibly due to the presence of graphite acting as a lubricant[7]. The alloyed surfaces, whilst harder, contain no free graphite. Under wet conditions however the alloyed surfaces perform significantly better, noticeably so for the chromium alloyed surface under salt water conditions where the corrosion component is absent as indicated by the small difference between distilled and salt water results. It is inferred that under wet conditions, the graphite lubricant is ineffective and the performance is dependent upon the matrix microstructure. In the chromium alloyed iron the fine dispersion of carbides and presence of austenite (which may transform to martensite during wear) is clearly preferable to the pearlitic matrix of the as-received iron. The wear performance of the nickel alloyed surface is similar to that of the chromium alloyed surface in distilled water but in salt the chromium alloyed surface is superior to the nickel alloyed surface possibly due to the presence of a protective chromium film.

3.3 Corrosion Testing

Corrosion testing of both chromium and nickel alloyed surfaces were carried out in 10% nitric, sulphuric and hydrochloric acid solutions. Testing of alloyed surfaces was also performed in 3% salt solution.

Figure 2 shows the weight loss of various chromium coatings in 10% HNO_3 after 3hrs immersion with results for pure iron laser alloyed with chromium also shown for comparison. It is known that pure Fe-Cr alloys show almost perfect passivation above about 12%Cr[8] and the present results indicate that the laser alloyed iron is behaving in a similar manner. In contrast, the alloyed cast iron requires a much higher Cr content to show passivation due to presence of graphite which is in competition for the Cr in order to form carbides.

Corrosion tests on chromium alloyed surfaces employing 10%H_2SO_4 and HCl acids produced much less clear trends. However it is clear that in both cases the corrosion rate increased with the amount of Cr in the coating and also that the corrosion rate was higher in H_2SO_4 than HCl. It should be noted that in the case of $HN0_3$, the acid is oxidizing and serves to promote formation of a protective chromium oxide film.

In contrast to the chromium alloyed surfaces, the 25wt%Ni- alloyed surfaces showed no attack after 3hrs immersion in H_2SO_4, HCl or HNO_3.

A 20wt% Cr coating also showed a high resistance to corrosion in 3% NaCl solution (not de-aerated) at room temperature. After a 50hr exposure less than 1μm of the coating had dissolved compared with about 10 μm of the untreated coating. Similarly, nickel coatings containing ~25wt%Ni showed no attack.

3.4 Cavitation Erosion Testing

Figure 3 shows weight loss rates of as-received and 22wt% chromium alloyed cast iron eroded in distilled and salt water. A dramatic improvement in cavitation resistance is observed due to laser alloying . Table 3 summarizes the results, the steady-state erosion rate being reduced to 0.04 and 0.11 of the as-received values in distilled and salt water respectively. Figure 4 shows the surfaces (SEM) of as-received and alloyed cast irons eroded in both distilled and salt water. For the as-received samples eroded in both distilled and salt water, surface damage is severe, cracks following graphite flakes; additionally for the sample eroded in salt water, extensive corrosion occurred in the region of the flakes. In contrast, the alloyed surfaces are damaged far less, attack occurring mainly in the dendritic region.

Surfaces alloyed with either nickel, cobalt or a cobalt-chromium mixture were also eroded in distilled water, Figure 5 indicating the results. Table 4 gives the general properties of the coatings, where it may be noted that a few cracks occurred for cobalt. From the test results, it is seen that the chromium coating performs best and the cobalt/chromium coating is almost as good. The as-received material exhibits an incubation period of low wear followed by a period of higher loss rate. In the alloyed coatings this change of wear rate is absent. For all alloyed surfaces, damage is minimal and occurs uniformly over the surface except in the case of the nickel sample where it is predominantly at the soft heat affected zones of the laser track overlaps. After testing, the cobalt alloyed surface shows some enhancement of the cracking, possibly stress induced and arising from the high hardness low ductility) of the coating. Figure 6 shows the general appearance of the surfaces in section after erosion.

4. CONCLUSIONS

Localized, surface alloying of a grey cast iron has been demonstrated and investigated using the elements chromium, nickel, cobalt or a cobalt-chromium mixture. The resistance of the surfaces to abrasive wear, corrosion and cavitation erosion have been assessed and results presented. Under wear situations, the presence of water, (and salt water in particular) increased the wear rate of unalloyed iron, but the wear rate of alloyed iron was virtually unaffected. Alloying with chromium provides a better wear resistance in salt water than nickel alloying. In corrosion testing, the chromium alloyed coatings showed a considerable reduction in weight loss in nitric acid for compositions >20%Cr; however, this trend was not seen in sulphuric and hydrochloric acids. Alloying with nickel virtually eliminates attack by sulphuric, hydrochloric and nitric acids. Both chromium and nickel coatings eliminated attack by salt water. All coatings reduced considerably the cavitation erosion in distilled water while the chromium coating reduced the erosion rate in both distilled and salt water.

5. ACKNOWLEDGMENTS

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Coating Composition (wt%)	Austenite (fcc)	Ferrite (bcc)
34% Ni	nearly all	none
22% Cr	major amount	substantial amount
55% Co	none	nearly all
30% Co-23% Cr	nearly all	negligible amount

In each coating there were small amounts of unidentified phases.

Table 1. Major phases identified by x-ray diffraction in the laser surface alloyed coatings on grey iron.

	As-Received			Cr-Alloyed			Ni-Alloyed		
Hardness HV_5		250			660			580	
Test Condition	Dry	Dis. Water	Salt Water	Dry	Dis. Water	Salt Water	Dry	Dis. Water	Salt Water
Test Length km	2	2.8	2.0	3	8.2	8.0	10.1	11.34	8.4
Weight Loss mg	7	50	78	17	54	50	122	90	127
Weight Loss μgm^{-1}	3.5	18	39	6	6.6	6.3	12.1	7.9	15.1

Table 2. Steady state wear results of a grey cast iron and laser surface alloyed grey iron containing ~20%Cr and 15%Ni.

	Distilled Water: Incubation* Time mins	Distilled Water: Final Slope $mghr^{-1}$	3% Salt Water: Incubation Time mins	3% Salt Water: Final Slope $mghr^{-1}$
As-received (AR)	60	20	17	140
Laser alloyed (LA)	>160	0.8	20	16
LA/AR ratio	>2.7	0.04	1.2	0.11

	3% Salt/Distilled Water Ratio: Incubation Time	3% Salt/Distilled Water Ratio: Final Slope
As-received (AR)	0.3	7.0
Laser alloyed (LA)	<0.13	20.0

*Nominal incubation time corresponding to extrapolation of final slope to time axis.

Table 3. Cavitation erosion properties of as-received and alloyed cast iron eroded in distilled and 3% salt waters.

Property	Ni	Co	Co/Cr
Coating thickness (±0.1mm)	0.5	0.5	0.5
Compositional (Point, EDAX)	57%	42.7%	26.6%Co 20.9%Cr
Hardness (HV_5)	297	772	435
Phases	Austenite	Ferrite	Austenite
Porosity	Little	Few Large ~0.5mmφ	Minimal
Integrity	Good	Few Cracks	Good

Table 4. General properties of coatings alloyed with nickel, cobalt or cobalt/chromium.

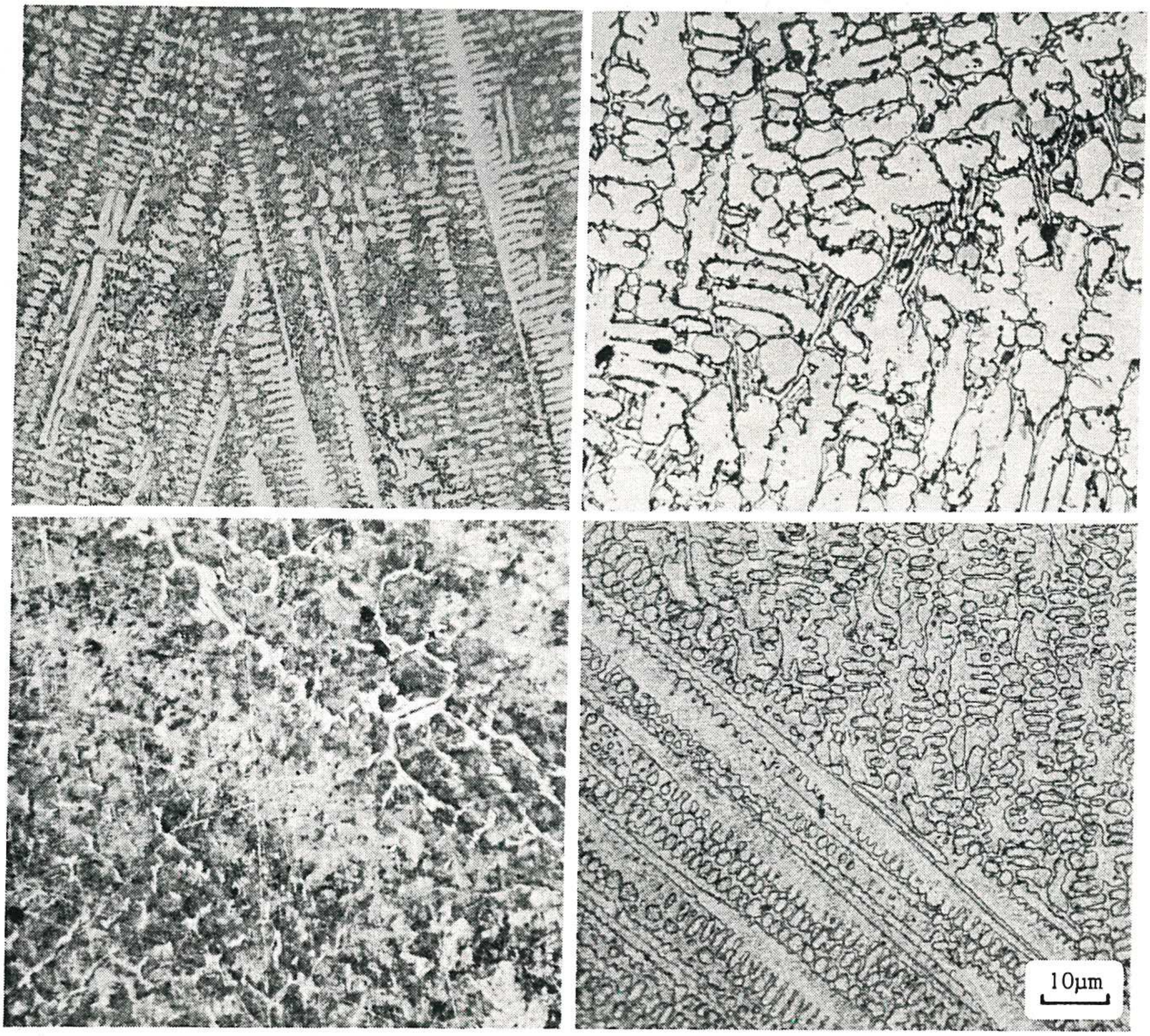


Fig. 1. Typical microstructures of surfaces alloyed with Cr (top left), Ni (top right), Co (bottom left) and Co-Cr (bottom right).

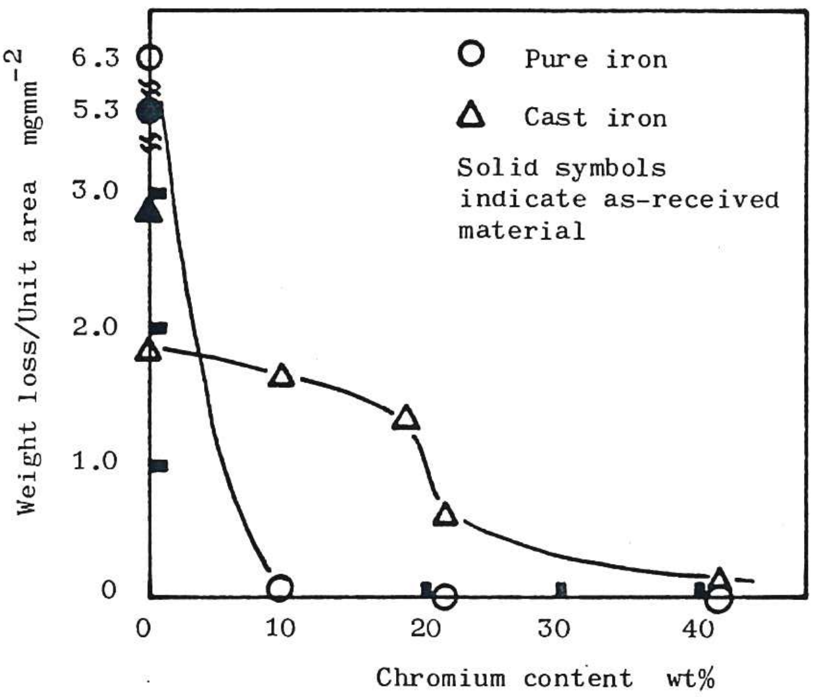
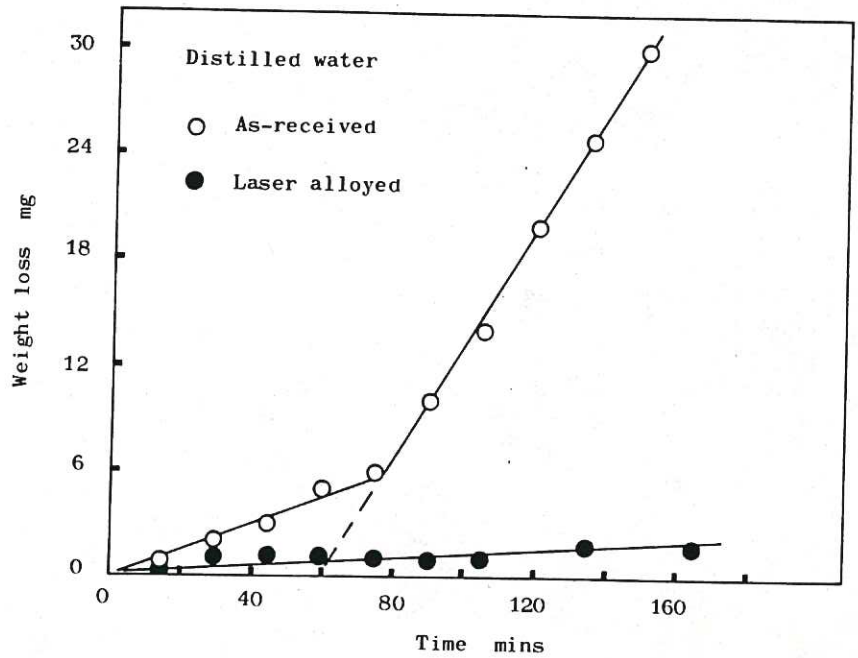


Fig. 2. Weight loss due to corrosion in 10% nitric acid for 3hrs at room temperature of laser surface alloyed coatings containing chromium on pure and cast irons.



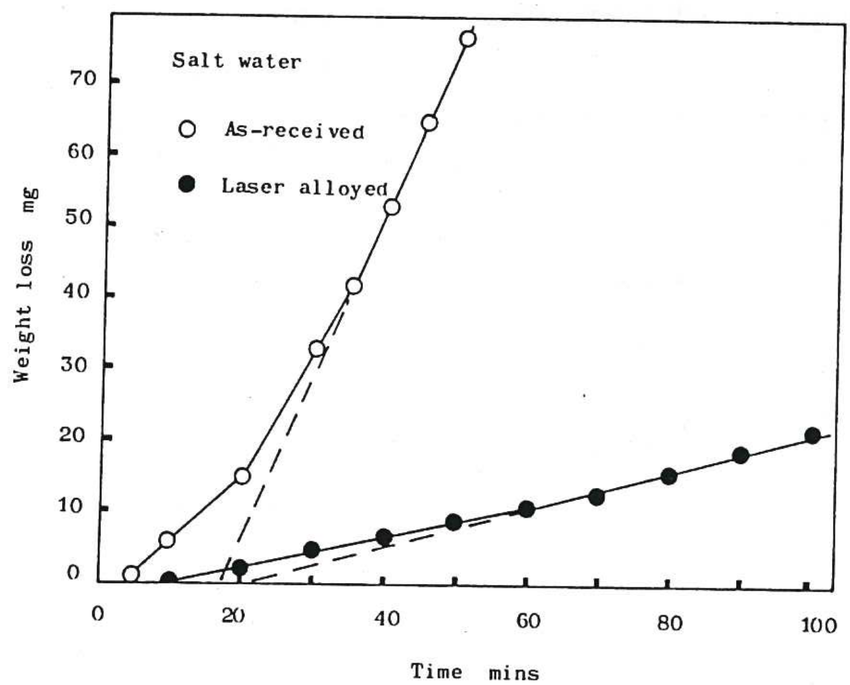


Fig. 3. Weight loss due to cavitation erosion as a function of time for as-received and chromium alloyed cast iron eroded in distilled (upper) and salt water (lower).

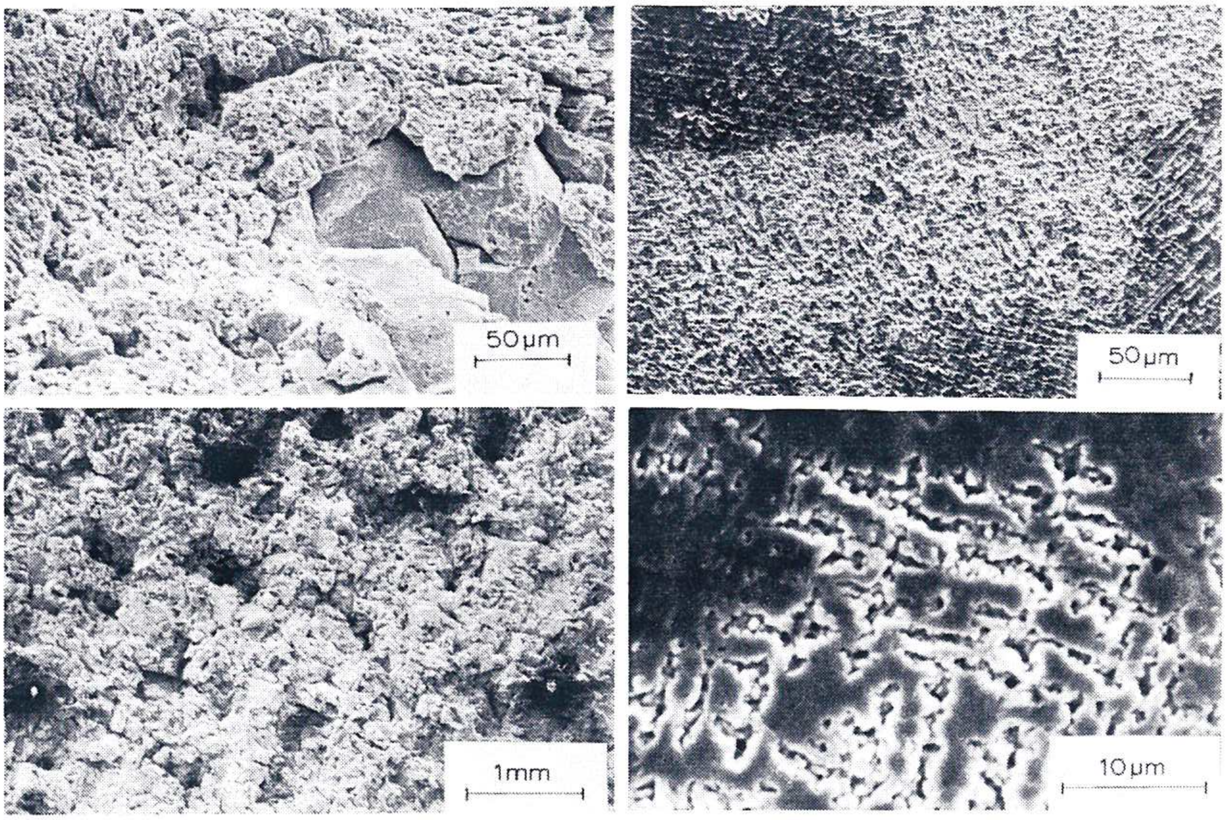


Fig. 4 . Surfaces (SEM) of as-received cast iron (left) and chromium alloyed cast iron (right) eroded in distilled water (upper) and salt water (lower). Note changes of scale.

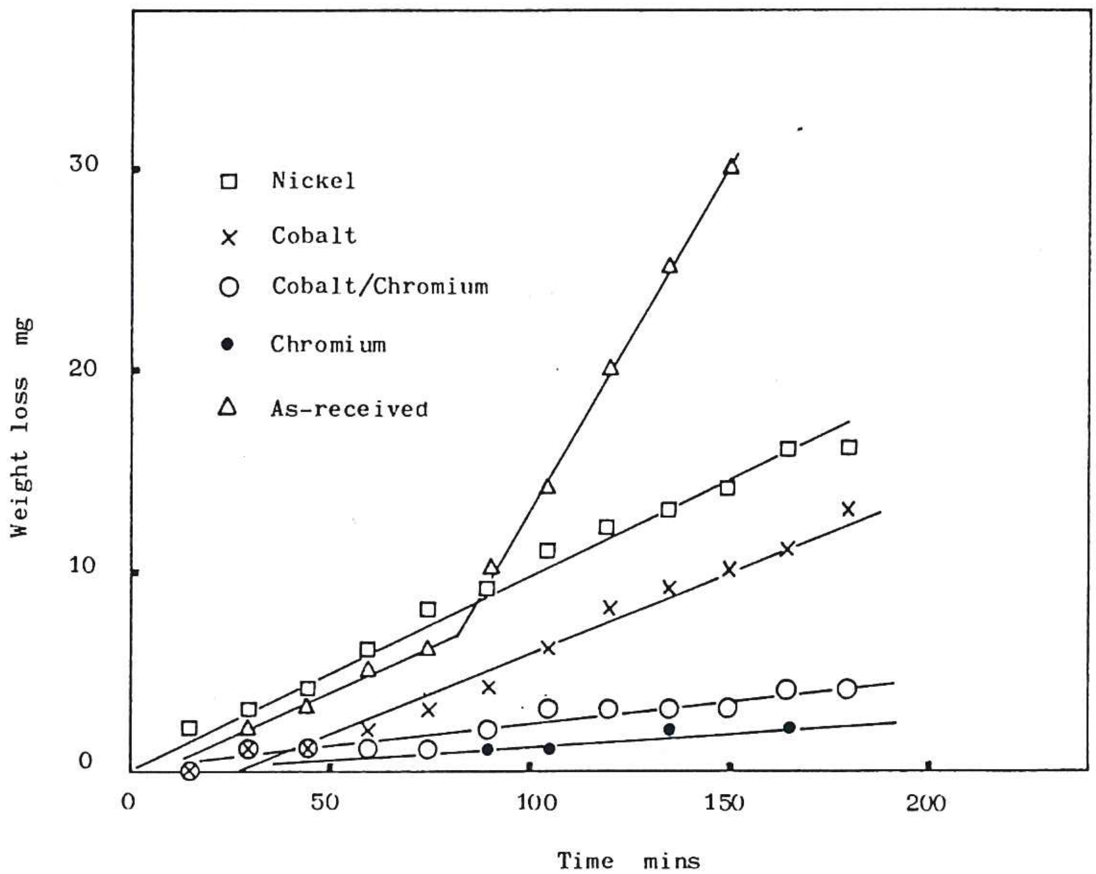


Fig. 5. Cavitation erosion results for alloyed surfaces eroded in distilled water. Also shown are results for as-received and chromium alloyed surfaces.

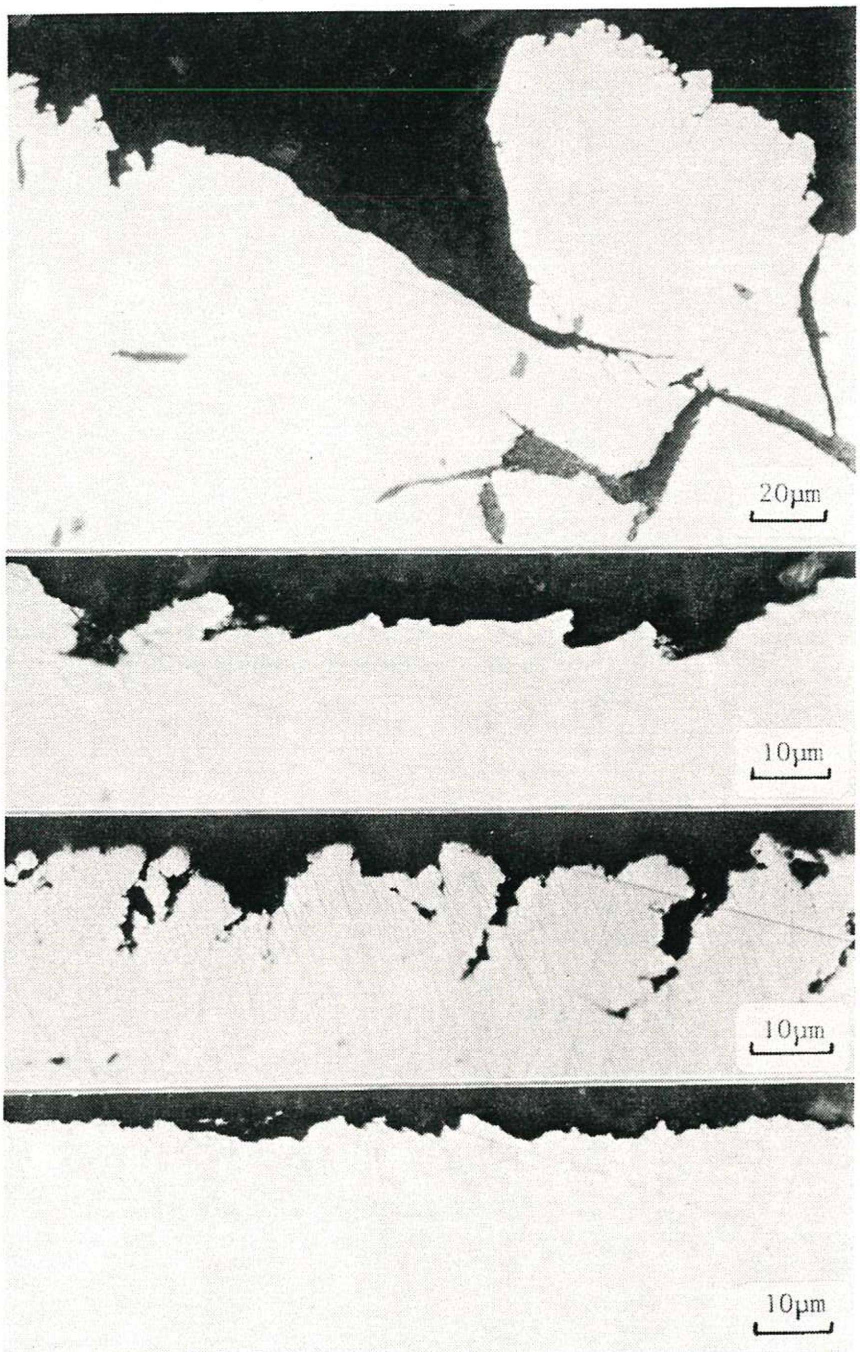


Fig. 6. Sectional appearance (top to bottom) of as-received, nickel, cobalt and cobalt-chromium alloyed surfaces after erosion in distilled water.