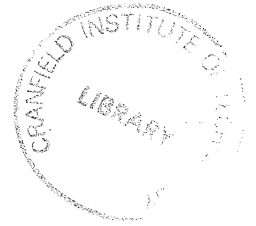




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Effect of Iron on the
Performance of IN 625 Weld Deposits

Final Technical Report
by
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Cranfield Institute of Technology
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1. Introduction

Alloys which have good sea water corrosion resistance often have low levels of strength. Attempts to increase the inherent strength of such alloys often result in a reduction in the corrosion resistance or in other important properties, such as weldability. Recently there has been a development towards the use of a steel substrate to meet the basic strength requirement with the corrosion resistance being supplied by the use of a protective surface coating. One accepted technique for providing such corrosion resistant layers is fusion weld cladding (1, 2). This process not only imparts corrosion resistance to the components but can also provide improved wear characteristics if the cladding material is carefully chosen. Many of the best corrosion resistant materials are expensive and this route therefore also allows the best properties of the two materials to be combined in the most cost effective way.

One metallurgical problem associated with weld cladding is that of diffusion across the steel/cladding interface during deposition. This can involve 'penetration' where elements from the cladding alloy diffuse into the steel, often along grain boundaries, causing subsequent embrittlement. Alternatively, iron dilution can occur where iron diffuses from the steel into the clad layer. The former is often a problem when depositing copper base alloys onto steel and careful procedures must be followed to avoid it. The latter can cause a deterioration in the corrosion resistance of the clad layer due to its modified composition particularly when iron rich phases are formed in the cladding (2).

A common way of avoiding such compositional variations is to use multilayer cladding techniques. This involves depositing a series of layers of the same cladding alloy to sequentially reduce the iron dilution that is occurring. Alternatively, less harmful barrier layers are deposited between the substrate and the cladding which reduces the harmful diffusion from the cladding to the steel, for example, a nickel layer between steel and a copper base alloy.

One cladding alloy which is finding increased usage in the protection of steel in seawater and is currently of interest to the Ministry of Defence Navy, is the nickel rich Ni-Cr-Mo alloy IN 625 (Wiggin Alloys Ltd)⁺. This alloy has

⁺Nominal composition of IN 625 is Ni 61, Cr 22, Mo 9, Fe 2.5, Mn 0.3, Al 0.2, Ti 0.2, Si 0.2, C 0.1, Nb + Ta 3.6.

excellent resistance to seawater corrosion attack (3) under both crevice or fast flowing situations, combined with high strength. The wrought product is however very expensive but the excellent deposition characteristics of the alloy and a low level of intergranular penetration make it an ideal cladding material. The iron content of the alloy is restricted to a minimum of 5% in the nominal composition (see Table I). This level is difficult to achieve during weld cladding especially with high heat input welding processes, due to dilution effects. Therefore, in order to restrict clad layer compositions to within the specification range, two or even three layer deposition techniques have to be used where each layer has a progressively reduced iron content.

There is a considerable economic advantage associated with single layer cladding techniques. This arises not only from the reduced welding costs but because of reduced interlayer machining costs and the elimination of non destructive testing between weld runs. For example, in a typical two layer deposit dye penetrant inspection may be demanded at three separate stages and ultrasonic testing at two. In each instance a suitably flat surface is required and extensive machining or grinding is necessary. Much of this expense would be saved if a single layer clad deposit could be used.

The present programme of work was instigated to determine the effect of iron dilution on the resulting properties of single layer clad deposits of IN625 on steel. By varying the welding procedure, the level of iron dilution was controlled and the effect on subsequent coating performance determined. Particular note was to be made of the corrosion behaviour of the various claddings in comparison to wrought IN 625 and to other materials currently being specified for their resistance to seawater corrosion attack.

2. Experimental Work

The weld cladding was undertaken at the Admiralty Marine Technology Establishment, Portsmouth using an automatic MIG system. The base material for cladding was a boiler quality carbon manganese steel plate which was cut to approximately 360 x 200 x 25mm. To control distortion each plate was attached to a heavy steel block by MMA welding. Following cleaning of the upper surface of the plate by disc abrasion and degreasing, stringer beads of IN 625 were deposited parallel to the longer side of the plate. Different welding

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parameters were chosen for each plate to vary the degree of arc penetration into the steel and hence the iron content of the clad layer. These included the use of pulsing techniques. These parameters are listed in Table II. A single reel of filler wire, the analysis of which is given in Table I, was used to minimise iron variations throughout the samples other than those due to dilution effects.

Following welding, each plate was cut into four sections and trimmed. The clad surface was then machined to a depth of 1mm below the minimum thickness of the weld beads. The clad material removed in the machining operation was retained for chemical analysis of iron content which is given in Table II.

Sections were then taken from each plate to enable the microstructure of the clad layer to be examined in both the longitudinal and transverse directions with respect to the weld runs, Figure 1. The samples were examined in a Cambridge Instruments S600 scanning electron microscope where the compositional changes in the clad layer from the steel/IN 625 interface to the surface were determined using a link systems dispersive X-ray analysis attachment. The microstructure of the clad layer was then examined using both optical and electron microscopy to identify any effects of iron contamination on second phase particle formation, on segregation and on the possible formation of new phases.

Several etches were used in an attempt to highlight different regions of the microstructure. The time taken to produce a detectable darkening of each specimen was noted because it was felt that this might give an approximate guide to the susceptibility of the different samples to corrosion attack.

Attempts were made to assess the corrosion behaviour of the IN 625 layers using a number of techniques. Polished surfaces were carefully examined in the scanning electron microscope after exposure to corrosion environments in an attempt to identify specific susceptible corrosion sites in the microstructure. In addition, weight loss experiments were used following accelerated corrosion testing in, for example, cupric chloride solution, a test designed to rate alloy susceptibility to sea water corrosion attack. These techniques did not prove very successful and later measurements were carried out using both the impedance technique and the determination of polarisation curves.

The specimens for the corrosion experiments were produced by removing the clad layer from the steel plate by cutting and grinding. This enabled 25mm square specimens to be cut from each clad layer which consisted entirely of clad material. The region of the clad layer which was previously in contact with the steel interface was removed by coarse polishing in order to restrict compositional variations within the cladding. Finally, both sides of each specimen were metallographically polished to a 1 micron finish. For the impedance tests, each specimen was then blanked off to give a totally exposed surface area of 400 sq mm. The specimens were immersed in 3.5% sodium chloride solution and the impedance measurements carried out.

Polarisation curves were obtained for clad layers containing a low, intermediate and high level of iron contamination. Each specimen was cut to produce identical surface areas of 400 sq mm, mounted in bakelite and polished to a 1 micron finish. The samples were then connected to a potentiostat and immersed in sea water solution. A potentiostat scan was carried out to produce the polarisation curves.

The effect of iron dilution on the mechanical properties of the clad layers was assessed in two ways. Firstly, hardness tests were carried out using both Vickers hardness with a 1kg load and microhardness traverses across the coating from the steel/IN 625 interface to the surface of the clad layer. Secondly, tensile samples were prepared from certain of the clad layers following the removal of the steel substrate. The tensile axis was orientated parallel to the direction of the weld run in each case. The samples had a gauge length of 25mm and were 10mm wide with the specimen thickness varying with the thickness of the clad layer. The specimens were tested on a Nene testing machine at a crosshead speed of 5mm/min.

3. Results

3.1 Metallographic Examination

Specimens were cut from each clad plate in both the longitudinal and transverse directions, Figure 1. These were then polished to a 1 micron finish prior to analysis using the X-ray dispersive analysis system on the scanning electron microscope. Spot analyses were carried out at 4 micron

intervals from the steel/IN 625 interface outwards for between 60 and 80 microns. In addition further analyses were taken between this point and the outer surface of the clad layer. The variation of iron content with distance is shown in Figure 2 for one series of spot analyses from each plate. A minimum of three series of spot analyses were carried out on each sample in both the longitudinal and transverse directions with respect to the weld runs. The results shown in Figure 2 represent typical analyses from each of the clad plates studied. There was a marked similarity in the curves from samples with a range of iron contents. The level of iron fell sharply over a distance of approximately 20 μm from the steel interface to a level that was thereafter fairly constant. The final level of iron was higher than the predetermined chemically analysed levels of iron in the IN 625 claddings (see Table II), but the technique is only semi-quantitative. No significant variation in analysis was found between each analysis set or between sets from longitudinal and transverse sections from the same specimen. The composition of the clad alloy therefore varies markedly in the vicinity of the substrate interface, but thereafter remains essentially constant as indicated by Figure 3 which shows in more detail how the concentration of iron and other major elements present in IN 625 change with distance from the steel/IN 625 interface.

Following the chemical analysis determinations, samples were etched and examined using both optical and scanning electron microscopy. Several etching reagents were tried in an attempt to highlight any significant differences there may have been between the clad layers with varying iron dilutions. Macro examination of the clad layers showed columnar growth from the steel interface outwards.

Electrolytic etching in sulphuric acid showed all samples to have a similar fine cored dendritic structure with randomly dispersed precipitates, Figure 4, which, from their composition and similarity to other published work (4, 5), were identified as carbides. The larger carbides appeared to be concentrated in the interdendritic regions and their angular morphology was typical of the MC type rather than that of more complex carbides. These samples were then examined in the scanning electron microscope where the analysis facility was used to identify any

major compositional variation between the dendritic and the interdendritic regions. No significant compositional difference was found between these regions indicating that no major segregation was present in the cladding at high or low iron dilutions.

Etching in hot Marbles reagent⁺ produced similar microstructures in all samples. However, the time taken to detect any noticeable etching of the samples in this reagent varied significantly, increasing as the iron dilution decreased. The results obtained for the samples tested in this way are presented in Table III.

Finally two samples, one with a low iron content and one with a high one, namely samples 1 and 2, were examined in the transmission electron microscope for any evidence of fine precipitates which may have been produced at high iron dilutions. The specimens, which were prepared using an ion beam thinning technique, showed no significant differences between them. The only second phase particles that were observed were in the form of large angular precipitates which were probably MC type carbides but which were too thick to identify by electron diffraction methods.

3.2 Corrosion Tests

The corrosion behaviour of the IN 625 clad layers was assessed in three ways. An accelerated immersion test was carried out using cupric chloride solution. Specimens were removed from the steel substrate, prepared as described earlier, and weight loss measurements were made following 478 hours immersion with and without agitation. The results are presented in Table IV along with those for a 70/30 cupro nickel alloy tested without agitation for comparison.

Polarisation measurements were carried out on five samples. Typical curves for specimens with low and high iron contents are presented in Figures 5 and 6. These curves are similar although they show minor

⁺Marbles reagent:- 50ml H Cl, 10 gms Cu SO₄, 50 ml H₂O

differences. For example, the breakout potential is about 0.7 volts for the low iron sample and nearer to 1.0 volts for the high iron alloy, indicating a slightly larger passive region in the higher iron containing layer. However, the five samples tested did not show a systematic change in breakout potential with iron content.

Finally, an assessment was made of the corrosion rate using the impedance technique (6). Samples of cladding and of 70/30 cupro-nickel were immersed in 3.5% NaCl solution and Nyquist plots of real impedance against imaginary impedance were produced. A typical plot is shown in Figure 7. Using this data the charge transfer resistance of the sample was found from the diameter of the semi-circle on the graph. This value, coupled with the exposed specimen surface area, allowed calculation of the corrosion resistance per square centimetre which in turn was used with the Stern-Geary equation to calculate a corrosion current. Using data from Uhlig (7) on the rate of dissolution of a metal under a specific corrosion current, the corrosion rate of each sample was then calculated. The Stern-Geary relationship is:-

$$i_{\text{corr}} = \frac{\beta_a \beta_c}{2.3 (\beta_a + \beta_c)} \frac{1}{R_t}$$

where β_a and β_c are the anodic and cathodic tafel constants respectively and R_t is the charge transfer resistance. β_a and β_c can be estimated from the slope of the polarisation curves around the rest potential and the β figures used in the calculation of i_{corr} were average values of β_a and β_c from the five experimental potential curves. The calculated corrosion currents and rates are given in Table V. The values for IN 625 were calculated using data from Uhlig (7) for pure nickel, while the value for the cupro-nickel was calculated using data for pure copper.

3.3 Mechanical Property Determination

The mechanical properties of the clad layers were assessed by hardness and tensile testing on three plates with low, intermediate and high iron dilutions. Vickers hardness tests with a 1kg load were carried out on the top surface of the clad layers from plates 1, 2 and 3 following

metallographic polishing to a 1 micron finish. The results, Table VI, showed that the hardness decreased slightly as the iron content of the cladding increased.

Microhardness traverses were carried out from the steel/IN 625 interface to the outside surface of the clad layer at intervals of 5 microns using a 35gm load. These tests indicated that no significant change in hardness occurred as the distance from the interface increased in any of the samples tested.

Tensile tests were carried out on the clad layers to give an indication of their overall mechanical properties. The results of these, shown in Table VIII, indicated that the tensile strength of the clad layers was always greater than 700 MN/mm^2 and their ductility over 29% elongation indicating a high degree of integrity and ample ductility within the coating. There was, however, a trend towards a decrease in strength and ductility at the highest levels of iron contamination.

4. Discussion

It can be seen from Figure 2 that the level of iron in the clad layer decreased rapidly with distance from the steel/IN 625 interface and had achieved a constant level within 60-80 μm of coating thickness. Thus, in the clad layers studied, which range in thickness from 2mm to 4mm, the variation in iron content throughout the thickness was negligible and the average iron level analysed at the surface can be considered to be representative of bulk of the clad layer.

It should be noted that the percentages quoted in Figure 2 are not exact chemical analyses. They are only semi quantitative at best, calculated from the relative peak areas of the elements present without any standards or corrections being applied. Thus these results give only a comparative iron level with distance into the clad layer, but this is sufficient to give an overall picture.

In addition to the variation of iron throughout the cladding, it is of interest to follow the profiles of the other elements present, to determine if any major composition variations have occurred. Figure 3 shows a typical trace for iron, nickel, chromium and molybdenum in the IN 625 cladding with distance

from the steel interface. It can be seen that both the nickel and chromium levels rose as the iron level decreased indicating that iron was simply present as a general dilutant.

Microstructural examination has revealed little or no difference in the microstructure of the IN 625 cladding alloys as the iron content varied. The alloy has a single phase cored dendritic structure with a coarse precipitation of angular carbides. No additional phases were produced as the iron level increased up to 20%, and no significant segregation of iron was found in the cored dendritic structure of the IN 625 cladding. In addition, the carbide precipitation was not markedly modified as the composition varied. The only noticeable difference between the samples was that the etching time decreased as the iron content increased, Table III. While this may reflect a trend to increased corrosion attack with higher iron dilutions, it is obviously not conclusive as the highly acidic environment is very different from that envisaged for service, and thus the conditions may be such as to exceed the breakout potential in the higher iron containing alloys. Thus the metallographic examination showed that the majority of the clad layer had a constant composition and that no noticeable microstructural differences were associated with increasing iron contents up to dilution levels of 20%.

The corrosion tests have shown how resistant IN 625 is to seawater corrosion even when compared to a reasonably corrosion resistant material such as 70/30 cupro-nickel. The immersion tests in cupric chloride solution have shown that the weight loss in 478 hours tests for IN 625 was negligible compared with that for an identical sized cupro-nickel specimen, Table IV. In addition, metallographic examination of the IN 625 samples after immersion using both optical and scanning electron microscopy showed no visible sign of any initiation sites for corrosion.

The polarisation measurements from IN 625 with varying levels of iron showed no significant variation with iron content. Two typical curves from layers containing low and high iron levels are shown in Figures 5 and 6. It can be seen that there was a slight change in both breakout potential and in the slope of the curve following breakout, however, neither of these showed a trend with increasing iron content and the differences were put down to experimental variations.

An accurate technique for assessing corrosion performance uses impedance measurements at the corrosion potential using a galvanostat. This technique is sensitive to very small changes in corrosion behaviour and so is applicable to materials with good corrosion resistance. It also reproduces the environment seen in practice because it does not alter the potential or solution to enable a measurement to be made. From the semi-circular Nyquist plots obtained, Figure 7, the charge transfer resistance per square centimetre of sample was found for each IN 625 specimen and for the 70/30 cupro-nickel. This was used together with the Stern-Geary equation to obtain a corrosion current, i_{corr} , for each specimen in 3.5% NaCl solution. It was considered that 3.5% NaCl was close enough to seawater to enable the results to be applied to seawater environments. The Stern-Geary equation also requires a knowledge of the anodic and cathodic Tafel constants for the material of interest. These values should be of the order of 100 mV (8) but can be estimated from potential scans by measuring the anodic and cathodic slopes around the rest potential. This was done for the five samples for which potential scans were available. The resulting constants, Table VIII, showed no systematic variation with iron dilution and so an average value was taken for the two Tafel constants and used to calculate i_{corr} for each sample. The same values were used for the cupro-nickel. This could lead to some errors but it is reasonable to assume that the data for cupro-nickel will also be close to 100 mV (8). The resulting i_{corr} values are presented in Table V.

The calculated values of i_{corr} can be used to estimate corrosion loss using data for the dissolution rate of a pure metal under a certain corrosion current in milligrams/decimetre/day. The values chosen were those for pure nickel and pure copper (7). The former being used for the IN 625 and the latter for the cupro-nickel. These numbers can be converted to corrosion loss in millimetres/year by considering the density of the metal concerned. It should be noted that the difference in figures for pure nickel and pure copper is almost negligible so pure copper data should be relevant to a cupro-nickel. This calculation led to the corrosion rates for IN 625 and cupro-nickel presented in Table V. It can be seen that the corrosion rate for IN 625 was very low and did not vary significantly with iron content. On average it was in two orders of magnitude less than that for cupro-nickel alloys, indicating a very high degree of corrosion resistance in this environment.

The corrosion loss calculated for the 70/30 cupro-nickel is higher than that normally considered for this type of alloy in static seawater by a factor of three (9). These errors could well be produced by the assumptions made for the Tafel constants and the fact that the experiments were carried out in 3.5% NaCl solution which is slightly more aggressive than seawater. However, the basic conclusions are unaltered, namely that IN 625 alloys are extremely resistant to seawater corrosion attack and that the degree of attack varies only slightly as the iron dilution increases. Moreover, the inherent corrosion resistance of IN 625 compared to alternative materials is confirmed. For comparison purposes, published rates of attack are 0.1mm/year for steel (9), 0.025mm/year for cupro-nickel (3), and <0.0025mm/year for wrought IN 625 (3).

Finally, the mechanical property determinations indicated that high integrity claddings with uniform performance had been produced. There was no significant change in hardness with increasing iron content, a result similar to that obtained previously by other workers, with iron dilutions ranging from 6% to 11% (5). The slight trend to decreased tensile strength and ductility with increasing iron dilution is unlikely to cause problems in practice because the claddings remain very strong even at high iron dilutions.

5. Conclusions

5.1 The corrosion behaviour of IN 625 clad layers on steel does not change significantly with iron dilutions up to 20%. In addition, the measured corrosion rates are extremely low, <2 $\mu\text{m}/\text{year}$, which are comparable with results from wrought IN 625 which contains low levels of iron (<5%).

5.2 Single layer, high quality clad coatings of IN 625 can be produced on steel substrates using the pulsed MIG technique with iron levels ranging from 5% to 20% by adjusting the welding variables.

5.3 The microstructures of the clad layers were similar for all iron levels produced consisting of columnar grains growing from the steel interface. Micro examination showed the layers to have a cored dendritic microstructure with carbide precipitates. No iron rich phases were found even at iron dilutions as high as 20%.

5.4 Particularly at the higher levels of iron dilution the clad layers are well bonded to the substrate. Chemical analysis using the scanning electron microscope has shown that the iron content of the clad layer decreases rapidly with distance from the steel/IN 625 interface and approaches an almost constant level within 60 μ m from the interface. The iron is present in the clad layer as a general dilutant.

5.5 The clad layers have uniform hardness and tensile strength indicating a sound coating. The tensile strength and ductility does decrease slightly with increasing iron content but this small decrease is unlikely to cause any problems in the envisaged application.

5.6 Single layer cladding of IN 625 by the pulsed MIG technique appears to be a viable process for sea water service operations. Even at iron dilutions up to 20%, the corrosion performance and mechanical properties remain comparable to those of the wrought alloy.

5. Future Work and Recommendations

The present work has indicated the potential of the pulsed MIG technique for producing sound single layer clad coatings of IN 625 alloy with iron dilution levels up to 20%. On the basis of a limited experimental assessment, both the mechanical properties and the corrosion resistance of such clad layers were found to be comparable to those of wrought IN 625 which is finding increased usage in marine applications. However, more work is required to assess the corrosion resistance in more detail particularly in longer term trials in sea water environments and under more stringent corrosion environments, such as under crevice or impingement attack.

Weld cladding could in future become more widely used as a maintenance or reclamation procedure on rotating shafts for use in marine environments. There is therefore a need to assess the performance of clad shafts in corrosion fatigue. If the fatigue performance of the clad component was significantly improved compared to that of the base steel material, there may be additional applications for such clad components where additional weight and cost savings are possible.

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TABLE I Composition of IN 625 filler wire used for weld cladding

Element	Wire Composition %	Nominal IN625 Composition %
Chromium	20.3	20 - 23
Iron	2.85	5 max
Manganese	0.27	0.50
Molybdenum	8.27	8 - 10
Silicon	0.40	0.50
Titanium	0.20	0.40
Aluminium	0.12	0.40
Carbon	0.05	0.10
Sulphur	0.008	0.015
Niobium	3.42	3.15 - 4.15

SPECIMEN CODE	TECHNIQUE	WIRE DIAMETER	VOLTS	AMPS	WELDING SPEED	WIRE FEED SPEED	BEAD SP	BEAD WIDTH	AVERAGE FE CONTENT
		MM	V	A	MM/MIN	MM/S	MM	MM	%
CIT 1	P-MIG	1.6	23	200	210	52.5	7	14	4.7
CIT 2	MIG	1.6	36	350	210	108	12	24	17.6
CIT 3	MIG	1.6	29.5	290	210	88	10	20	9.3
CIT 4	MIG	1.6	30	300	210	78	11	21	11.8
CIT 11	P-MIG	1.6	27	241	500	66	4.5	8	10.86
CIT 12	P-MIG	1.6	27	241	500	66	5.5	8	19.10

TABLE II Welding parameters and chemical analysis of cladding alloys deposited during the present study

TABLE III Time taken to etch the samples in hot Marble's reagent

Sample No.	% Fe	Time to etch at 60°C (secs)
2B	18.8	61
3C	8.64	108
3A	8.23	674
1A	5.45	1285
1B	5.15	888
1C	3.50	1020

TABLE IV Weight loss after 478 hours immersion in CuCl₂ solution

Specimen	% Fe	Wt. Loss (gms)	
		Agitated	Not agitated
1	4.7	0.002	< 0.001
2	17.6	.004	< 0.001
3	9.3	.001	< 0.001
4	11.8	—	< 0.001
70/30 Cu/Ni for comparison	—	—	0.399

TABLE V Calculated charge transfer resistance and corrosion rate from impedance measurements

Specimen	% Fe	Charge transfer resistance ohms/sq.cm.	i_{corr} A/cm ²	weight loss μm/year
1	4.7	224600	1.49×10^{-7}	1.6
2	17.6	233600	1.43×10^{-7}	1.5
3	9.3	219256	1.52×10^{-7}	1.6
4	11.8	240816	1.39×10^{-7}	1.5
11	10.86	271200	1.23×10^{-7}	1.3
12	19.10	274472	1.22×10^{-7}	1.3
Cu/Ni	—	4225	79.0×10^{-7}	92

TABLE VI Results of Vickers hardness tests on top surface of clad layer

Specimen No.	Fe Content %	VPN (Hv) (1kg load)
1B	5.15	273 ± 14
1C	3.50	273 ± 7
3B	11.03	264 ± 13
3C	8.64	252 ± 9
2B	18.8	222 ± 8

TABLE VII Results of tensile tests on clad layers

Sample No.	% Fe	0.2% Proof Stress MN/m ²	UTS MN/m ²	Elongation %
1A	5.45	482	833	53
1C	3.50	500	829	52
4B	12.6	473	790	46
4C	11.52	476	803	45
2B	18.8	342	712	29
2C	17.3	311	757	32

TABLE VIII Tafel constants measured from polarisation curves

Specimen	% Fe	β_a	β_c
1C	3.5	160	160
2B	18.8	260	140
3B	11.03	100	180
3C	8.64	120	200
11	10.86	100	124

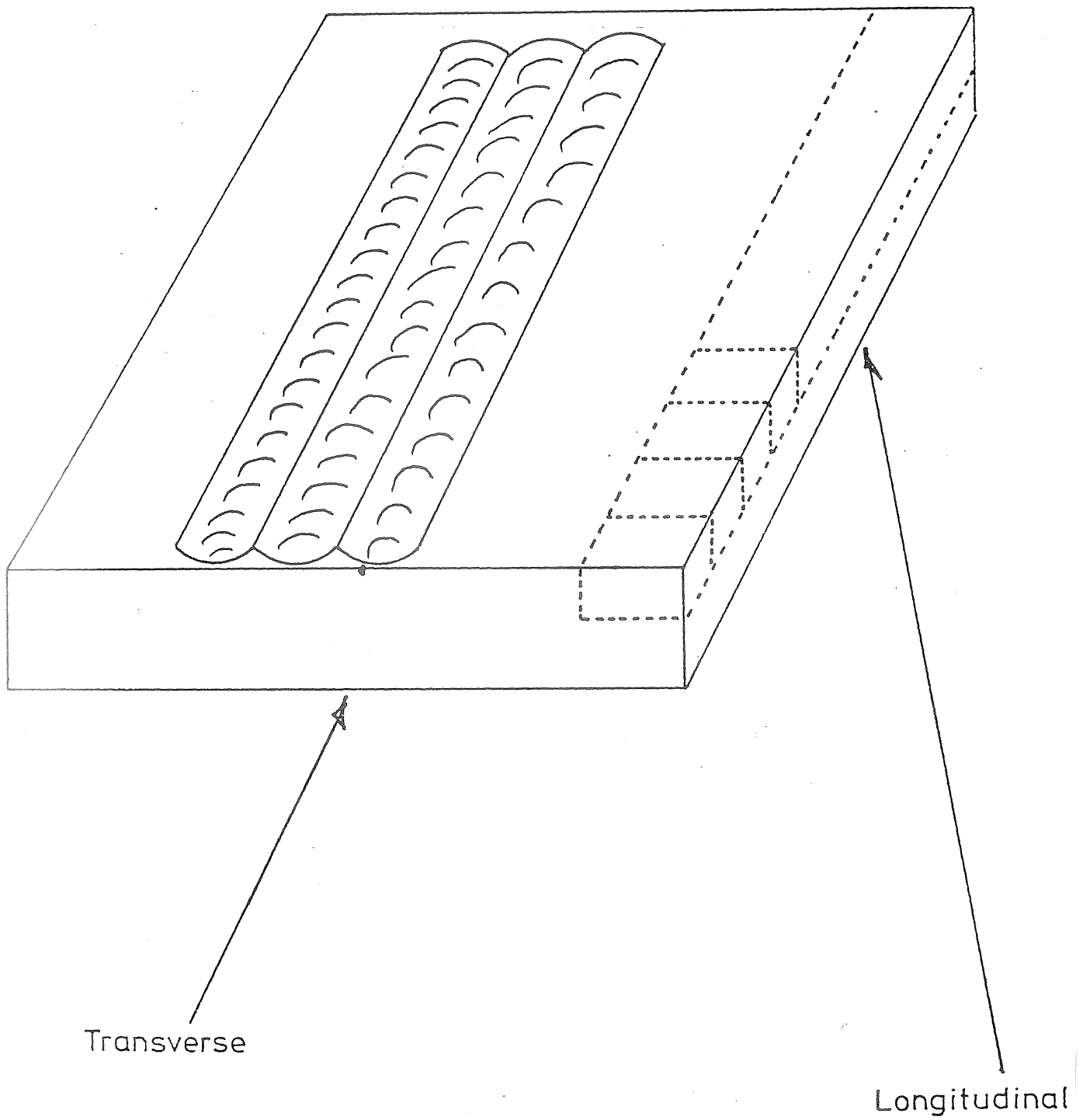


Figure 1 - Diagram showing orientation of samples from plate.

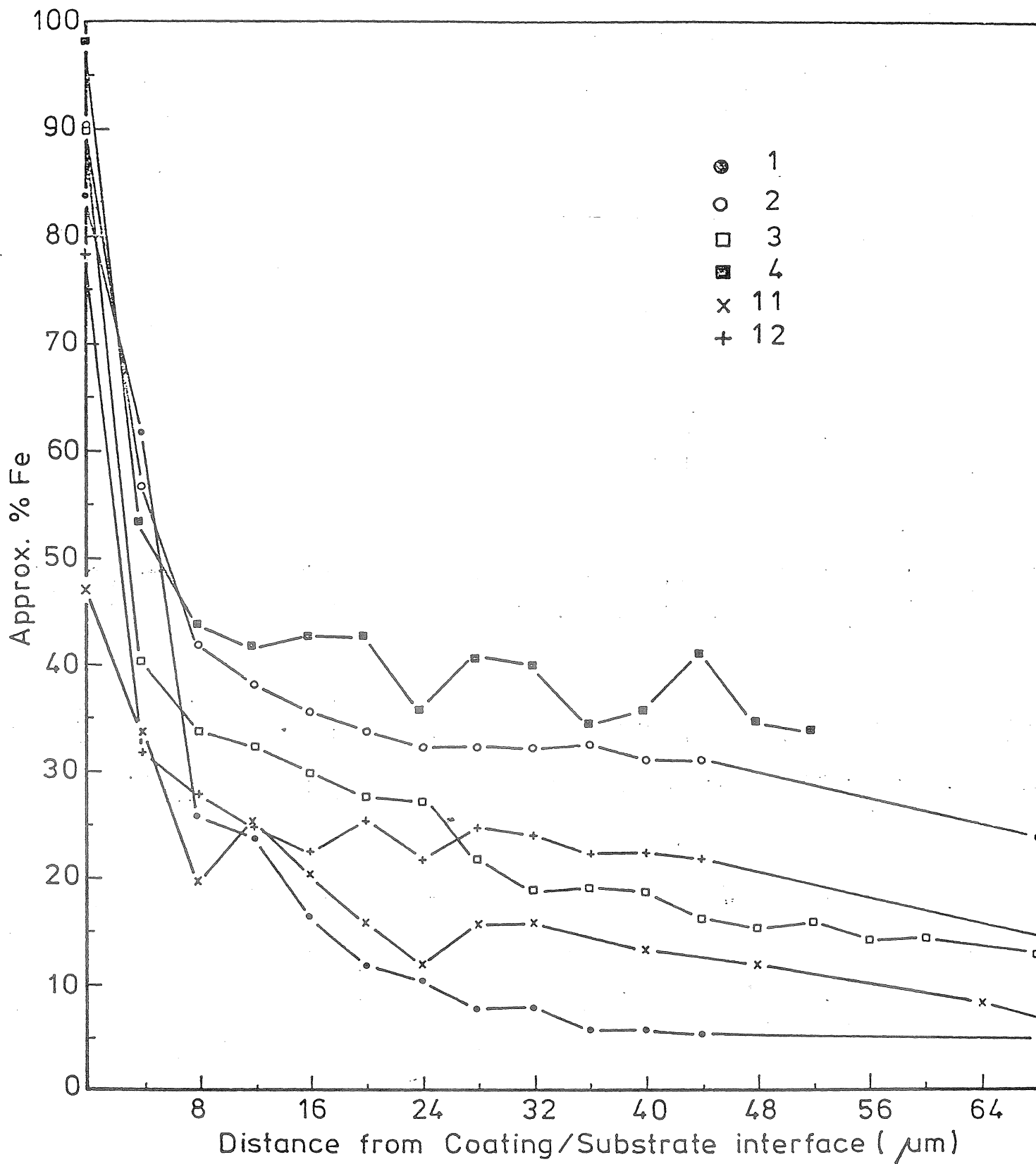


FIG. 2. IRON CONCENTRATION PROFILE IN WELD DEPOSITED LAYERS OF IN 625

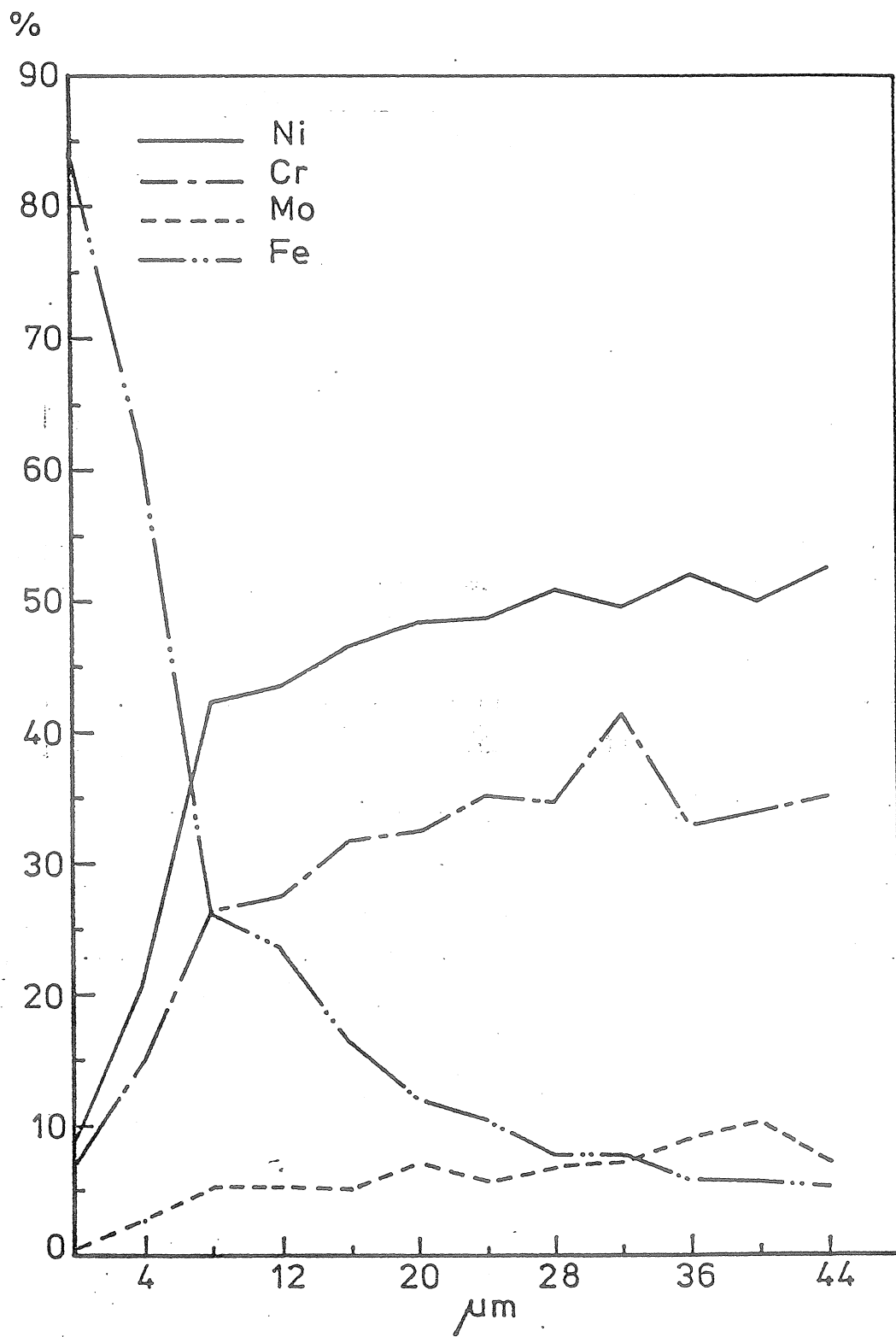


Figure 3 - Concentration profiles for Ni, Fe, Cr and Mo from the steel/IN625 interface.

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3	9.3	219256	1.52×10^{-7}	1.6
4	11.8	240816	1.39×10^{-7}	1.5
11	10.86	271200	1.23×10^{-7}	1.3
12	19.10	274472	1.22×10^{-7}	1.3
Cu/Ni	—	4225	79.0×10^{-7}	92

TABLE VI Results of Vickers hardness tests on top surface of clad layer

Specimen No.	Fe Content %	VPN (Hv) (1kg load)
1B	5.15	273 ± 14
1C	3.50	273 ± 7
3B	11.03	264 ± 13
3C	8.64	252 ± 9
2B	18.8	222 ± 8

TABLE VII Results of tensile tests on clad layers

Sample No.	% Fe	0.2% Proof Stress MN/m ²	UTS MN/m ²	Elongation %
1A	5.45	482	833	53
1C	3.50	500	829	52
4B	12.6	473	790	46
4C	11.52	476	803	45
2B	18.8	342	712	29
2C	17.3	311	757	32

TABLE VIII Tafel constants measured from polarisation curves

Specimen	% Fe	βa	βc
1C	3.5	160	160
2B	18.8	260	140
3B	11.03	100	180
3C	8.64	120	200
11	10.86	100	124

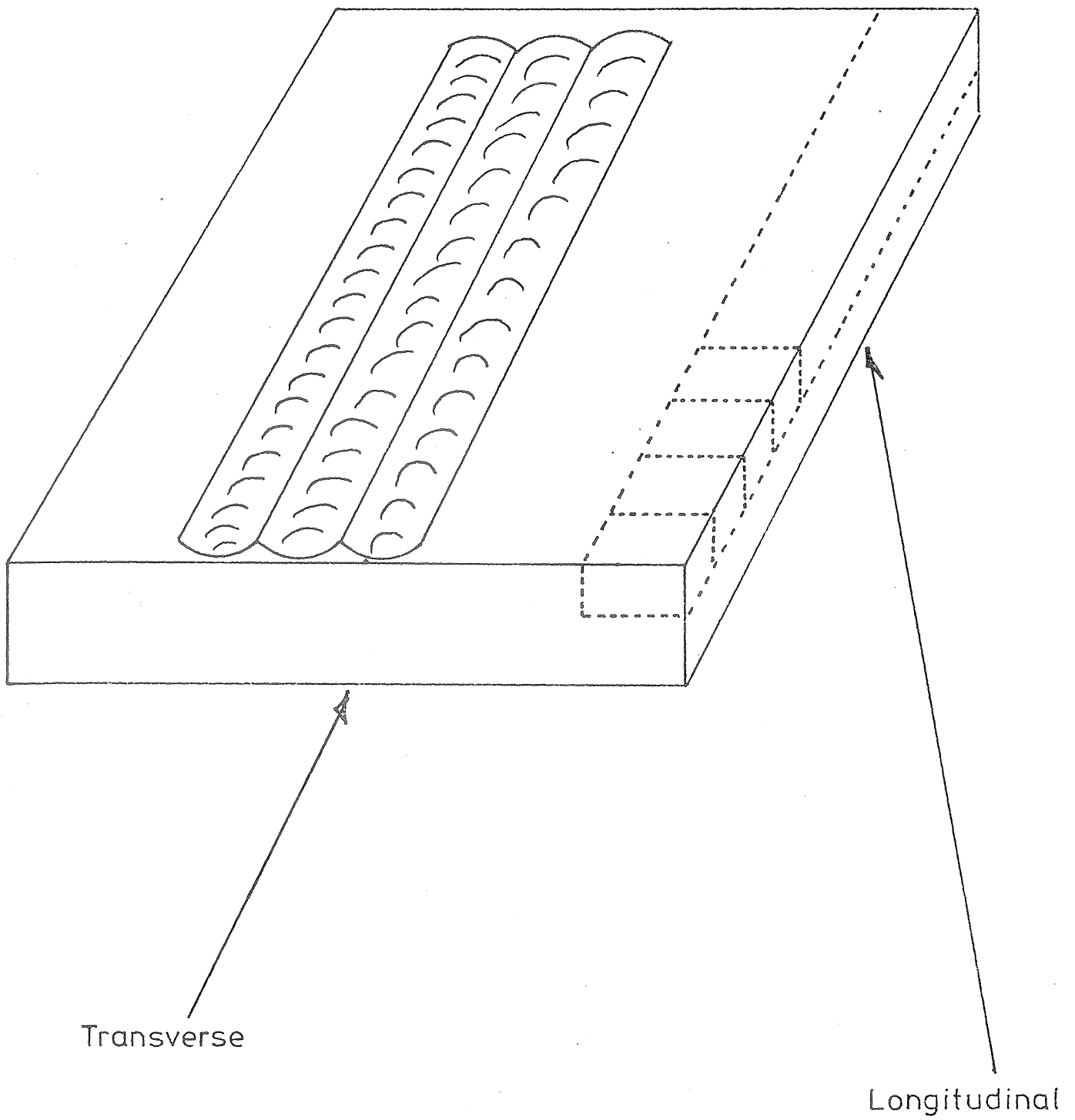


Figure 1 - Diagram showing orientation of samples from plate.

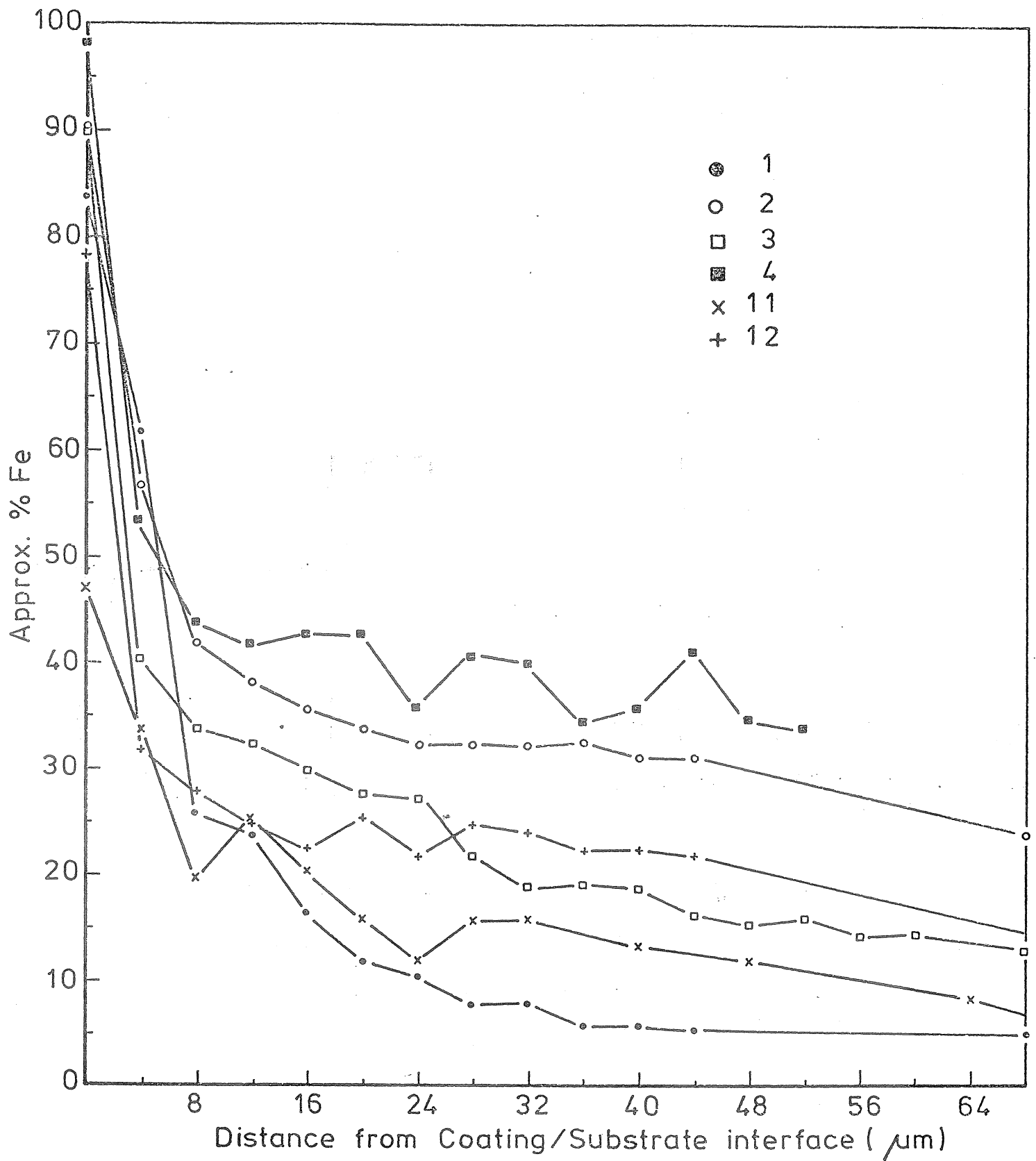


FIG. 2. IRON CONCENTRATION PROFILE IN WELD DEPOSITED LAYERS OF IN 625

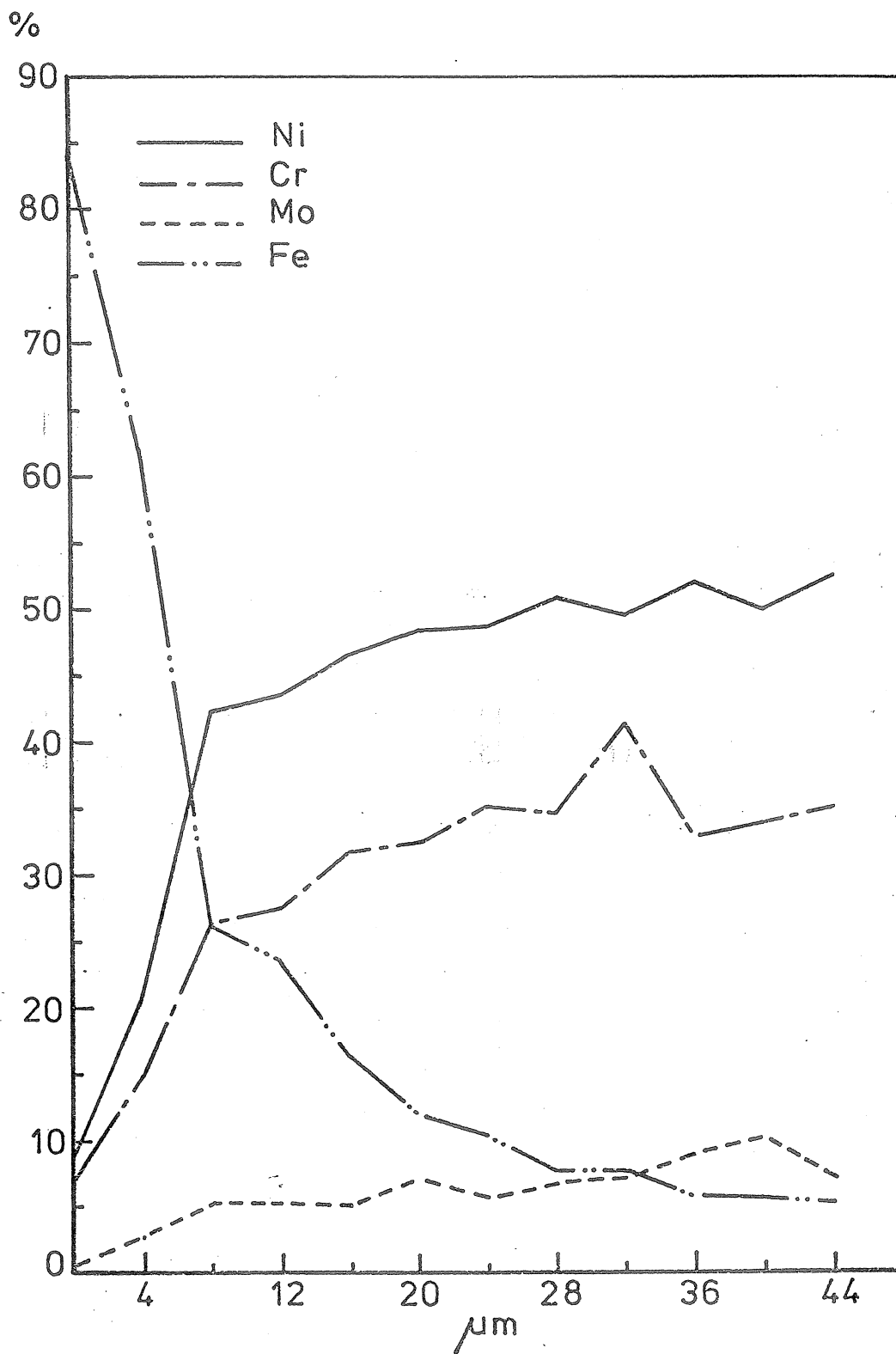


Figure 3 - Concentration profiles for Ni, Fe, Cr and Mo from the steel/IN625 interface.

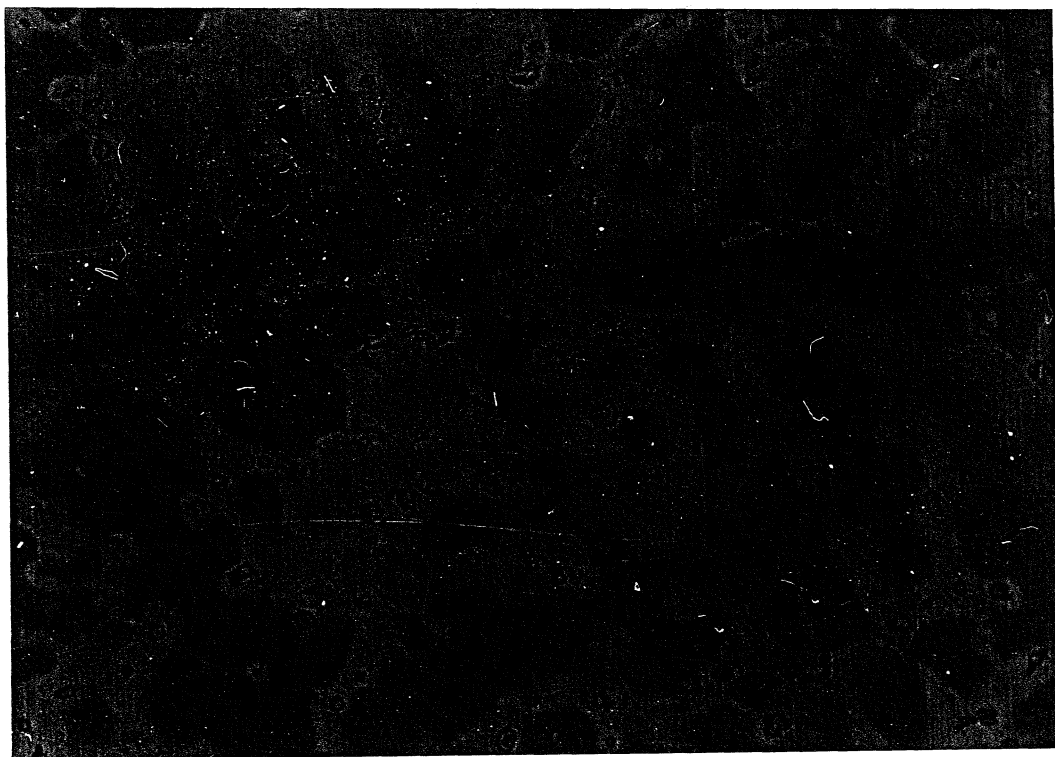


Figure 4 An optical micrograph showing the typical cored dendritic structure in an IN625 clad layer x 1000

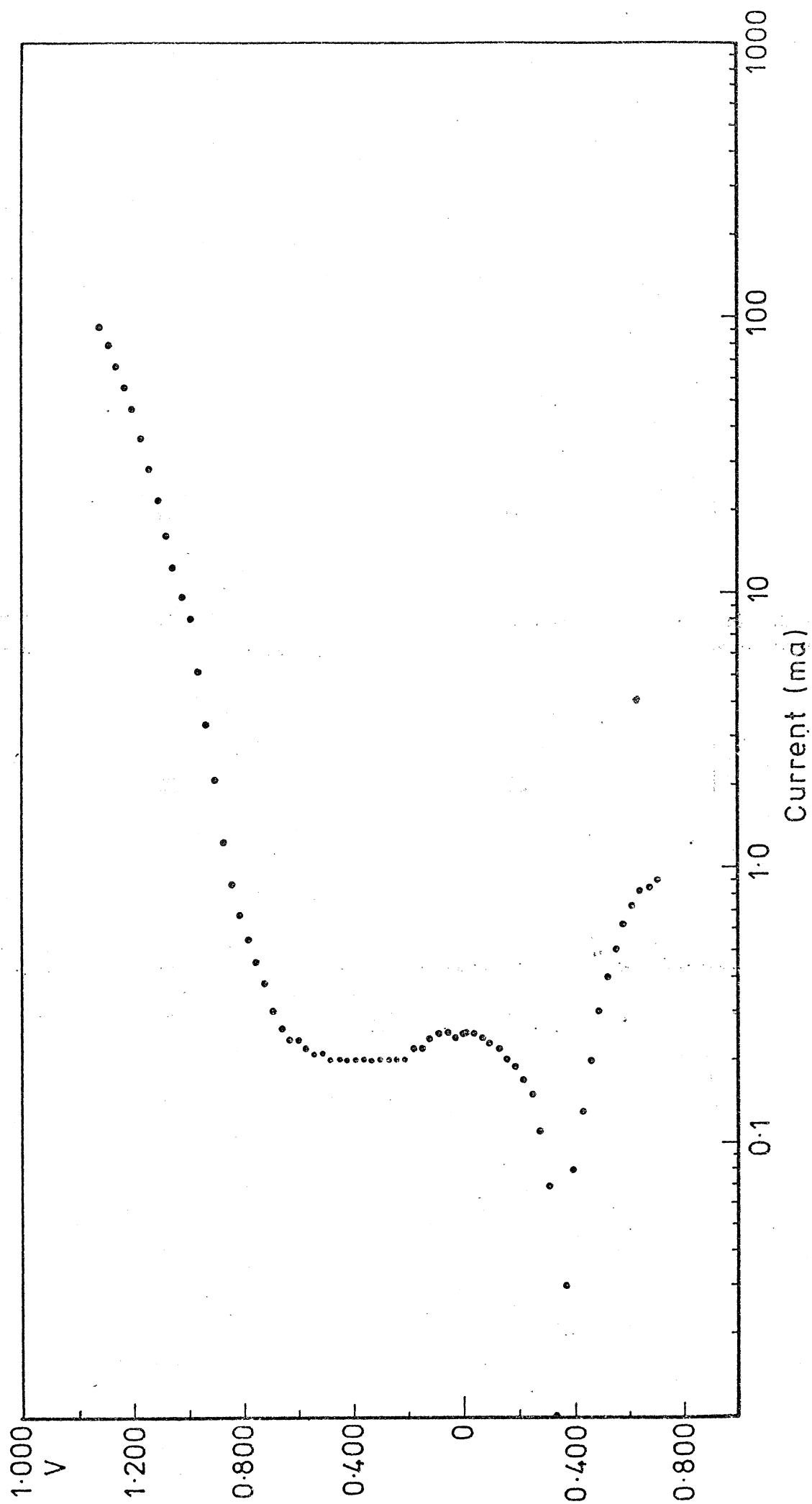


FIG. 5. POLARISATION CURVE OBTAINED ON A SAMPLE FROM PLATE 1, LOW % Fe

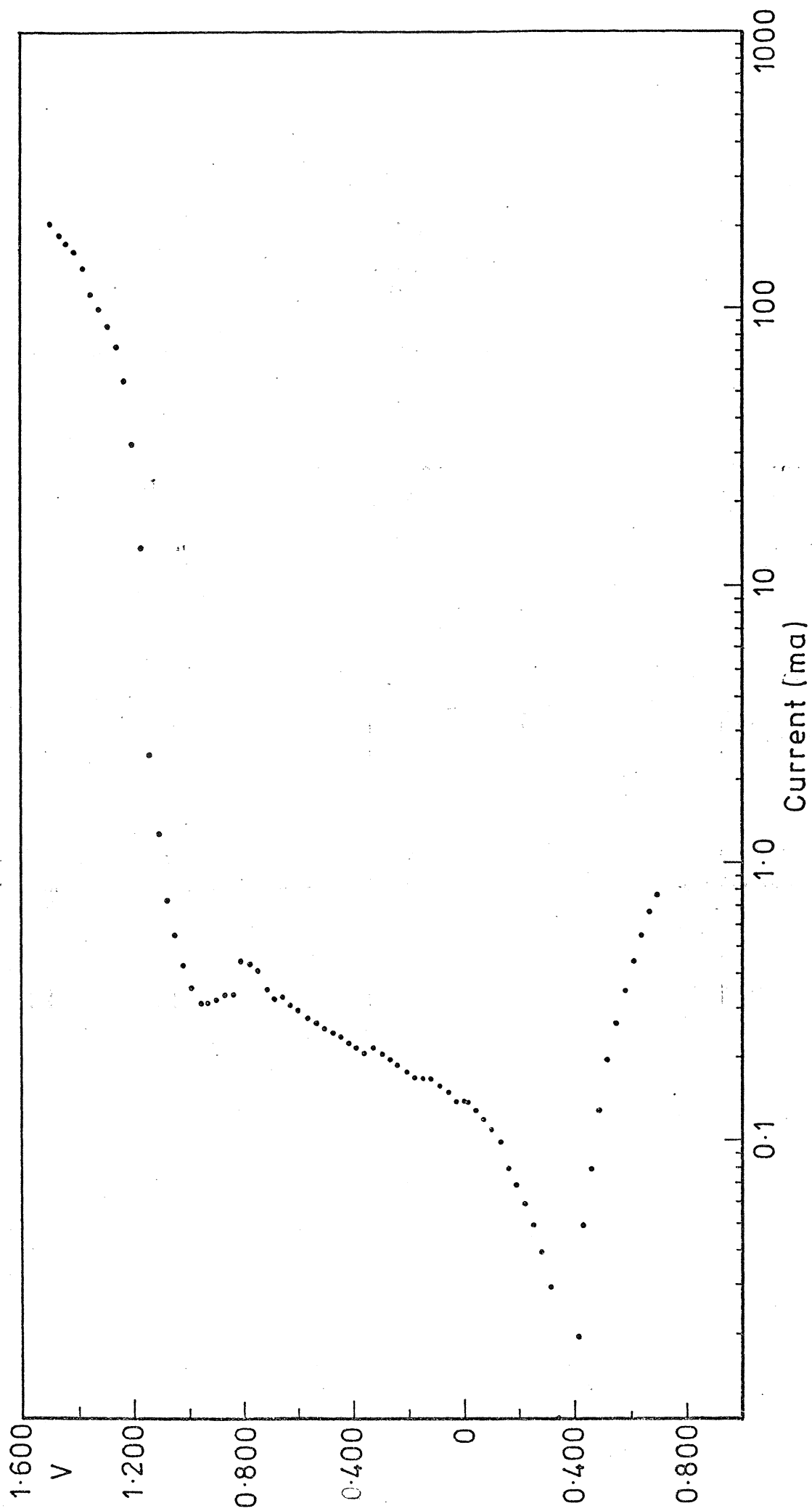
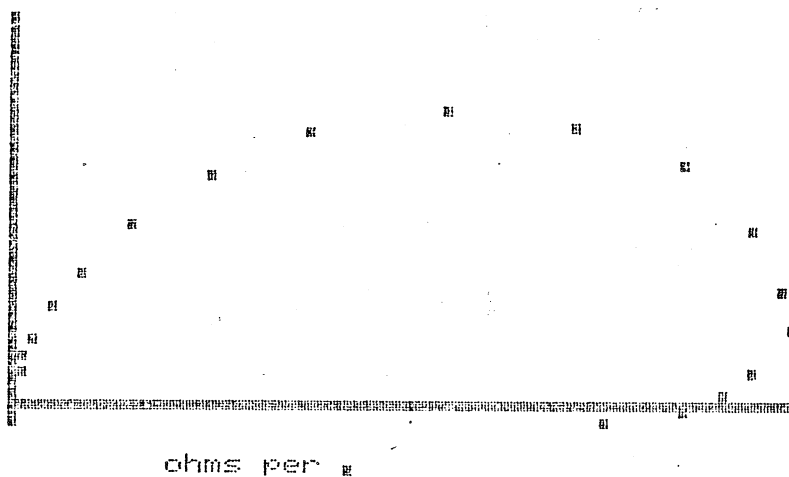


FIG. 6. POLARISATION CURVE OBTAINED ON A SAMPLE FROM PLATE 2, HIGH % Fe

9/2/84

WHT

6 Spec 4 3.5% NaCl



4 CuNi NaCl 1sq cm

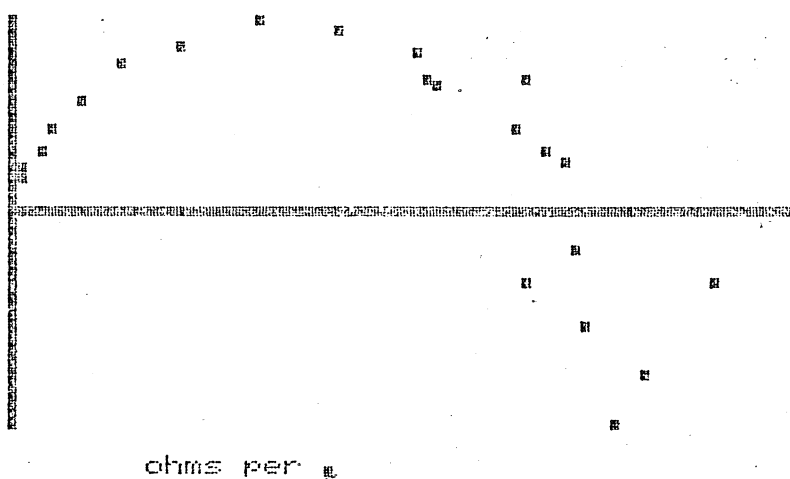


Figure 7 Typical Nyquist plots, (a) specimen 4
(b) 70/30 cupro-nickel



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