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The development of soft ferritic stainless steels for coining

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SYNOPSIS

The limiting criterion in the use of stainless steel for certain forming operations such as coining is its hardness, which determines parameters such as required striking pressure, wear on dies, and integrity of pattern detail. Attention is given here to the development of ultra-soft ferritic stainless steels for coinage.

In the first instance, the influence of carbon content on the striking properties of a series of commercial and experimental 17%Cr alloys was evaluated. It was found that a lower carbon content permitted the striking of relatively highly profiled and intricate patterns, provided that the hardness did not exceed 125 HV. Hardnesses as low as 115 HV were achieved in the fully annealed condition, but these alloys required high striking pressures.

In a further study, three grades of experimental 14%Cr ferritic stainless steels were produced with a view to optimizing the ductility. When the residual impurities were minimized, hardness values of about 100 HV and lower were achieved. Micro-alloying additions allowed the heat-treatment response and grain size to be controlled. Excellent tensile properties, with elongations of up to 42 per cent, were achieved in the fully annealed condition, and highly profiled patterns were produced in coining trials.

SAMEVATTING

Die beperkende maatstaf by die gebruik van vlekvrye staal vir sekere vormingsbewerkings soos die slaan van munte is sy hardheid wat die parameters soos slagdruk, slytasie van die stempels en integriteit van die patroondetails bepaal. Daar word hier aandag geskenk aan die ontwikkeling van ultrasagte ferritiese vlekvrye staal vir munte.

In die eerste plek is die invloed van die koolstofinhoud op die slageienskappe van 'n reeks kommersiële en eksperimentele 17%Cr-legerings geëvalueer. Daar is gevind dat 'n laer koolstofinhoud die slaan van betreklik hoog geprofileerde en ingewikkelde patrone moontlik maak, mits die hardheid nie 125 HV oorskry nie. Daar is in die ten volle uitgegloeide toestand 'n hardheid van so laag as 115 HV verkry, maar hierdie legerings het 'n hoë slagdruk vereis.

In 'n verdere studie, is drie grade eksperimentele ferritiese vlekvrye staal met 14%Cr geproduseer met die doel om die rekbaarheid te optimeer. Toe die oorblyfsels van onsuiwerhede tot die minimum beperk is, is hardheidswaardes van ongeveer 100 HV en laer verkry. Mikrolegeerbyvoegings het dit moontlik gemaak om die reaksie op hittebehandeling en die korrelgrootte te beheer. Uitstekende trekeienskappe met verlengings van tot 42 persent is in die ten volle uitgegloeide toestand verkry en hoogs geprofileerde patrone is in proeflope met die slaan van munte gelewer.

INTRODUCTION

The objectives of the study described here originated in a long-standing interest in an increased usage of chromium-containing alloys. The prohibitive economics of the traditional nickel coin, together with a concurrent initiative to replace the South African coinage, made an assessment of more cost-effective alternatives timely. The well established ferritic stainless-steel coinage industry made these alloys a logical focus in the context of a chromium lobby.

While the then major obstacle to stainless-steel coinage, namely the high hardness of the annealed material, can be largely overcome, subsequent developments have seen the establishment of a more sophisticated coinage material on the local market. However, notwithstanding the high hardness of stainless steels when compared with nickel or bronze alloys, ferritic grades containing between 16 and 18 per cent chromium by weight have found widespread use in coinage abroad. It is the contention of this paper that if the properties of these alloys are optimized, they may be used even more in future.

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TECHNICAL ASPECTS OF COIN MANUFACTURE

The important requirements for coinage metals can be listed as follows:

Economic Importance
- Intrinsic value
- Useful life
- Availability
- Differentiation from other coinage

Public Acceptance
- Appearance
- Colour
- Weight
- Size
- Design
- Use in vending machines

Metallurgical Requirements
- Production by standard processes
- Suitability for the minting of deep impressions
- Sufficient minted hardness for wear resistance
- Compatibility with a long die life
- Tarnish resistance
- Electrical and magnetic properties amenable to coin-detection devices.

The advantages of stainless steel include lower material costs than those of nickel, excellent wear and corrosion resistance, favourable lustre, and the capability of being produced and fabricated by standard methods. After coining, the blanks must be sufficiently softenable to give a high relief on striking, yet provide adequate hardness for wear resistance after minting. Even with annealing treatments, the hardness of ferritic grades is higher than that of nickel or cupro-nickel coinage (Vickers hardness (HV) of about 80 to 100), resulting in a shorter die life in the blanking, edging, and coining processes, and higher wear of the blank feeding and extraction systems. This is particularly relevant to production processes of high striking rate. The hardness of the alloy is therefore of paramount importance, and receives attention in this study.

PRODUCTION OF STAINLESS-STEEL COINAGE

The use of stainless-steel alloys for coinage is a well-established practice, and such coins make up an estimated 10 per cent of the 180 kt of coinage metal used annually[1]. Countries that mint stainless-steel coinage (for export purposes or for their own use) include Great Britain, Canada, Brazil, Mexico, Italy, Turkey, France, and, more recently, India and Iraq.

Ferritic stainless steels for coins usually have a chromium content of between 16 and 18 per cent, and several patents cover a chromium content of between 12 and 18 per cent[2–4]. Blanks with a hardness as high as 155 HV have been coined successfully[5], although this requires a compromise between depth of relief and die life. An additional factor is the rate of work-hardening. The ferritic stainless steels do not work-harden as severely as their austenitic counterparts, and have properties comparable with those of the cupro-nickels. Cold reductions, typically 20 to 30 per cent in coining operations, can yield a final coined surface with a hardness approaching 250 HV[6]. In view of the wear resistance of stainless steel, a shallower design is not lost as readily in use and is tolerable. The specifications given in Table I are illustrative of typical coinage grades of ferritic stainless steel.

The results of a correlation analysis of 87 different embodiments of ferritic stainless steels are disclosed in a patent[4] that yields the following relationship between Vickers hardness and minor-element chemistry:

$$\begin{aligned}HV = 73{,}3 - 12{,}3[\%C] + 22{,}7[\%Si] + 0{,}8[\%Mn] + \\ 361[\%P] - 55{,}1[\%S] + 2{,}9[\%Cr] + 2{,}8[\%Ni] + \\ 9{,}8[\%Cu] + 5{,}1[\%Mo] + 370[\%N].\end{aligned} \quad [1]$$

Table I
Composition of ferritic stainless-steel coining grades

Specification for coin blanks for Indian 1 rupee	Chemical analysis of Brazilian centavos coins	Specification for Italian 'acmonital'
AISI 430 modified hardness: 143–160 HV		AISI 430 modified
C : 0,03 max	C : 0,06	C : 0,14 max
Cr : 17,5–18,5	Cr : 17,4	Cr : 17,5–19,0
S : 0,02 max	S : 0,06	S+P : 0,03 max
Ni : 0,30 max		
Si : 0,30 max	Si : 0,29	Si : 1,5 max
Mn : 0,30 max	Mn : 0,30	Mn : 0,5 max
P : 0,03 max	P : 0,035	
Mo : 0,20 max		

Thus, it appears that the control of the residual silicon, phosphorus, copper, molybdenum, and nitrogen contents is particularly crucial. Although the low levels ideally required are technically obtainable, refining to such a high degree has commensurate cost implications.

The surprising effect of carbon on the hardness has been explained by the formation of chromium carbide precipitates, thus reducing solution-hardening. This enhanced softness has been verified in higher-chromium ferritic alloys[7]. This suggests that the carbon content is less critical provided that the correct annealing practices are adhered to. This is examined further in the present study.

Additional factors that can potentially optimize the softness include an increase in residual sulphur content (in tension with the corrosion resistance), and a decrease in the nitrogen in solid solution, by employment of a stabilization practice. An increased grain size may also decrease the strength of the alloys in accordance with a Hall–Petch relationship. This, however, may result in a poorer surface quality.

SCOPE

The development programme reported here initially had two objectives, specifically:

(1) to evaluate the influence of carbon content on the coining properties of ferritic stainless steel based on a type 430 grade with nominally 17%Cr, which is the most commonly produced commercial ferritic grade after type 409
(2) to develop a stainless steel with a hardness comparable with that of other coinage-grade materials, such as nickel- and copper-based alloys, which involved the study of a modified type 405 alloy with 14%Cr and a minimum of residual impurities, the 14%Cr composition having the advantage of being less readily available and therefore more difficult to counterfeit.

EXPERIMENTAL

17%Cr Alloys

In the first phase, a series of 17%Cr alloys with varying carbon contents were made by the vacuum-induction melting of high-purity charge materials. One alloy was stabilized with twice the stoichiometric equivalent of titanium in an attempt to remove the C+N from solution. In addition, two standard commercial grades of AISI 430 steel were included for comparison. The analyses of the alloys are reported in Table II.

The 50 mm ingots were rolled to 15 mm sections from 1100°C to finish above 700°C. The plates were then halved, and either hot-rolled to a thickness of 5 mm (designated A) or cold-rolled to 2 mm thickness (designated B). Hot-rolled scale was removed by pickling in a sulphuric acid solution, followed by sand-blasting. A final reduction to the thickness required for the blanks preceded blanking and edging without intermediate annealing. The commercial material was included at this stage of the process. The blanks were annealed in a salt bath at 800°C for 30 minutes, followed by pickling and tumbling in a soap solution to provide a bright lustre. The results of mechanical tests conducted on the annealed plate are summarized in Table III.

The design of the old South African 20-cent coin with the protea pattern was selected for the coining trials owing to

Table II

Composition of the experimental and commercial 17%Cr alloys (in percentages by weight)

Melt no.	C	S	P	N	Si	Mn	Cr
246	0,005	0,013	0,002	0,002	0,26	0,19	17,0
247	0,002	0,011	0,002	0,002	0,2	0,21	17,1
248	0,002	0,01	0,002	0,001	0,27	0,24	17,1
249	0,002	0,011	0,001	0,002	0,26	0,2	17,0
250	0,012	0,01	0,002	n/a	0,17	0,29	16,7
251	0,018	0,009	0,002	n/a	0,28	0,24	17,1
252	0,019	0,013	0,001	0,002	0,21	0,23	18,4
253	0,027	0,011	0,001	0,002	0,3	0,32	17,5
254(Ti)	0,046	0,011	0,001	0,002	0,27	0,26	17,5
1237344	0,06	0,003	0,027	0,037	0,68	0,57	16,5
795282	0,064	0,005	0,024	0,04	0,71	0,61	16,6

its intricate motif and size. Coining was carried out at a striking load of 70 t for comparative purposes, and tests were conducted to establish the minimum load required to produce an acceptable relief. A sample of five coins from each batch was evaluated and graded on a scale of 0 to 9 in ascending order of poor relief (Table IV).

14%Cr Alloys

A further series of alloys based on a composition of 14%Cr was made by vacuum-induction melting. An addition of 1500 ppm of sulphur was made to one alloy, while another was stabilized with 0,1 per cent niobium. The chemical analyses are reported in Table V. Based on the relationship given by equation [1], hardnesses of between HV 105 and 115 were expected in the fully annealed condition.

The ingots were rolled from 1050°C to 4 mm plate sections. After descaling, a 50 per cent cold reduction was carried out. Annealing curves were derived over a range of temperatures for two schedules. In the first schedule, the hardness of the cold-rolled alloys was measured as a function of time at an intermediate annealing temperature in the range 550 to 900°C. The second schedule comprised a solution heat-treatment at 1000°C for one hour, followed by water quenching and an ageing anneal between 550 and 900°C. Plots of Vickers hardness against temperature are shown in Figures 1 and 2, in which each hardness value represents an average of eight determinations using a 20 kg load.

The mechanical properties for a selection of heat-treated conditions are summarized in Table VI. Table VII lists the hardness values in the as-wrought condition. In summary, the lowest hardness values were achieved for the following annealing conditions:

For alloy 760, 99 ± 1,6 HV after annealing at 800°C (30 min)

For alloy 761, 104 ± 1,2 HV after annealing at 800°C (60 min)

For alloy 762, 103 ± 1,2 HV after annealing at 900°C (60 min).

Slightly lower hardnesses were achieved by solution heat-treating prior to ageing:

Table IV

Results of the coining trials on experimental and commercial 17%Cr alloys

Melt no.	Hardness (HV20) after rolling A	B	Hardness (HV20) before striking A	B	Grain size µm A	B	Grading* A	B
246	242	261	116	119	32	27	2	4
247	236	264	118	115	38	27	3	1
248	232	244	118	117	38	27	3	4
249	202	237	121	118	45	32	1	0
250	236	258	117	119	75	32	2	6
251	210	241	121	122	75	27	6	6
252	213	254	124	129	55	38	7	7
253	226	257	121	129	27	32	4	8
254	223	262	138	131	32	32	8	5
1237344	258	–	150	150	27	27	5	5
795282	269	–	150	150	27	27	9	9

* 0 = good 9 = poor

Table V

Composition of the experimental 14%Cr alloys (in percentages by weight)

Melt designation	760	761	762
C	0,010	0,012	0,011
N	0,001	0,001	0,002
O	0,06	0,06	0,06
Si	0,01	0,01	0,01
Mn	0,02	0,02	0,02
P	0,001	0,001	0,002
S	0,013	0,13	0,005
Nb	–	–	0,10
Cr	14,2	14,1	14,0

Table III

Mechanical properties of the experimental and commercial 17%Cr alloys

Melt no.	A: Yield strength MPa	A: UTS MPa	A: Elongation %	A: n value	B: Yield strength MPa	B: UTS MPa	B: Elongation %	B: n value
248	255	384	47,8	0,26	245	386	47,2	0,25
249	245	376	45,4	0,26	250	382	40,4	0,26
250	226	379	40,9	0,27	257	389	39,1	0,27
251	257	392	41,7	0,27	281	407	39,4	0,26
252	258	409	41,2	0,27	286	414	39,2	0,26
253	267	405	39,6	0,27	294	430	38,6	0,26
254	264	448	42,2	0,27	265	440	38,0	0,26
1237344	363	559	26,0	–	–	–	–	–
795282	368	555	26,0	–	–	–	–	–

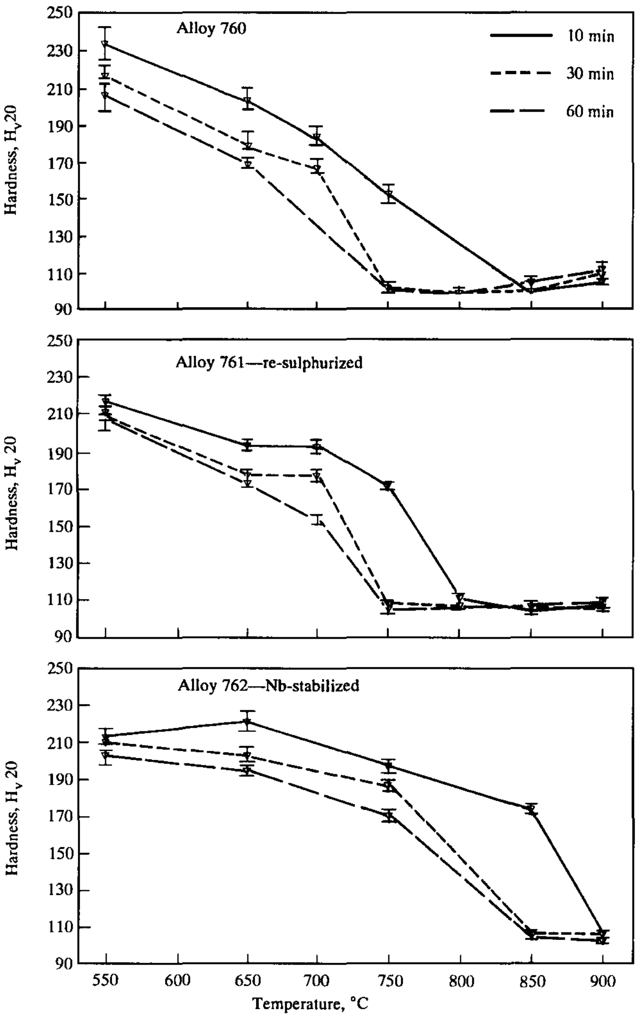


Figure 1—Effect of annealing schedule on hardness

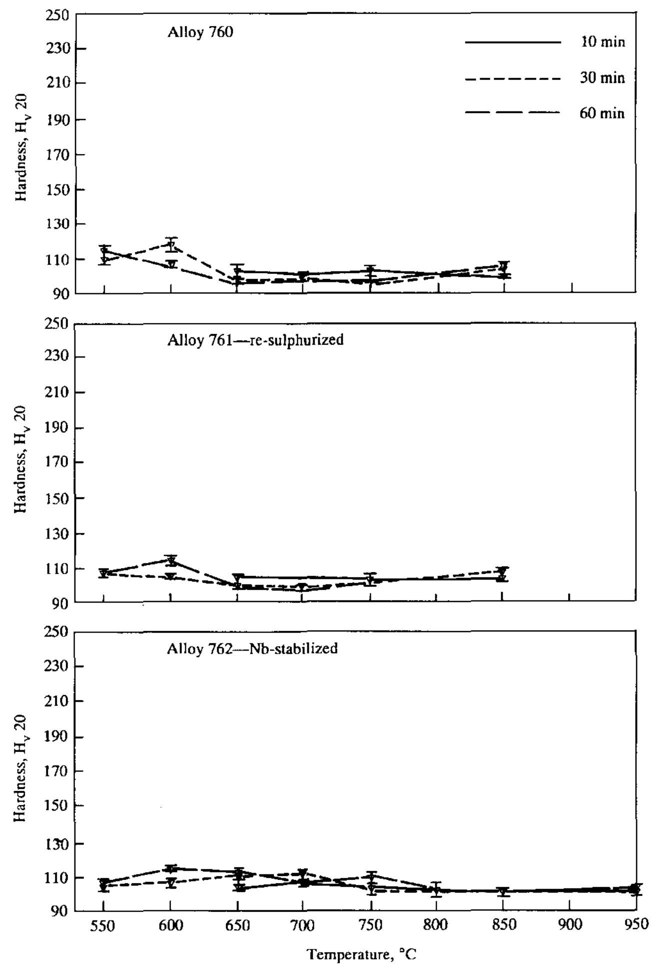


Figure 2—Effect on hardness of ageing following solution annealing

Table VI

Mechanical properties of the experimental 14%Cr alloys (initial strain rate = 1,16 x 10^{-3}/s)

Melt no.	Annealing temp °C	Time s	UTS MPa	Yield stress MPa	Elongation %
Annealed condition:					
760	650	60	454	369	14,7
	750	60	322	164	38,6
761	650	60	467	373	12,9
	750	60	335	170	41,5
762	850	10	410	272	19,2
	900	10	357	175	42,4
Solution heat-treated and aged condition:					
760	600	60	317	190	36,2
	700	60	302	151	35,5
	850	60	302	159	37,8
761	600	60	327	191	38,8
	700	60	320	159	39,4
	850	60	322	181	36,5
762	650	60	338	211	34,5
	700	30	332	191	37,4
	750	10	305	158	36,7
	800	10	333	172	38,2
	850	60	332	176	39,1

For alloy 760, 97 ± 1,5 HV after ageing at 700°C (30 min)

For alloy 761, 99 ± 1,7 HV after ageing at 700°C (60 min)

For alloy 762, 101 ± 1,4 HV after ageing at 800°C (10 min).

Prior to the coining trials, the cold-rolled sheets were surface ground for a good finish. Based on the annealing curves, heat treatments designed to optimize the ductility were selected for each alloy. Hardnesses of between 100 and 110 HV were achieved for all the alloys.

After descaling, the coins were blanked and struck at various pressures for comparison. Various die designs were used so that the pattern profile, depth of flow, and integrity

Table VII

As-wrought hardness of hot- and cold-rolled 14%Cr alloys

Condition	Melt no.	Hardness (HV20)
Hot-rolled	760	114
	761	107
	762	119
Cold-rolled	760	216
	761	202
	762	208

of the detail could be evaluated. Samples of a type 430 alloy were once again coined for comparison.

Measurement of Colour

Colour determinations carried out with a Spectrogard automatic colour system showed that the ferritic alloys have a deeper blue colour than their nickel counterparts. The average results are shown plotted on colour axes in accordance with CIELAB notation in Figure 3. In practical terms, the differences are not readily apparent to a casual user unless the coins are compared directly, but colour can be one of the subjective factors that determine the acceptability of a coin.

COMMENT ON THE RESULTS

17%Cr Alloys

A plot of the Vickers hardness values as a function of the carbon content shows that the hardness increases gradually as the carbon levels are increased (Figure 4). Stabilization with titanium, and the different rolling schedules showed little apparent effect on the hardness. However, the rolling sequence does affect the grain size, and a coarser grain structure was generally found to yield a higher grading.

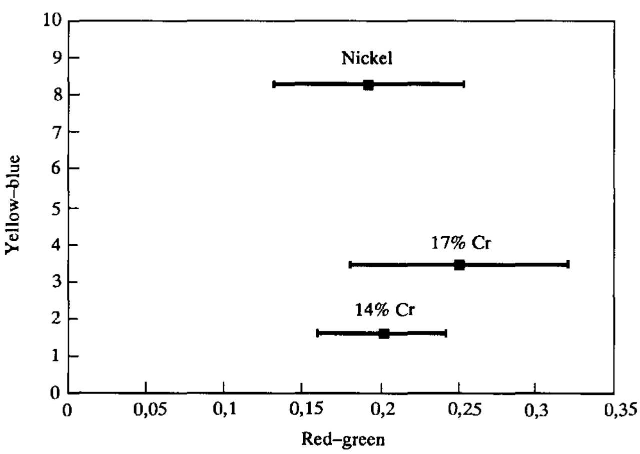


Figure 3—Location of coinage materials on the colour spectrum, plotted for increasing (positive) yellow and red

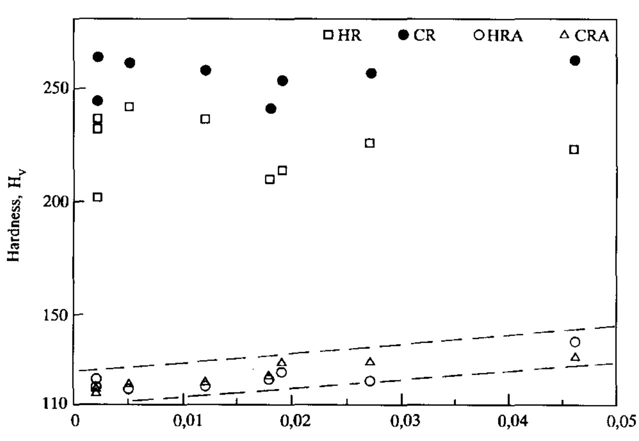


Figure 4—Influence of carbon content on the hardness of the 17%Cr experiment alloys
CR = cold-rolled CRA = cold-rolled and annealed
HR = hot-rolled HRA = hot-rolled and annealed

A lower carbon content appears to be correlated with improved coinability. While studies on higher-chromium ferritic alloys[7] support the conclusion that carbon in higher concentrations acts favourably to soften the alloy by being precipitated as second-phase particles, the present investigation showed the converse. Alloys 251 to 254 showed a noticeable increase in the number of second-phase particles on a microstructural level, but these did not appear to be associated with a significantly higher work-hardening rate. It is possible that the heat treatments were not effective in completely precipitating the carbon from solution.

The trends in grading as a function of hardness and tensile properties are shown in Figures 5 and 6. Generally, the hardness was found to be a valid criterion for ease of coinability, and material with a hardness above 125 HV coins poorly at a load of 70 t.

Scanning electron microscopy (SEM) was utilized to show the differences in surface relief and pattern detail. Figure 7(a) shows the protea design as struck on a nickel blank at 70 t, and represents the minimum requirement in the coining profile. Figures 7(b) and 8(a) show the designs struck on the commercial alloy 1237344 at the same pressure and at 99 t, which entails a load increase of 41 per cent in order to achieve an acceptable relief. The distinction lies in the development of the crown leaves of the protea and the grooves within the flower.

Similarly, Figure 8(b) shows the pattern on the titanium-stabilized grade 254A, which had a carbon content

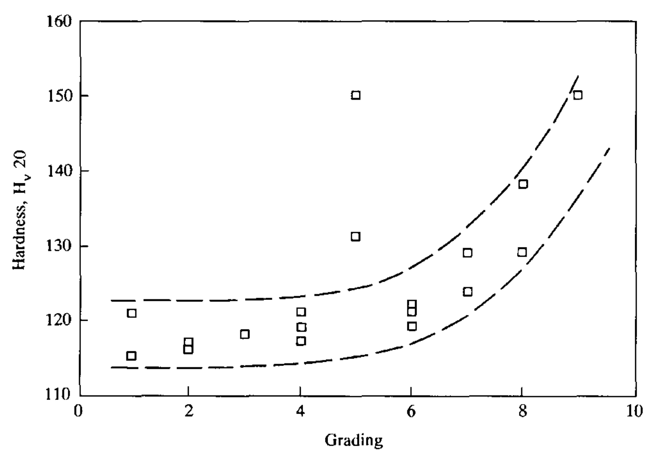


Figure 5—Influence of hardness on the grading of the 17% Cr alloys

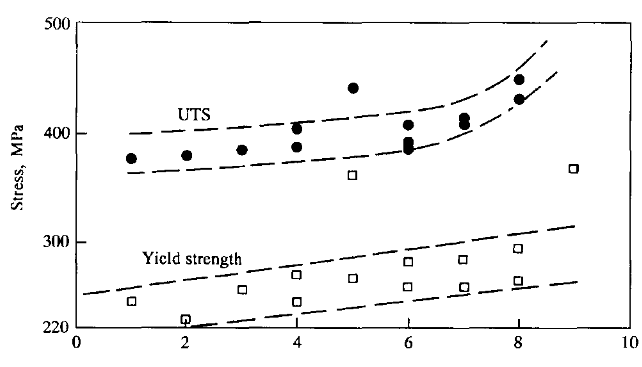
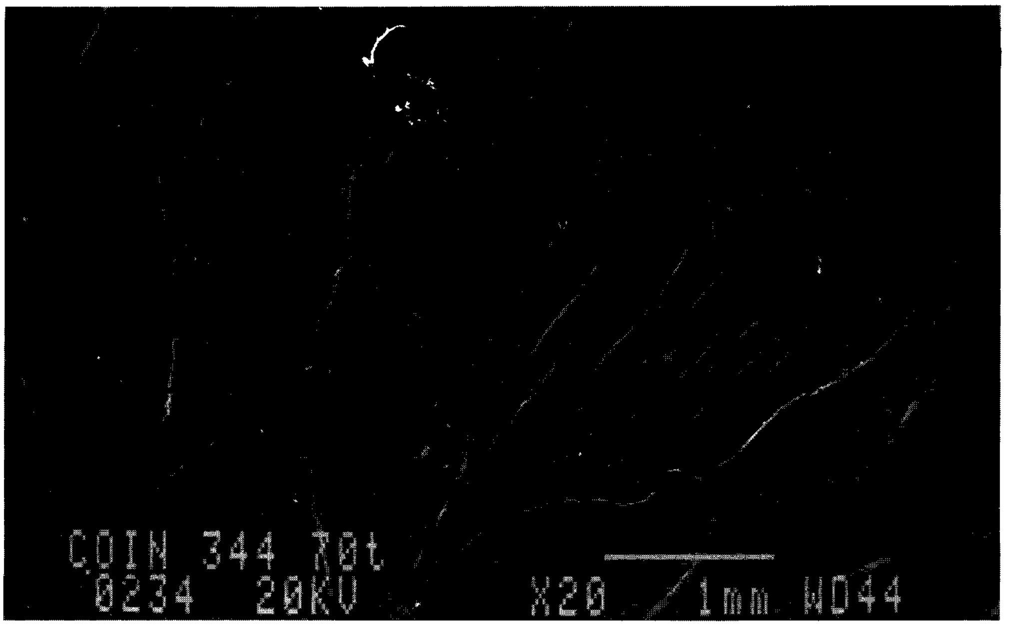


Figure 6—Influence of tensile properties on the grading of the 17%Cr alloys

(a) Conventional nickel coin struck at 70 t



(b) Type 430 (1237344) struck at 70 t, showing the poor development of the crown leaves

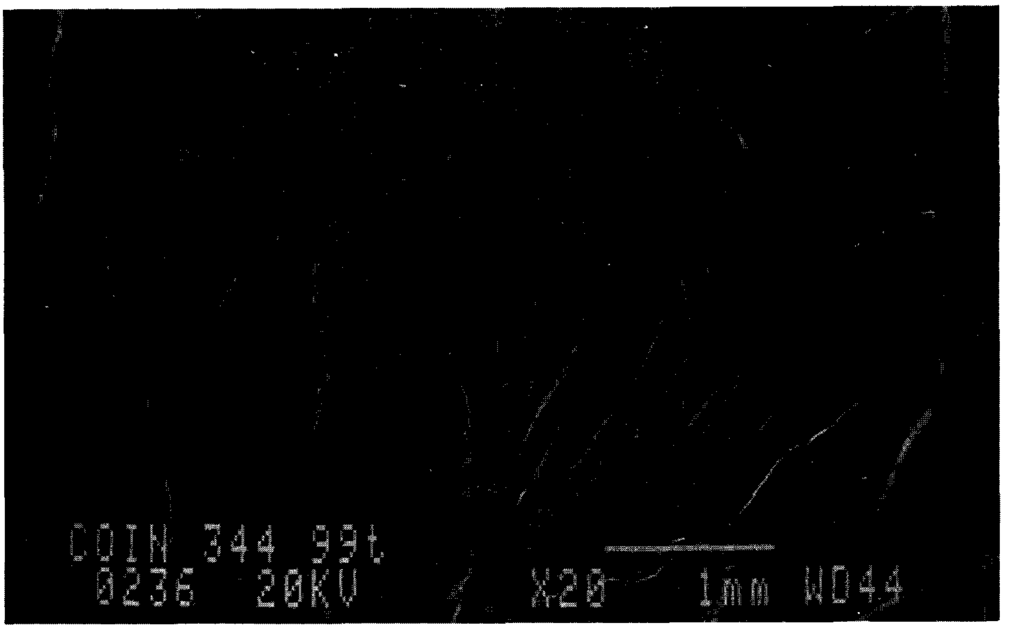
Figure 7 —Scanning electron micrographs of the 20 cent coins following striking at 70 t

comparable with that of commercial-grade alloy. This alloy was the hardest and had the lowest grading of the experimental alloys, with an acceptable appearance after being struck at 80 t (a load increase of 14 per cent). No 17%Cr grade coined acceptably at 70 t, but the experimental compositions required only a 14 per cent increase in pressure to attain sufficient clarity in the relief. Since the carbon levels were comparable with those of the commercial alloy, differences in the phosphorus, silicon, and manganese contents are believed to be significant. The levels of the controlled residual elements are substantially higher than those specified for coining grade 430 alloys in Table I.

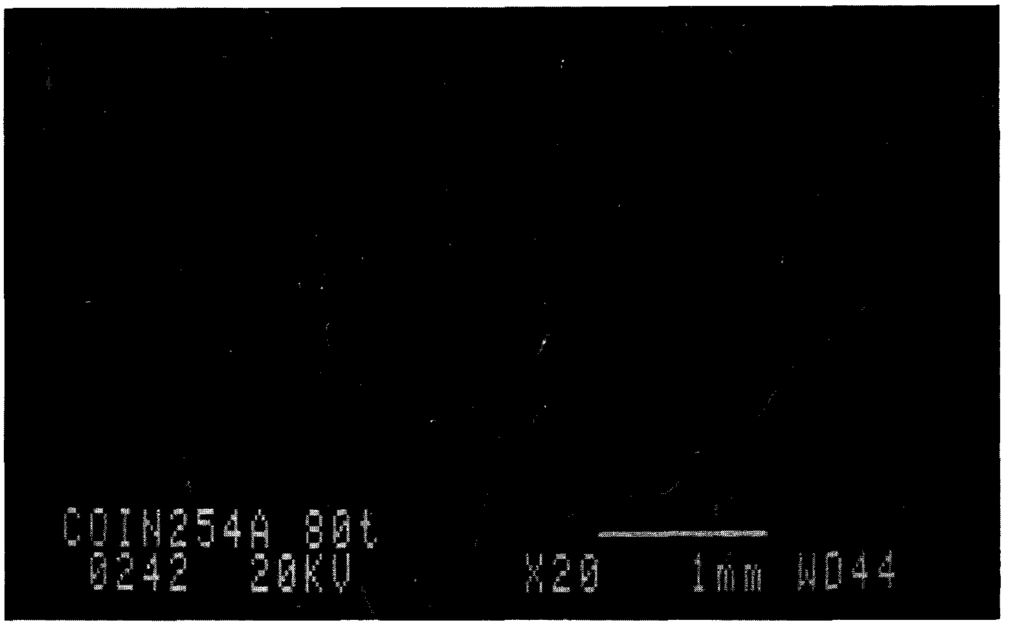
14%Cr Alloys

Evaluation of the heat-treatment response of the 14%Cr experimental alloys yielded the following observations.

(1) Hardness values of the order of 100 HV or less are readily achievable.
(2) Hardness values ranging from approximately 200 HV in the cold-rolled condition to 100 HV in the fully annealed state represent a range that allows sufficient strength for blanking purposes, and adequate softness for striking to be attained.
(3) The hardness is lowered progressively as the wrought structure is restored until a minimum value is attained. Thereafter, the hardness increases, probably as the result of the pick-up of nitrogen at elevated temperatures.
(4) Although solution heat-treatment followed by ageing produces slightly lower hardness values, annealing at an intermediate temperature appears to be adequate for practical purposes.



(a) Type 430 (1237344) struck at 99 t



(b) Alloy 254A struck at 80 t, yielding an acceptable definition of the design

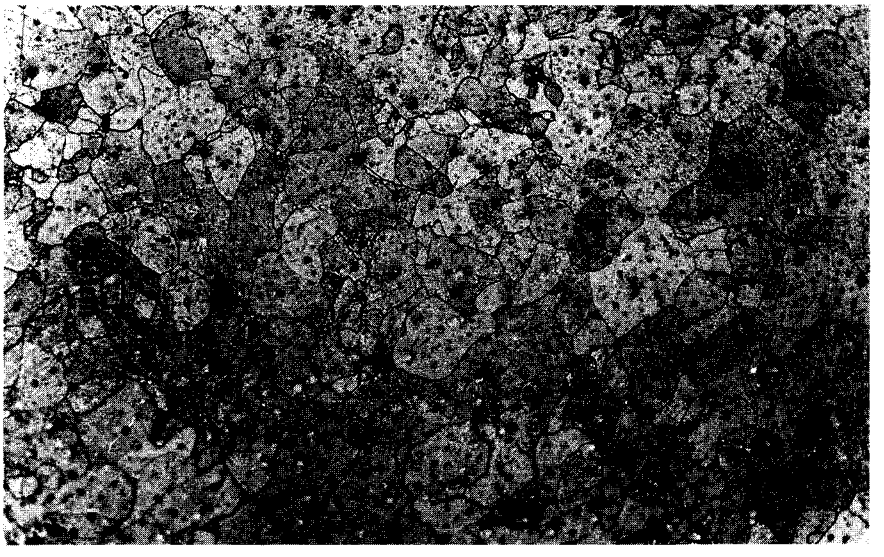
Figure 8—Scanning electron micrographs of the 20 cent coins following striking at 99 t and 80 t

(5) No clear advantage was found in re-sulphurization or stabilizing additions to lower the hardness, but properties such as ease of blanking and grain size are contingent on these.

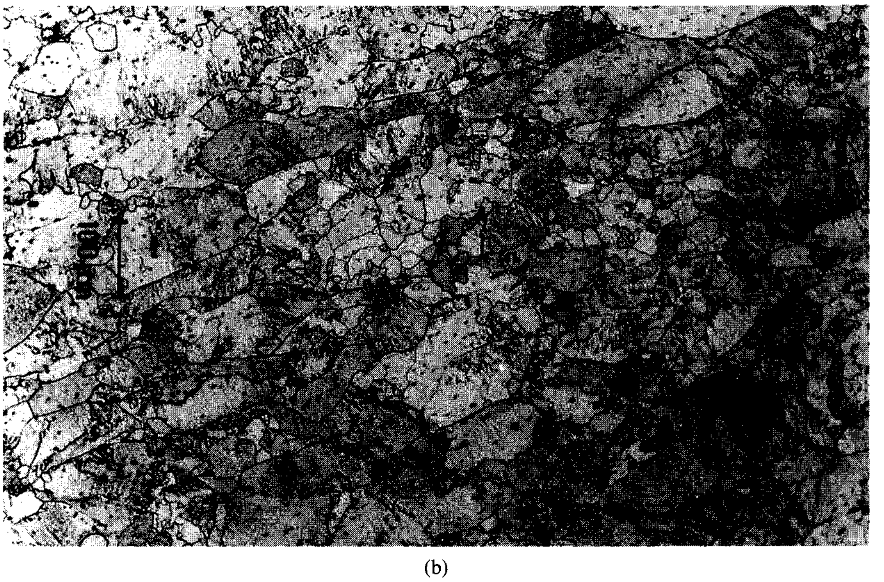
(6) The fully annealed condition is attainable within approximately 10 minutes for temperatures above 750 to 850°C, depending on the alloy composition. The rapid response of the wrought alloys to heat treatment has several advantages, including shorter production cycles, reduced exposure to oxidizing environments, and more cost-effective heat-treatment schedules.

The response of the 14%Cr alloys to the heat-treatment cycles can be understood from a consideration of their microstructures. Figure 9 shows the degree of recrystallization in the annealed alloys. After 1 hour at 750°C, the 760 and 761 compositions were almost fully recrystallized, whereas the stabilized alloy 762 had not yet begun to recrystallize. One hour at 850°C was sufficient to ensure full recrystallization in all the alloys, and the 762 alloy exhibited a considerably finer grain structure than the unstabilized alloys. The niobium addition acts as a grain refiner, ostensibly, in agreement with previous findings[8], by being precipitated as fine carbo-nitrides to pin the grain boundaries.

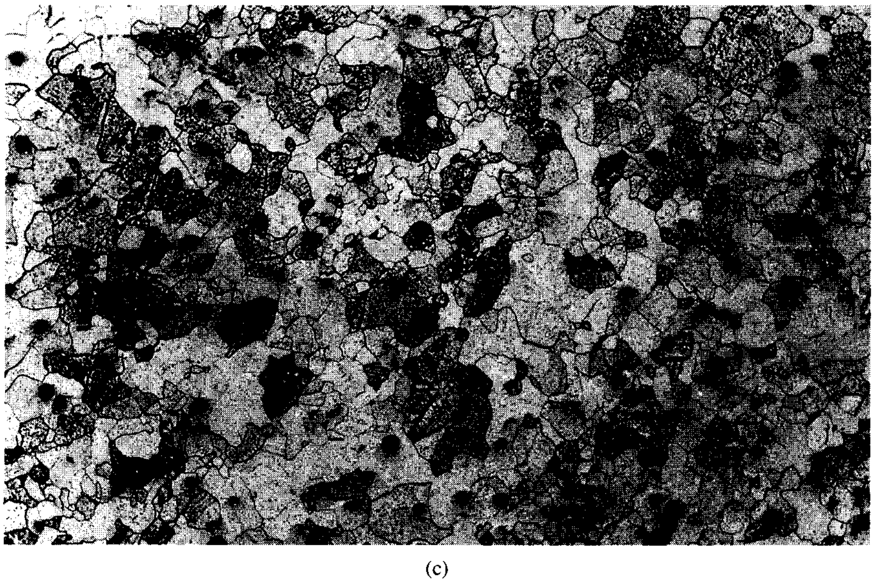
An increase in annealing temperature affects the morphology and distribution of the precipitate. In the 761 free-machining alloy especially, sulphide precipitates were observed to depart from a fine deformation-aligned distribution of elongated particles to a sparser and coarser distribution of globular precipitates. The solution heat-



(a)



(b)



(c)

Figure 9—Microstructural development of the wrought 14%Cr alloys following annealing
(a) Alloy 760 annealed at 750°C for 60 minutes
(b) Alloy 761 annealed at 700°C for 60 minutes
(c) Alloy 762 annealed at 850°C for 60 minutes

treated alloys of all grades appeared to have coarser precipitates than the annealed samples.

While both the 17%Cr and 14%Cr experimental alloys exhibited excellent tensile ductility, the salient feature of the 14%Cr alloys was their low yield strength in the fully annealed condition. This is compatible with the considerable plastic flow required to give the high-relief design shown in Figure 10. The design in the 14%Cr alloys showed sharp relief. Increased striking load, from 80 to 100 t, did not improve the clarity of the pattern in the 761/762 alloys and, in the 430 alloy, the motif was poorly developed even at a load of 100 t.

Similar observations were made for the large medallions (30 mm diameter) shown in Figure 11. The 430 alloy exhibited poor pattern detail compared with the 14%Cr alloys. An increase in the strain rate of the 14%Cr alloys increased the yield stress, which is an important factor in high-volume production rates.

OTHER DEVELOPMENTS IN COINAGE ALLOYS

The use of vending machines is becoming increasingly important in more-developed economies. These machines have sophisticated detection systems that allow the weight, size, shape, colour, absence (or presence) of a central hole, and elastic modulus to be determined against known standards, simultaneously with a highly selective test. For example, one such test uses an eddy-current technique that measures the electrical resistivity and density of the coinage material. In practice, the ferromagnetic properties of ferritic stainless steels are such that they can overwhelm the spectrum detectable by wave comparitors, and adjustment of the vending machines renders them susceptible to fraud. This problem can, of course, be circumvented by development work conducted by the manufacturers of vending-machines.

Ingenious solutions to the fluctuating nickel price and the advent of intelligent coin-readers have been devised by way of novel coinage materials. Most notable of the more sophisticated coins in circulation today are those containing a less-noble bulk material plated to give the appropriate appearance and coinability. Plating allows the bulk composition of the coin to be varied to obtain the desired cost and physical properties, while a relatively thin, more-noble coating yields the required wear, corrosion, aesthetic, and coining properties. Fully automatic processing allows a very uniform and homogeneous coating to be applied (Figure 12), which readily meets tolerances in weight (±2,9 per cent, or ±1% over 100 blanks) and thickness (±0,04 mm). Mass production on a continuous-plating line is a fairly new concept, started by Sherritt Gordon of Canada in the 1970's, but only a few such lines exist outside South Africa. Plated metals constituted 40 per cent of all the coins minted in the world between 1980 and 1984, but 90 per cent of these appeared to be circulated in the USA[6].

A similar principle is embodied in a new coinage material, designated MATINOX, produced by VDM in Germany[9]. This material comprises a sandwich of ferritic and austenitic stainless steels. By variation of the layer thicknesses, electro-physical properties can be achieved that correspond, for example, to those of nickel. A variation of this is found in Italy's bimetallic 500-lire coin, which consists of a stainless rim with a centre of a nickel-containing aluminium bronze.

A fully austenitic coin developed by a UK company[10] exploits the change occurring when non-magnetic austenitic steel is cold-worked to produce ferro-magnetic martensite. The austenitic blank is coined with up to six concentric rings at six possible sites, allowing 64 possible combinations, each with a specific magnetic signature that can be detected by coin-readers.

LOCAL PRODUCTION OF COINAGE

The capacity of the South African Mint's continuous plating line is currently some 2 billion coins per year, and

Figure 10—A comparison of 26 mm diameter coins struck at 80 t. The 761/762 alloys show sharp relief of the highly profiled pattern, while the 430 alloy exhibits rounded contours

Figure 11—A comparison of 30 mm diameter coins struck at 100 t. Good pattern detail was developed in the 14%Cr grades

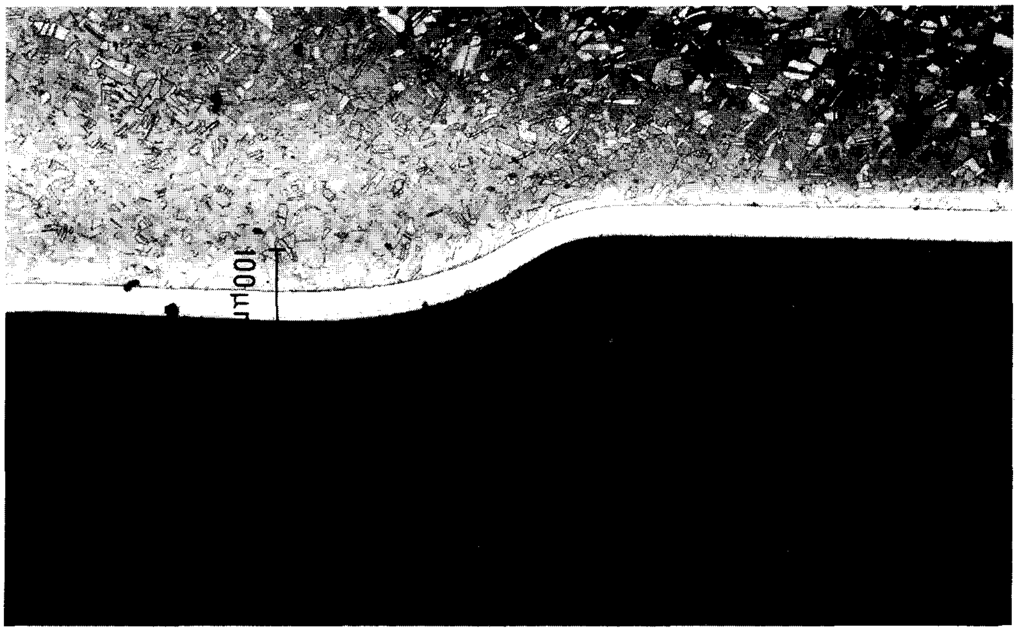


Figure 12—A nickel-plated layer on a copper-cored coin. The uniformity achievable in the deposited thickness is noteworthy

can be upgraded to 3 billion. The mint is able to produce copper, nickel, and bronze coins in plated or conventional form. The cost-effectiveness of production on such a scale positions the mint as a potential large-scale exporter of coin blanks. It is therefore expedient that stainless steels should be developed to fill those niches that call for the unique properties and advantages of such steels.

Although not insuperable, the biggest obstacle to the commercial production of coinage-grade stainless alloys is the need for high degrees of refining. While the commercial-grade material is acceptable for coin designs of low relief, for high-volume production processes (700 coins per minute), the hardness must be minimized to spare the dies. Low levels of residual impurities are readily obtainable with existing technologies, but with associated cost penalties. Practices such as vacuum or electroslag refining (used by the Italian mint to refine their coinage material known as Acmonital) have been adopted.

The essential advantage of stainless steel lies in its intrinsic properties, its versatility, and its adaptability to the manufacture of coins by conventional means. The high performance profile of stainless steel provides a base for wider use, and it is hoped that development work such as the present study can contribute to its specification in a growing number of applications.

CONCLUSIONS

Coining trials on commercial and experimental ferritic stainless steels demonstrated the importance of hardness as a criterion for good coinability. Strict control of the minor-element chemistry achieved hardnesses comparable with those of conventional coinage materials. Specifically, the following were demonstrated.

(1) A decrease in the carbon content is beneficial to the reduction of hardness in 17%Cr alloys. Minimization of the nitrogen, manganese, silicon, and phosphorus contents is also essential.

(2) Although higher striking pressures are required, relatively highly profiled and intricate patterns are achievable in alloys based on 17%Cr. These alloys are well suited to low-profile, high-volume designs.

(3) Experimental ferritic alloys based on a composition of 14%Cr exhibit hardness values of 100 HV and less, have excellent tensile ductility, and allow the attainment of highly profiled patterns.

(4) Micro-alloying additions allow control of the grain size, response to heat treatment, and possibly the wearing properties of the stainless steel.

(5) There is a compromise between the advantages of stainless steel as a coining material and the constraints imposed by a restricted composition range.

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- Mr T. Bell of Metal Images, who conducted minting trials on the experimental 14%Cr alloys
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REFERENCES

1. ANON. Stainless coinage. *Chromium Review*, no. 11, Nov. 1990. p. 11.
2. NISSHIN STEEL CO. LTD. Stainless steel plates for coin manufacture. *Jap. Pat.* 55089431.
3. ARMCO STEEL CORPORATION. Heat treating stainless steel. *Brit. Pat.* 1549338.
4. KAWASAKI STEEL CORPORATION. An ultrasoft ferritic stainless steel having excellent stamping formability. *European Pat.* 0192236A2.
5. HEUBNER, U. Aspects of hardness and hardness testing for coinage alloys. *Metall.*, vol. 36, no. 3. Mar. 1982. pp. 254–258.
6. PATARINI, P., and GANGULY, P.K. Stainless steel for coinage. *Proceedings INCOSS-89, International Conference on Stainless Steels.* New Delhi, Omega Scientific Publishers, 1992. pp. 199–203.
7. WOLFF, I.M., and BALL, A. Ductility in high-chromium superferritic alloys. Part I. *Acta Metall. Mater.*, vol. 39, no. 11. 1991. pp. 2759–2770.
8. WOLFF, I.M., and BALL, A. Substitutional alloying and deformation modes in high-chromium ferritic alloys. *Metall. Trans. A.*, vol. 23A. Feb. 1992. pp. 627–638.
9. VEREINIGTE DEUTSCHE METALLWERKE (VDM). Technical specification. MATINOX. Sixteenth Conference of Mint Directors, Effingham Park, UK.
10. WELDON, B.A. Gaming machines sense ferromagnetic tokens made from nonmagnetic stainless. *Nickel*, Sep. 1990. p. 9.

Announcement

XV CONGRESS OF THE COUNCIL OF MINING AND METALLURGICAL INSTITUTIONS

South Africa's first general election for all the people of the country has recently been set for 27 April 1994.

This long awaited advent of a true democracy should herald a new era of peace, unity and prosperity for a country so rich in resources and manpower.

The election date coincides with the XV Congress and its Southern African programme of technical and sight-seeing visits long planned for 23 April to 14 May.

The Organizing Committee does not wish to hold Congress when very many people will be preoccupied with the election, and has therefore decided to postpone Congress and its itinerary of visits to September 1994 as follows:

Sunday 4 to Thursday 8 September 1994
— Congress Sessions at Sun City Complex
Friday 9 to Saturday 24 September 1994
— Post Congress tours

The second information brochure on Congress which was in preparation for issue in August will accordingly be delayed and mailed to prospective delegates towards the end of 1993.

A reminder: All those persons interested in receiving further details about the Congress should, if they have not already done so, send their names and addresses to me at the following address without delay:

Bill Emmett, Congress Manager, XV CMMI Congress, P O Box 809, Johannesburg 2000, South Africa.
Telephones: (27) (11) 838-8211 Fax (27) (11) 838-4255.