AN INVESTIGATION INTO THE DEVELOPMENT OF PROSPECTIVE INDIAN AUSTENITIC STAINLESS STEELS

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Abstract

The development of substitute stainless steels in which all or the bulk of nickel in the standard austenitic stainless grades is replaced by manganese became a live issue in many steel-producing countries during World War II due to restricted or non-availability of nickel. The research and development work carried out during the war period yielded a series of commercially useful alloy steels, which are enumerated.

The paper goes on to refer to an investigation in progress in the National Metallurgical Laboratory into the development of substitute austenitic stainless steels based on the use of manganese, nitrogen, copper, chromium and rare earth additions. The results of experimental heats made are presented in terms of working properties, metallographic studies, corrosion resistance under different media, intergranular brittleness and physical tests, etc. Tentative views are expressed on the merits of these austenitic stainless compositions under Indian conditions, which will be reviewed after further work which is being pursued in the National Metallurgical Laboratory along lines stated.

Introduction

THE development of substitute stainless steels in which all or part of the nickel in the conventional austenitic 18 : 8 is replaced by manganese became a live issue in many steel-producing countries during World War II following the non-availability of nickel which was needed so desperately for important defence applications. Considerable research and development work carried out during the war yielded a series of commercially useful alloys produced on a tonnage basis.

While a low-carbon 18 per cent Cr, 8 per cent Ni alloy is fully austenitic, an 18 per cent Cr alloy of low carbon content in which manganese replaces nickel cannot be made fully austenitic. The relatively lower austenite stabilizing power of manganese is well established and, in fact, it has been recognized that the austenitizing effect of manganese is about half that of nickel. Hence, a weight-for-weight replacement of nickel by manganese cannot be expected to produce similar structures in the alloys. Burgess and Forgens[1] showed that stable austenite requires a minimum of 16 per cent Mn for a steel of 15 per cent Cr. However, the brittle sigma-phase appears on slow cooling of steels with higher chromium, when the manganese is high, too, and compositions have to be consequently avoided in which it is likely to be present. When the chromium exceeds 15 per cent, it is no longer possible to render the low-carbon alloys completely austenitic even though the manganese be increased to 50 per cent. A marked widening of the alpha-gamma field does occur, with an increase in manganese, and a type of duplex structure consisting of austenite and ferrite grain is stabilized when the manganese reaches or exceeds 4 per cent with chromium exceeding 15 per cent in low-carbon steels.

Mitchell[2] recommended addition of nickel or copper or both, in addition to the manganese, to ensure presence of more austenite. Substitute steels, particularly those containing 18 Cr, 4 Ni and 4 Mn, are already in commercial production and have been used extensively in the U.S.A. and Europe for some applications.

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Corrosion Resistance

The most extensive use of the stainless steels is for withstanding corrosion by a great variety of chemicals. Hence the susceptibility of the chromium-manganese alloys to such corrosive agents must be investigated before they can be substituted for the standard 18 Cr : 8 Ni steels. Nickel is added to 18 : 8 stainless steel for two purposes: (i) to produce gamma-phase alloys and (ii) to take advantage of the special corrosion-resistant behaviour of nickel. Chromium-nickel stainless steels are chiefly merited for their high resistance to oxidizing corrosive conditions. Their resistance to oxidation depends upon interaction with oxidizing agents causing the formation of a protective oxide film. Nickel is less chemically reactive than either chromium or iron, consequently nickel in 18 Cr: 8 Ni steel should increase resistance to corrosion. Nickel itself is capable of developing passivity and, therefore, tends to widen the range under which the steel remains passive. Stainless steels are often employed for the making and handling of nitric acid. The nickel content of steels for this purpose is relatively unimportant. For the handling of sulphuric acid, on the other hand, the presence of nickel is necessary. Whereas nickel by its presence partially contributes to overall corrosion resistance of the standard 18 : 8 steel, manganese even in large amounts would exercise practically no effect on the all-round corrosion resistance of these steels. Thus it is to be expected that substitution of manganese for nickel in 18 : 8 steel would impair its corrosion resistance in certain media.

Concerning susceptibility to intergranular corrosion, the presence of manganese should exert a beneficial influence. Manganese, unlike nickel, is a carbide former and, hence, it will tie up some of the carbon.

The replacement of nickel by manganese in stainless steels was investigated many years ago by the Union Carbide & Carbon Corporation and several chromium-manganese steels were in commercial production in the late 1930's and early 1940's. In Europe, both the Germans and Russians have had steels in commercial usage for a number of years in which manganese replaced all or part of the nickel.

Among elements which promote the retention of austenite are carbon, nitrogen, manganese and copper in addition to nickel. These elements are more plentiful than nickel, and it should be possible to replace most of the nickel by using them. Investigations have shown that alloys containing 16-18 per cent chromium and 6-14 per cent manganese can be made fully austenitic by the addition of 0·1-0·15 per cent nitrogen and by adding nickel in the range 2-6 per cent. The addition of nickel to chromium-manganese 18 : 8 increases its ductility. The effect is apparent with 1-2 per cent nickel, but is still more noticeable with 3-6 per cent. In low-carbon steels of this type, the manganese can be reduced below 8 per cent. Fully annealed steels containing 6 per cent manganese and 5 per cent nickel are comparable in ductility to 18:8 chromium-nickel steels. The quantity of nickel necessary to form austenite in these chromium-manganese steels varies with the manganese content and numerous equivalent combinations are possible.

Addition of nitrogen to the low-nickel or low-manganese alloy also stabilizes the austenite. Although they are not commercial, other austenitic steels which have been stabilized by nitrogen are: (1) 23 per cent chromium, 5 per cent nickel, 0·25 per cent nitrogen; (2) 20-22 per cent chromium, 3·5 per cent manganese, 3·5 per cent nickel, 0·2 per cent nitrogen; and (3) 15 per cent chromium, 15 per cent manganese, 0·2 per cent nitrogen. It has been estimated that 0·2 per cent nitrogen is equivalent to 4 per cent nickel.

16-16-1 Chromium-Manganese-Nickel

This grade has a nominal composition of 15 per cent chromium, 16·5 per cent manganese, 1 per cent nickel, 0·15 per cent nitrogen and 0·10 per cent carbon. This steel is called TRC by the Budd & Co. in the U.S.A. who have used it in the construction of railroad cars and trailer truck bodies. TRC has a higher work-hardening rate than 18 : 8 chromium-nickel steel, but about equal to 17-7 chromium-nickel steel and can be fabricated by methods used in forming type 301 or 302 stainless steel. In resistance to mild atmospheric corrosion, TRC appears to be equivalent to 18 : 8. On the basis of the production of parts from several thousand tons of the new alloy, Budd & Co. consider TRC and type 302 to be interchangeable.

In the opinion of Allegheny Ludlum Steel Corporation, U.S.A., the 16-16-1 alloy does not completely match 18 : 8 for highly corrosive media, but is useful for less critical applications.

17-6-4 Chromium-Manganese-Nickel

The composition of this steel is 17 per cent chromium, 6 per cent manganese, 4 per cent nickel, 0·15 per cent nitrogen and 0·10 per cent carbon. The mechanical properties and corrosion resistance of this steel are quite close to those of 17-7. Working characteristics of the two materials were also similar; thus it was possible to replace 3 per cent nickel with 4½ per cent of manganese and produce an alloy of similar characteristics.

Two standard Russian steels are quite close to this steel in composition. However, both with nitrogen about 0·15 per cent have considerably higher carbon contents and one contains 1 per cent tungsten while the other contains 2 per cent silicon. This tendency to use high-carbon stainless steels appears to be rather general in Russian steel-making practice.

18-10-4 Chromium-Manganese-Nickel

This alloy developed by Allegheny Ludlum Steel Corporation contains 18 per cent chromium, 10 per cent manganese and 4 per cent nickel and is similar to 18 : 8 in mechanical properties and also in resistance to corrosion as determined by laboratory tests in boiling nitric acid, salt-spray and copper sulphate-sulphuric acid mixture.

Welding Rods

Two chromium-manganese stainless steels are used in Germany as welding rods. Their compositions are 19 per cent chromium, 5·8 per cent manganese, 8·0 per cent nickel, 1·3 per cent silicon, 0·6 per cent titanium and 0·45 per cent carbon, and 10 per cent chromium, 18 per cent manganese, 0·4 per cent titanium, 0·8 per cent silicon and less than 0·12 per cent carbon. These steels are used for high grade welds in carbon and alloy steels of all kinds and for the welding of heat-resisting chromium-manganese steels.

Pruger[3] compared the merits of two manganese stainless steels — 17 per cent Cr, 16 per cent Mn, 2 per cent Ni, and 15 per cent Cr, 17 per cent Mn, 1 per cent Ni — with the conventional 18 per cent Cr, 8 per cent Ni, on the basis of corrosion resistance, creep rate, oxidation resistance at high temperatures, weldability, hot-workability, rate of strain-hardening, strength, ductility and costs. These steels have the desirable mechanical properties of 18 per cent Cr, 8 per cent Ni steel, but are inferior in resistance to corrosion in certain media. This deficiency can be overcome by increasing the nickel content, and recent tests of a newer alloy — 18 per cent Cr, 10 per cent Mn, 4 per cent Ni — showed that this alloy is similar to 18 per cent Cr, 8 per cent Ni in the boiling nitric acid, salt-spray and copper sulphate-sulphuric acid tests.

It may also be stated that the 16 per cent Cr, 17 per cent Mn, 1 per cent Ni, 0·15 per cent N steel, although it resembles a more stable austenitic steel similar to Type 304, possessing less ductility for a given strength, is very difficult to make because of the accurate composition balance necessary to obtain a commercially hot-workable product with the users' limit of 0·10 per cent carbon. It also lacks manufacturing consistency[4].

Indian austenitic chromium-manganese steels would be sure to centre around 18 per cent chromium, 12-14 per cent manganese, 2·4 per cent nickel or less with suitable nitrogen additions. These may be useful for a multitude of applications where the standard 18 : 8 is now being employed indiscriminately.

Effect of nitrogen additions to stainless steels[5] has been investigated in Japan using metallographic studies in conjunction with hardness and corrosion-resistance measurements. A low-nickel austenitic stainless steel was produced by substituting nitrogen for part of nickel and the following composition appeared optimum for weakly corrosive environments:

	Per cent
Cr	20-22
Ni	5·5-6·0
N	0·18-0·22
C	0·10

Higher chromium resulted in the formation of the gamma-phase and it was necessary to add more nitrogen which was apt to cause unsoundness.

Metallurgists at Battelle Memorial Institute have patented a new iron base alloy as a substitute for stainless steel used in the reinforcing braid of light-weight cable. The new alloy is expected to be useful in many applications requiring a material with moderate resistance, good workability and resistance to magnetization. The new alloy substitutes manganese and copper for all of the nickel and much of the chromium used in the original wire material. Previously, stainless steel was the only commercial material that met the requirements of signal corps specifications for a reinforcing braid wire in cables known as the 'spiral four' type. Since cable of this type is encased in a protective cover, the superior corrosion resistance of nickel-chromium steel is not required and Battelle metallurgists have developed this substitute for conservation purposes. H. McIntyre and G. Manning, who developed the new alloy, have shown that required properties can be expected from alloys with the following range of composition:

	Per cent
C	0·08- 0·15
Mn	14·50-18·50
Si	0·30- 1·30
Cu	1·80- 2·20
Ni	0·08- 0·15
Balance Fe	

Table 1 gives the properties of chromium-manganese stainless steels developed in America, Germany and Russia, mainly in the late 1940's[6]. At present the only commercial steel of this type produced in America has a nominal composition of 15 per cent chromium, 16·5 per cent manganese, 1 per cent nickel, 0·15 per cent nitrogen and 0·10 per cent carbon. This steel is being manufactured by Messrs Budd & Co. and is used for railroad cars and trailer truck bodies.

It is envisaged that a steel containing manganese might be introduced in India for such purposes and domestic utensils, where it would have many advantages over the traditional materials, brass and bronze. In the National Metallurgical Laboratory, Jamshedpur, detailed investigations are being carried out on chromium-manganese austenitic stainless steels with this objective. The investigation was carried out on the following serial basis:

If nickel in the 18 : 8 type of stainless steels is replaced by even double the manganese, the steel will not be completely austenitic since manganese has got a much lower austenite-stabilizing power than nickel; to produce a fully austenitic structure from the chromium-manganese combination, chromium should not exceed 13 per cent and more than 13 per cent manganese must be added[7,8].

Among other elements which stabilize and promote austenite formation at room temperature are nitrogen[9] and copper. With the

TABLE 1 — PROPERTIES OF SOME CHROMIUM-MANGANESE STAINLESS STEELS

Nominal composition, %					Condition	Yield stress, tons/sq. in.	Maximum stress, tons/sq. in.	Elong. % on 2 in.
C	Cr	Mn	Ni	Others				
				American Steels				
0·10	16-20	8-10	—	—	W.Q. 1920°F.	21	54	27
0·10	15	16·5	1·00	0·15 N	H.R. Ann.	18	45	60
0·10	17	6	4·00	—	Ann.	19	56	70
0·15	12	16	0·25	—	A.C. 1875°F.	13	63	67
0·80	15-17·5	6·5-8·5	14-17	5·5-7 Mo, 0·1-0·2 N	W.Q. 1900°F.	26	49	45
				German Steels				
0·10	9	18	—	3 Si, 0·4 Ti	W.Q. 1925°F.	—	49	40
0·10	12	18	—	0·5 Si, 0·7 V, 0·2 N	O.Q. 2100°F.	—	56	20
0·10	14	8	1·5	0·08 N	—	14	63	33
0·10	15	14	1·5	0·1 N	—	17	45	69
0·21	19	8	1·0	—	A.C. 1560°F.	31	57	25
0·16	17	16	1·3	—	A.C. 1560°F.	28	45	34
				Russian Standard Steels				
0·15-0·30	12-14	8-10	3·7-5·0	—	W.Q. 1920°F.	—	53	36
0·35-0·45	17-20	4-6	3-7	0·8-1·0 W	—	—	—	—
0·35-0·45	17-20	3-5	5-7	1·4-2·2 Si	—	—	—	—
0·38-0·47	14-16	6-8	5-7	0·4-0·8 Mo 1·4-1·8 V	—	—	—	—

Note — W.Q., Water-Quenched; H.R., Hot-Rolled; A.C., Air-Cooled; O.Q., Oil-Quenched.

proper use of these elements in conjunction with manganese it is possible to get a fully austenitic structure at 18 per cent chromium. For 1 per cent addition of copper it was still found necessary to add more than 5 per cent nickel and more than 6 per cent manganese to the 17-18 per cent chromium steel to get a wholly austenitic structure. With 0·2 per cent carbon in these steels less difficulty was encountered to secure the austenitic structure[10,11]. Initial hot-working is difficult with steels of this composition and also austenite is not so stable as that of 18 : 8 chromium-nickel stainless steel. Nitrogen is a strong austenite-former and a stabilizer. It has been estimated that 0·2 per cent nitrogen is equivalent to 4 per cent nickel. Recent investigations in the U.S.A. have shown that steels containing chromium 16-17 per cent, nickel 3·5-4·5 per cent, manganese 7-9 per cent, carbon 0·10 per cent and nitrogen 0·12-0·18 per cent have excellent austenitic stability and have good hot-working properties[12]. They also have good mechanical properties in the solution-treated condition.

Experimental Work

Six-pound steel experimental melts were made in high-frequency induction furnace and cast in small ingots. The raw materials used were Armco ingot iron, low-carbon ferro-manganese, low-carbon ferro-chrome and ferro-silicon. Nitrogen was introduced by blowing nitrogen gas in some of the heats and in the rest by the addition of calcium cyanamide. Rare earth additions were made in the form of mischmetal. The chemical compositions of the steels so far investigated are given in Table 2. It will be seen that the compositions selected for initial investigation are of the 17 : 9 : 4, 17 : 9 : 2, 17 : 8 : 4, 17 : 8 : 2 and 17 : 7 : 4 chromium-manganese-nickel types. Two 18 : 8 type steels were also treated in the same way for comparison with the experimental chromium-manganese-nickel alloys. The chemical compositions of these two steels are given in Table 2.

The ingots were hot-worked at 1150°C. and forged down to $\frac{3}{4}$ in. sq. bars. No difficulties whatever were encountered. The finishing temperature was 950°C. The forged bars were solution-treated for one hour at 1050°C., then water-quenched, turned to $\frac{5}{8}$ in. dia. rounds and then used for extensive mechanical and corrosion tests.

Mechanical Tests — Tensile tests were carried out using A.S.T.M. specimens with 1 in. gauge length. The results of tensile and hardness tests are tabulated in Table 3.

TABLE 2 — CHEMICAL COMPOSITION OF CHROMIUM-MANGANESE-NICKEL AND 18 : 8 STAINLESS STEELS

Cast No.	Nominal composition	Chemical composition, %							
		Cr	Mn	Ni	C	N	Si	Cu	Ti
A 25	17: 9: 4 Cr: Mn: Ni	16·82	9·24	3·84	0·25	0·113	1·43	1·20	0·260
A 24	,,	17·16	9·43	4·04	0·27	0·123	1·54	—	0·150
A 23	,,	17·35	9·46	4·12	0·40	0·135	1·53	—	0·076
A 22	,,	16·47	9·70	5·24	0·36	0·150	1·47	—	—
A 13-2	17: 9: 2 Cr: Mn: Ni	17·85	9·02	1·97	0·36	0·252	1·36	—	0·080
A 11	,,	16·40	9·20	1·96	0·23	0·130	1·30	—	—
A 14	,,	16·40	9·20	1·99	0·24	0·115	1·23	1·20	—
A 15	,,	16·75	9·70	2·05	0·32	0·060	1·63	—	—
A 16	,,	15·94	8·60	2·05	0·35	0·074	1·77	—	0·070
A 19	,,	16·47	8·63	1·93	0·30	0·163	1·58	—	0·300
A 21	,,	16·47	8·88	1·78	0·36	0·144	1·51	1·31	0·180
A 20	,,	17·16	8·91	2·05	0·29	0·210	1·46	—	0·262
A 9	17: 8: 4 Cr: Mn: Ni	16·29	8·02	4·27	0·19	0·072	1·47	0·26	—
A 8	,,	16·29	8·52	3·91	0·16	0·071	1·20	—	—
A 7	,,	15·52	8·60	4·17	0·28	0·067	1·50	—	—
A 12	17: 8: 2 Cr: Mn: Ni	16·47	8·04	2·02	0·18	0·101	1·47	—	—
A 18	,,	16·70	8·10	2·02	0·32	0·079	1·59	0·86	0·110
A 17	,,	16·96	8·10	2·02	0·31	0·069	1·67	—	0·120
A 13	,,	16·99	8·33	2·07	0·14	0·067	1·50	—	—
A 3	17: 7: 4 Cr: Mn: Ni	17·34	6·74	3·76	0·11	0·042	1·20	—	—
A 5	,,	15·61	7·08	3·84	0·23	0·082	1·33	—	—
A 6	,,	14·73	7·22	4·27	0·28	0·094	1·51	0·88	—
A 4	,,	15·78	7·46	3·74	0·21	0·184	1·31	—	—
A 26	18: 8 Cr: Ni	18·73	0·81	7·96	0·10	Stabilized			
A 27	,,	18·56	0·70	7·27	0·13	Unstabilized			

TABLE 3 — MECHANICAL PROPERTIES OF CHROMIUM-MANGANESE-NICKEL AND 18:8 CHROMIUM-NICKEL STEELS

CAST No.	NOMINAL COMPOSITION	YIELD STRESS, tons/sq. in.	MAXIMUM STRESS, tons/sq. in.	ELONGATION % ON 1 IN. GAUGE LENGTH	REDUCTION IN AREA, %	HARDNESS, V.P.H. No.
A 25	17:9:4 Cr:Mn:Ni	28·4	44·6	25·0	22·10	221
A 24	,,	38·7	48·3	12·5	18·10	245
A 23	,,	37·4	55·6	18·8	17·50	269
A 22	,,	30·6	54·8	56·3	49·10	243
A 13-2	17:9:2 Cr:Mn:Ni	—	51·5	12·5	17·00	264
A 11	,,	—	56·3	50·0	63·22	227
A 14	,,	29·0	48·3	62·5	66·80	203
A 15	,,	30·6	58·0	43·8	46·90	242
A 16	,,	36·3	56·8	37·5	25·60	249
A 19	,,	36·3	55·6	43·8	34·60	245
A 21	,,	36·3	55·6	37·5	30·00	245
A 20	,,	34·6	48·4	25·0	31·00	236
A 9	17:8:4 Cr:Mn:Ni	28·4	51·6	50·0	54·60	206
A 8	,,	32·2	49·9	56·3	68·20	210
A 7	,,	38·1	66·1	56·3	61·10	222
A 12	17:8:2 Cr:Mn:Ni	30·6	54·8	48·4	45·10	244
A 18	,,	32·2	53·2	43·8	36·10	235
A 17	,,	33·9	56·8	50·0	38·60	254
A 13	,,	30·5	53·0	53·0	60·00	245
A 3	17:7:4 Cr:Mn:Ni	29·0	53·2	56·3	66·80	209
A 5	,,	30·6	52·4	59·3	57·10	232
A 6	,,	30·6	54·8	50·0	59·90	213
A 4	,,	34·1	54·4	56·3	65·50	238
A 26	18:8 Cr:Ni	18·1	41·5	68·8	72·40	163
A 27	,,	24·6	45·5	56·3	70·60	181

Microscopical Examination — Typical microstructures of the steels investigated are shown in Figs. 1-6. The steels examined were fully austenitic except the cast specimen No. A 3 which showed duplex structure (FIG. 7).

Oxidation Tests — Oxidation tests were carried out on the steels at 850°, 1000° and 1150°C. for 24 hr. The results of the tests are set out in Table 4.

Boiling Nitric Acid Test — The specimens were held for 48 hr. in boiling 65 per cent (by weight) nitric acid (A.S.T.M. specification A262-52T). The results are given in Table 5.

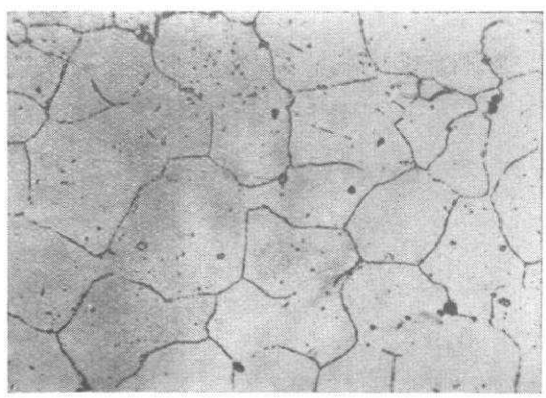

FIG. 1 — 17:9:4 Cr:Mn:Ni STEEL (C, 0·25-0·40; N, 0·12-0·15 PER CENT). ETCHED: OXALIC ACID, ELECTROLYTIC. × 250

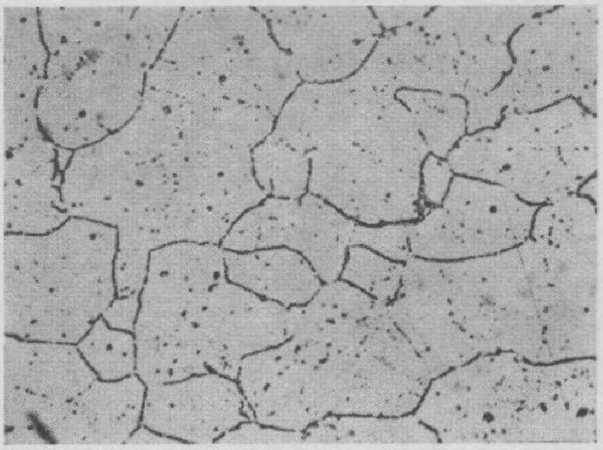

FIG. 2 — 17: 9: 2 Cr: Mn: Ni STEEL (C, 0·24-0·38; N, 0·060-0·252 PER CENT). ETCHED: OXALIC ACID, ELECTROLYTIC. × 250

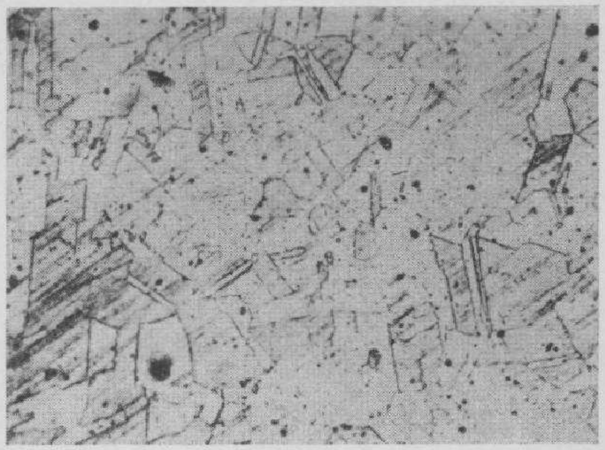

FIG. 5 — 17: 7: 4 Cr: Mn: Ni STEEL (C, 0·21-0·28; N, 0·042-0·184 PER CENT). ETCHED: OXALIC ACID, ELECTROLYTIC. × 250

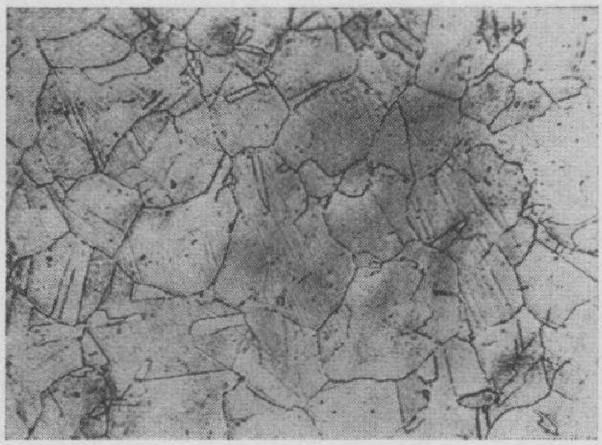

FIG. 3 — 17: 8: 4 Cr: Mn: Ni STEEL (C, 0·16-0·28; N, 0·067-0·072 PER CENT). ETCHED: OXALIC ACID, ELECTROLYTIC. × 250

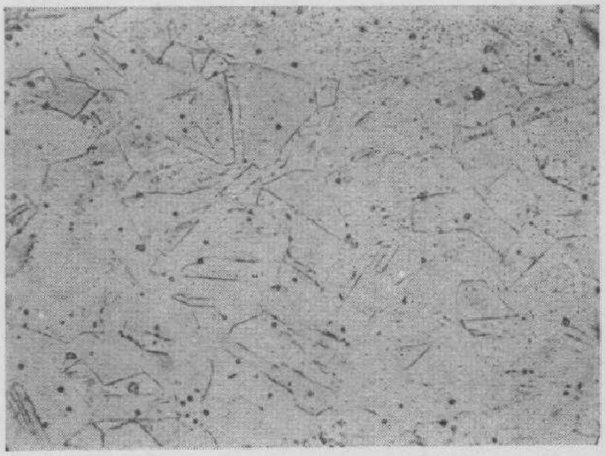

FIG. 6 — 18: 8 Cr: Ni: STEEL (C, 0·10-0·13 PER CENT) ETCHED: OXALIC ACID, ELECTROLYTIC. × 250

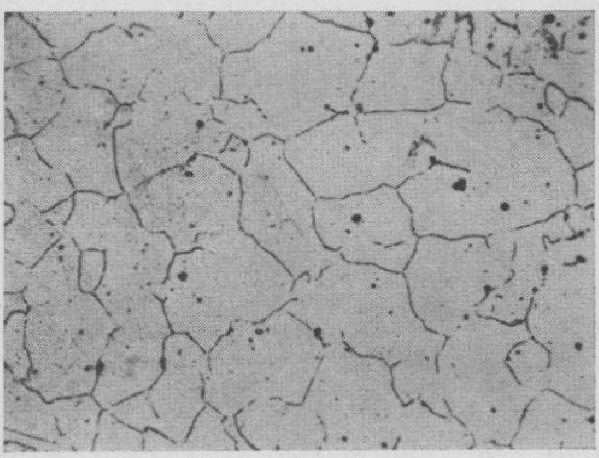

FIG. 4 — 17: 8: 2 Cr: Mn: Ni STEEL (C, 0·14-0·32; N, 0·070-0·101 PER CENT). ETCHED: OXALIC ACID, ELECTROLYTIC. × 250

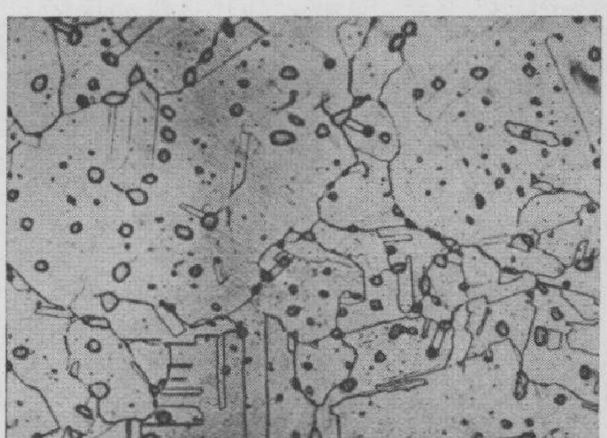

FIG. 7 — CAST NO. A 3, SHOWING DUPLEX STRUCTURE (Cr, 17·34; Mn, 6·74; Ni, 3·76; C, 0·11; N, 0·042 PER CENT). ETCHED: OXALIC ACID, ELECTROLYTIC. × 250

TABLE 4—OXIDATION TEST

Duration of test : 24 hr. at 850°, 1000° and 1150°C.

Cast No.	Nominal composition	Gain in weight in gm./sq. in. for 24 hr.			Ratio: Gain in wt. for Cr:Mn:Ni steels / Gain in wt. for 18:8 Cr:Ni steels		
		850°C.	1000°C.	1150°C.	850°C.	1000°C.	1150°C.
A 25	17:9:4 Cr:Mn:Ni	0·00250	0·0162	0·7275	1·39	0·75	1·21
A 24	,,	0·00220	0·0135	0·5683	1·22	0·62	0·94
A 23	,,	0·00220	0·0197	0·3160	1·22	0·92	0·52
A 22	,,	0·00270	0·0260	0·4017	1·50	1·20	0·67
A 13-2	17:9:2 Cr:Mn:Ni	0·00210	0·0215	0·7299	1·16	1·00	1·21
A 11	,,	0·00250	0·0219	0·6530	1·39	1·02	1·08
A 15	,,	0·00190	0·0195	0·4363	1·05	0·91	0·72
A 16	,,	0·00200	0·0216	0·5115	1·11	1·01	0·85
A 19	,,	0·00050	—	0·8729	0·28	—	1·44
A 21	,,	0·00210	0·0285	0·8341	1·16	1·32	1·38
A 20	,,	0·00190	0·0242	0·8444	1·05	1·13	1·40
A 9	17:8:4 Cr:Mn:Ni	0·00210	—	0·7079	1·16	—	1·17
A 8	,,	0·00180	0·0159	0·9574	1·00	0·74	0·74
A 7	,,	0·00260	0·0253	0·8810	1·50	1·17	1·46
A 12	17:8:2 Cr:Mn:Ni	0·00220	0·0249	0·6174	1·22	1·15	1·02
A 18	,,	0·00190	0·0215	0·6531	1·05	1·00	1·08
A 17	,,	0·00180	0·0318	0·4322	1·00	1·47	0·72
A 13	,,	0·00210	0·2400	0·8992	1·16	1·11	1·49
A 3	17:7:4 Cr:Mn:Ni	0·00194	0·0055	0·5971	1·08	0·26	0·99
A 5	,,	0·00200	0·0260	0·6178	1·11	1·20	1·02
A 6	,,	0·00170	0·0256	0·7871	0·04	1·19	1·31
A 4	,,	0·00180	0·0258	0·6790	1·00	1·20	1·13
A 26	18:8 Cr:Ni	0·00200	0·0189	0·4500	—	—	—
A 27	,,	0·00160	0·0242	0·7563	—	—	—

Salt-spray Test — For the salt-spray test 5 per cent (5 parts by weight of salt in 95 parts of distilled water) salt solution with pH of 6·6-6·8 was used. The test was carried out for 48 hr. at 32·5°-36°C.

Susceptibility to Intergranular Corrosion — For the intergranular corrosion test the following solution was used[13]:

88 gm. H_2SO_4 (sp. gr. 1·84)

111 gm. $CuSO_4.5H_2O$

Distilled water to make the solution to one litre.

The specimens were heated at 650°C. for 20 min. and air-cooled. They were kept in boiling solution for 72 hr. The results of the tests are given in Table 6.

Discussion

Mechanical Tests — The steels investigated showed higher yield stress in solution-treated condition than 18 : 8 variety steels. The percentage elongation and reduction in area dropped down markedly with the increase in carbon. Nitrogen did not appear to

TABLE 5 — BOILING NITRIC ACID TEST

Strength of acid: 65% by weight. Duration of test: 48 hr.

CAST No.	NOMINAL COMPOSITION	INCHES PENETRATION PER MONTH
A 25	17 : 9 : 4 Cr : Mn : Ni	0·057010
A 24	,,	0·018580
A 23	,,	0·071550
A 22	,,	0·102800
A 13/2	17 : 9 : 2 Cr : Mn : Ni	0·099220
A 11	,,	0·011290
A 14	,,	0·015490
A 15	,,	0·083030
A 16	,,	0·234600
A 19	,,	0·068060
A 21	,,	0·074040
A 20	,,	0·033400
A 9	17 : 8 : 4 Cr : Mn : Ni	0·012270
A 8	,,	0·012720
A 7	,,	0·057710
A 12	17 : 8 : 2 Cr : Mn : Ni	0·088490
A 18	,,	0·086480
A 17	,,	0·028210
A 13	,,	0·055900
A 3	17 : 7 : 4 Cr : Mn : Ni	0·004747
A 5	,,	0·012180
A 6	,,	0·050090
A 4	,,	0·008042
A 26	18 : 8 Cr : Ni (Standard)	0·001479
A 27	,,	0·001913

TABLE 6 — INTERGRANULAR CORROSION TEST

Duration of test: 72 hr.

CAST No.	NOMINAL COMPOSITION	LOSS IN WT. IN GM./SQ.CM. FOR 72 HR.
A 25	17 : 9 : 4 Cr : Mn : Ni steels	0·01734000
A 24	,,	0·02058000
A 23	,,	0·01180000
A 22	,,	0·08351000
A 13/2	17 : 9 : 2 Cr : Mn : Ni steels	0·03896000
A 11	,,	0·02015000
A 15	,,	0·01508000
A 16	,,	0·02687000
A 19	,,	0·02044000
A 21	,,	0·01889000
A 20	,,	0·00032480
A 9	17 : 8 : 4 Cr : Mn : Ni steels	0·04560000
A 8	,,	0·02621000
A 7	,,	0·01542000
A 12	17 : 8 : 2 Cr : Mn : Ni steels	0·00969000
A 18	,,	0·02666000
A 17	,,	0·02626000
A 13	,,	0·04389000
A 3	17 : 7 : 4 Cr : Mn : Ni steels	0·01171000
A 5	,,	0·03701000
A 6	,,	0·06699000
A 4	,,	0·07411000
A 26	18 : 8 Cr : Ni steels	0·00009016
A 27	,,	0·00150400

influence the mechanical properties. Cast Nos. A 5, A 4, A 13 and A 12 show that with identical composition, except that of nitrogen, the mechanical properties remained the same (Tables 2 and 3). Additions of copper helped to increase the ductility of the steels (cast Nos. 11 and 14, Table 3).

Microscopical Examination — Microscopical examination showed that all the steels were austenitic with the exception of cast No. 3. This can be explained as being due to the low carbon (C, 0·11 per cent) and high chromium (Cr, 17·34 per cent).

Oxidation Tests — From the study of Table 4 it will be clear that the steels studied compare very favourably with the standard 18 : 8 chromium-nickel steels. The ratio of gain in weight for chromium-manganese-nickel steels to 18 : 8 chromium-nickel steels varied between 0·22 and 1·5. Carbon or manganese did not appear to have any effect, only chromium gave the resistance to oxidation.

Boiling Nitric Acid Test — Only cast steel No. 3 gave comparatively good result in this test (Table 5). This cast steel had the lowest carbon percentage amongst the steels investigated. It is evident that the steels should have low carbon to withstand the boiling nitric acid test.

Salt-spray Test — Perceptible amount of rust appeared in all the steels. A 26 did not show signs of rusting while one spot of rust appeared on A 27.

Susceptibility to Intergranular Corrosion — All the present series of chromium-manganese-nickel steels showed very heavy loss in weight in the test (Table 6). The specimens broke and in some cases crumpled down in the bend test. Out of two 18 : 8 stainless steels, A 26, which was stabilized, withstood the bend test without showing any cracks.

Conclusions

From this investigation it can be tentatively summarized that the chromium-manganese-nickel steels studied were readily worked down with good mechanical properties up to 0·25 per cent carbon and 0·1-0·2 per cent nitrogen. They compare well with 18 : 8 Cr : Ni steels as regards resistance to scaling at high temperature and adequately resist tarnishing in the atmosphere. They did not withstand the action of strong media and certainly could not be recommended for chemical plants.

Further work will be extended to steels in the range of : C, less than 0·1 per cent; Cr, 16-18 per cent; Mn, 14-18 per cent; N, 0·1-0·2 per cent; Cu, up to 2-3 per cent, with boron and rare-earth metal additions. These steels will be studied for their austenitic stability under cold work, their deep-drawing qualities, weldability and corrosion and other intergranular brittleness tests.

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References

1. *Metals Technology*, **8** (1937).
2. *Alloy of Iron and Chromium* — Monograph series.
3. *Metals Review* (Jan. 1954), 19.
4. *Metal Progress*, **65**(6) (June 1954), 124.
5. Mishima, G. T. & Fujita, T., *Annual Report, Engineering Research Institute, Tokyo University*, Dec. 1953, No. 12, 111-112.
6. Everhart, J. L., *Materials & Methods*, **39**(3) (March 1954), 94.
7. Everhart, J. L., *Materials & Methods*, **39**(3) (March 1954), 92.
8. Harris, G. T. & Johnson, E., *Metallurgia*, **51** (Jan. 1955), 19.
9. Rassback, H. P., Saunders, E. R. & Harbrecht, W. L., *Amer. Inst. Min. Metal Eng.*, **2** (1953), 244-255.
10. Thum, E. E., *The Book of Stainless Steels*, (American Society for Metals, Cleveland), 1935.
11. Hinustin, F. F., *Transactions, All Research Institute Aviation Materials*, No. **32**, Part I, 1935.
12. Franks, R., Binder, W. O. & Thompson, J., *Amer. Soc. Met.* (1954). Preprint.
13. Monypenny, J. H. G., *Stainless Iron & Steel*, Vol. II, 3rd Edition (Chapman & Hall), 1954, 202.