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54 **The production of stainless steel.**

57 A process for the production of steel includes the addition of at least one of the required chromium, manganese, vanadium, nickel, cobalt or molybdenum alloy metals in the form of a finely divided oxide thereof intimately mixed with a finely divided reductant with the mixture of oxide and reductant being in an agglomerated form.

FIELD OF THE INVENTION

5 **THIS INVENTION** relates to the production of steel and, more particularly, but not exclusively, to the production of stainless steel wherein chrome oxide in the form of the particular ore, is added substantially directly to iron as opposed to conventional processes which usually involve the preparatory treatment of a chromium ore to produce, for example, high carbon ferrochromium prior to its addition to iron.

BACKGROUND TO THE INVENTION

10 In this specification extensive reference is made to the production of stainless steel. This should not be construed as limiting the scope or application of the invention in any way.

 Stainless steel is most commonly produced by alloying iron and high carbon ferrochromium to produce a high carbon alloy which is then subjected to argon-oxygen decarburisation in order to lower the carbon content to acceptable levels.

15 It is also possible, and practised on a relatively small scale, to avoid the step of argon-oxygen decarburisation by using low carbon ferrochromium as the chrome containing alloying component for the production of chromium steels.

 Various processes for the production of stainless steel wherein chromium is added directly in the form of chromite have been made. Thus, the so-called Hamilton-Evans process, involves the melting of iron and the provision of a large quantity of slag, known as the reception slag (a mixture of limestone, fluorspar, mill scale and chromite) on top of the molten steel. When the reception slag is molten, and adequately heated, chrome ore, intimately mixed with high grade ferro-silicon, is fed on top of the slag. The use of the receptor slag is imperative as it provides a thermal and chemical buffer for the reduction reaction to take place, alloy droplets passing through the slag to the melt. The receptor slag also prevents segregation of the reactants which would otherwise occur on the surface of the melt which, in turn, would lead to chromite accretion and dissolution of reductant in the melt; and, the basicity of the receptor slag, being high, assists in the prevention of silica enrichment of the residual oxide and protects the furnace lining from excess wear.

20 The disadvantages of this process are that the efficiency is low regarding silicon utilisation and chromium recovery; the tap-to-tap time is long, (of the order of 5 hours) because of the bulk mass of the molten slag; considerable quantities of Cr_2O_3 are contained therein; and excessive wear on the furnace lining results in consequence of these disadvantages. Furthermore, it is difficult to produce an alloy containing more than 13% chromium because of the high slag to metal ratio.

25 The so-called Wild process is similar to the above except that the silicon content can be maintained below 0,5% by suitable alternate additions of chromite and ferro-silicon. The slag resulting from the reduction process is removed from time to time and the tap-to-tap time is believed to be about 8 hours which is also unduly excessive.

30 It appears that once it was possible to produce low carbon ferrochromium, the aforementioned processes were gradually abandoned and replaced firstly by alloying with low carbon ferrochromium, and then, by the present day process mentioned above, ie. the alloying with high carbon ferrochromium followed by argon-oxygen decarburisation.

35 It is the object of this invention to provide an effective process for the production of steel in which the required alloy metals may be included in an iron base substantially directly from the oxide or ore form of such metals.

SUMMARY OF THE INVENTION

40 In accordance with this invention there is provided a process for the production of steel in which at least one of the alloy metals of the steel chosen from the group comprising the required chromium, manganese, vanadium, nickel, cobalt and molybdenum is provided in the form of a finely divided oxide of the alloy metal intimately mixed with a finely divided reductant with the mixture of oxide and reductant being in an agglomerated form.

45 Further features of the invention provide for the finely divided oxide to have a maximum particle size of one millimetre, and preferably less than seventy five microns in which case the maximum particle size of the reductant is about 1mm, and preferably about less than seventy five microns; for the reductant to be present in an amount of at least about 0,4 times the stoichiometric amount required to reduce all the alloy metal and iron oxides in the oxide, and preferably about 1,3 times the stoichiometric amount; and for the oxide to be an ore.

50 The agglomerated mixture of oxides of chromium together with the reductant may be in the form of bri-

quettes, pellets or other agglomerated units and can either be added to an existing bath of molten iron or, alternatively, can be heated together with the solid iron with which the alloy metal is to be alloyed. Any usual or suitable binders can be used for the agglomerate.

In either case, experiments have shown that what occurs is a solid state reduction of the alloy metal oxides followed by melting as the temperature of the agglomerated units increases.

Tests indicate that solid state reduction commences at about 1200°C and progresses rapidly towards completion at between 1300°C and 1400°C whilst melting of the material takes place at 1500°C and 1550°C. The solid state reduction takes place extremely rapidly and a batch of stainless steel, for example, can be produced in as short a time as 45 minutes using the process of this invention.

When the alloy metal is chromium, it may be added in the form of chromite and the reductant may be ferrosilicon or ferro-alumino-silicon. In such an instance the reduction approaches substantial completion at 1400°C even in an oxidising environment such as air.

Production of the steel may take place in any suitable furnace including electrical arc furnaces, plasma-arc furnaces, induction furnaces and the like in order to supply the marginal energy that is required for the progress of the reduction, and to compensate for the heat losses.

In order that the invention may be more fully understood, various tests which have been conducted to date will now be described.

DETAILED DESCRIPTION OF TESTWORK CONDUCTED

In total three series of tests were conducted, the first small scale or crucible tests which were scaled up to testwork on a 200kVA d.c. transferred plasma arc furnace and further to a 300kVA 3-phase a.c electric arc furnace. The results of these tests are outlined below.

CRUCIBLE BATCH TESTS

Various tests were carried out on composite pellets made from fines of chromite and ferrosilicon with bentonite being used as a binder in many cases. The composition of the pellets is set out in the accompanying Table 2 under the heading "charge mass in g" from which it will be seen that various ratios of the different ingredients were employed. The analysis of the starting materials as is set out in Table 1.

Table 1

| Composition of the raw materials used for crucible tests (in mass %) | | | | | |
|--|-------|--------------|-------|-------------|---------|
| Chromite | | Ferrosilicon | | Iron Flakes | |
| Cr ₂ O ₃ | 43,0 | Si | 79,4 | C | 0,015 |
| FeO | 21,6 | Fe | 18,8 | Mn | 0,35 |
| Fe ₂ O ₃ | 4,7 | Al | 1,4 | P | 0,02 |
| SiO ₂ | 5,30 | Ca | 0,07 | S | 0,02 |
| CaO | 0,50 | C | 0,10 | Oxygen | 0,05 |
| MgO | 9,97 | P | 0,035 | Fe | balance |
| Al ₂ O ₃ | 14,20 | S | 0,005 | | |
| TiO ₂ | 0,72 | Mn | 0,15 | | |
| S | 0,01 | | | | |
| P | 0,003 | | | | |

In each case the moist pellets were oven dried at 120°C for 24 hours and measured masses of composite pellets and iron flakes were heated in an alumina crucible in the atmospheric environment of a small vertical tube furnace at 1550°C for an hour. The product metal and slags were analysed for their composition which is set out in Table 2.

TABLE 2
Summary of the crucible tests and results

| | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Test 7 | Test 8 | Test 9 | Test 10 |
|--|--------|--------|---------------|-------------|-----------|--------|---------------------------|---------------------------|-------------------------|--------------------------|
| 1. Charge mass in g: | | | | | | | | | | |
| (a) Chromite Composite | 8,15 | 8,00 | 8,00 | 8,00 | 8,00 | 24 | 16 | 16 | 4 | 16 |
| (b) Fe-Si pellets | 1,77 | 1,75 | 1,75 | 1,75 | 1,75 | 5,25 | 3,50 | 3,50 | 0,88 | 3,5 |
| (c) Bentonite | 0,08 | 0,50 | 0,00 | 0,25 | 0,25 | 0,35 | 0,50 | 0,00 | 0,00 | 0,00 |
| (d) Iron flakes | 5,00 | 4,88 | 5,06 | 4,92 | 4,50 | 14,96 | 10,08 | 10,10 | 4,91 | 9,92 |
| (e) Additive (Additive composition) | - | - | 1,75 (Cement) | 1,00 (NaCl) | 0,70 (Ni) | - | 10,00 (Calcined dolomite) | 12,00 (Calcined dolomite) | 4 (Uncalcined dolomite) | 16 (Uncalcined dolomite) |
| 2. Results | | | | | | | | | | |
| (1) Masses, g: | | | | | | | | | | |
| Metal | 8,50 | 8,43 | 8,53 | 8,48 | 8,50 | 25,45 | 16,80 | 17,35 | 6,83 | 17,26 |
| Slag | 6,50 | 6,70 | 8,03 | 7,44 | 6,70 | 19,11 | 23,28 | 24,25 | 6,96 | 23,45 |
| (2) Yields, %: | | | | | | | | | | |
| (a) Metal (FeCr) recovery | 80 | 81,31 | 79,30 | 81,56 | 75 | 79,88 | 76,51 | 83,20 | 88,64 | 84,34 |
| (b) Cr recovery | 63,5 | 62,5 | 64 | 64 | 64 | 64 | 66 | 68,5 | 77 | 77,50 |
| (c) Cr Accountability | 95,90 | 96,20 | 92 | 95,60 | 99,20 | 96,63 | 94,12 | 91,72 | 100 | 98,40 |
| (d) Si utilisation | 94,13 | 94,59 | 97,60 | 95,67 | 96,88 | 94,38 | 99 | 97,50 | 99,28 | 98,70 |

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| Cont: | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Test 7 | Test 8 | Test 9 | Test 10 |
|------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|
| (3) Composition (in mass %): | | | | | | | | | | |
| (i) Metal | | | | | | | | | | |
| <u>ASTM 304</u> | | | | | | | | | | |
| C | 0,03 | 0,04 | 0,04 | 0,04 | 0,06 | 0,05 | 0,06 | 0,04 | 0,08 | 0,05 |
| Si | 0,96 | 0,90 | 0,39 | 0,71 | 0,51 | 0,92 | 0,18 | 0,40 | 0,07 | 0,21 |
| Mn | 1,34 | | | | | | | | | |
| P | 0,022 | | | | | | | | | |
| S | 0,028 | | | | | | | | | |
| Cr | 18,20 | 17,40 | 17,60 | 17,80 | 17,70 | 17,70 | 18,60 | 18,60 | 13,20 | 21,10 |
| Ni | 8,38 | | | | 8,35 | | | | | |
| Mo | 0,29 | | | | | | | | | |
| Cu | 0,23 | | | | | | | | | |
| Al | - | | | | | | | | | |
| V | - | | | | | | | | | |
| Ti | 0,005 | | | | | | | | | |
| Nb | 0,009 | | | | | | | | | |
| Sn | 0,013 | | | | | | | | | |
| Fe | 80,30 | 78,40 | 78,00 | 78,00 | 74,00 | 81 | 80,4 | 76,5 | 81,8 | 80,0 |
| (ii) Slag | | | | | | | | | | |
| Cr total | 12,20 | 11,8 | 8,2 | 9,9 | 4,5 | 12,1 | 5,6 | 4,5 | 3,8 | 4,2 |
| Cr acid leachable | 11,50 | 11,2 | 7,6 | 8,6 | 3,8 | 7,3 | 4,9 | 3,8 | 3,0 | 3,4 |
| Fe total | 1,30 | 1,2 | 1,3 | 1,3 | 0,5 | 1,3 | 1,2 | 0,5 | 0,6 | 0,8 |
| Fe acid leachable | 1,20 | 1,1 | 1,2 | 1,2 | 0,5 | 1,1 | 1,2 | 0,5 | 0,4 | 0,8 |

55 **D.C. PLASMA-ARC TESTS**

In this example tests were conducted in a 200kVA furnace manufactured by applicant. The furnace was of a known d.c. plasma-arc furnace type employing a single graphite electrode located centrally above the fur-

nace bath. A direct current power supply was employed in which the molten bath formed, in use, the anode, while the graphite electrode formed the cathode.

5 The furnace which had an outside diameter of 830mm and a refractory lining thickness of 140mm, was lined with a refractory material wherein the Al₂O₃ content was approximately 90 percent. The hearth was lined with a similar material to a thickness of 300mm and a number of mild steel rods were used to make the d.c. (anode) electrical connection from the molten bath through the hearth refractory to the anode cable.

10 The feed materials consisted of steel scrap, nickel and composite pellets made from chromite fines and ferrosilicon with bentonite as a binder. The composition of the pellets is set out in Table 4. The analysis of the starting materials can be seen in Table 3.

Prior to the testwork the pellets were air dried for 24 hours and further indurated for approximately 4 hours at 800°C in order to develop pellet strength.

15 Each heat or test consisted of two stages. The first stage being simply a melt-down of the steel scrap and nickel requirements over a half-hour period, and the second stage a smelt in which the chromite and ferrosilicon composite pellets were charged over a further one-hour period. In both stages the furnace power and energy requirements were adjusted in order to achieve and maintain a melt temperature of between 1550 and 1600°C.

All feed materials were charged to the furnace by hand through feed ports in the furnace roof.

The product metal and slags were analysed for their composition which is set out in Table 4.

Table 3

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| Composition of the raw materials used for the d.c. plasma-arc tests (in mass %) | | | | | | |
|---|--------------------------------|-------|--------------|-------|--------|---------|
| | Chromite | | Ferrosilicon | | | |
| 25 | Cr ₂ O ₃ | 40,10 | Si | 80,7 | C | 0,015 |
| | FeO | 15,0 | Fe | 18,5 | Mn | 0,35 |
| | Fe ₂ O ₃ | 12,40 | Al | 0,39 | P | 0,02 |
| 30 | SiO ₂ | 4,61 | | | S | 0,02 |
| | CaO | 0,57 | C | 0,08 | Oxygen | 0,05 |
| | MgO | 10,25 | P | 0,035 | Fe | balance |
| 35 | Al ₂ O ₃ | 16,10 | S | 0,005 | | |
| | TiO ₂ | 0,95 | Mn | 0,15 | | |
| | S | 0,006 | | | | |
| 40 | P | 0,004 | | | | |
| | C | 0,01 | | | | |

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TABLE 4
Summary of the d.c plasma-arc furnace tests and results

| | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Test 7 | Dig-out * |
|---------------------------|--------|--------|--------|--------|--------|--------|--------|-----------|
| 1. Charge mass in kg: | | | | | | | | |
| (a) Chromite Composite | 80,3 | 80,3 | 100,4 | 80,3 | 80,3 | 80,3 | 80,3 | - |
| (b) Fe-Si pellets | 18,7 | 18,7 | 23,3 | 18,7 | 18,7 | 18,7 | 18,7 | - |
| (c) Bentonite | 1,00 | 1,0 | 1,3 | 1,0 | 1,0 | 1,0 | 1,0 | - |
| (d) Steel Scrap | 31,5 | 31,5 | 31,5 | 21,5 | 17,5 | 17,5 | 17,5 | - |
| (e) Nickel | 6,0 | 6,0 | 6,0 | 5,0 | 5,0 | 4,5 | 4,5 | - |
| 2. Results | | | | | | | | |
| (1) Masses, kg: | | | | | | | | |
| Metal | 64,2 | 67,4 | 70,0 | 55,6 | 54,2 | 52,0 | 40,6 | 85,0 |
| Slag | 66,2 | 66,1 | 87,0 | 69,9 | 87,0 | 70,4 | 68,8 | 6,9 |
| (2) Yields, %: | | | | | | | | |
| (a) Metal (FeCr) recovery | 75,4 | 80,1 | 73,5 | 77,0 | 80,3 | 77,2 | 60,4 | 90,1 |
| (b) Cr recovery | 35,0 | 42,7 | 37,5 | 41,2 | 43,1 | 45,5 | 33,2 | 49,9 |
| (c) Cr Accountability | 84,1 | 92,2 | 91,9 | 92,5 | 103,7 | 97,1 | 89,3 | 104,2 |
| (d) Si utilisation | 95,7 | 94,7 | 95,8 | 94,3 | 94,1 | 93,2 | 96,9 | 93,8 |

* Yields reflected here are totals for the seven tests including dig-out

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Cont: Test 1 Test 2 Test 3 Test 4 Test 5 Test 6 Test 7 Dig-out

(3) Composition (In mass %):

(i) Metal

ASTM 304

| | | | | | | | | | |
|----|-------|--------|--------|--------|--------|--------|--------|--------|-------|
| C | 0,050 | 0,027 | 0,028 | 0,024 | 0,027 | 0,044 | 0,041 | 0,045 | 0,075 |
| Si | 0,51 | 1,01 | 1,18 | 1,13 | 1,56 | 1,63 | 1,96 | 1,14 | 1,52 |
| Mn | 1,59 | 0,039 | 0,043 | 0,041 | 0,046 | 0,045 | 0,047 | 0,044 | |
| P | 0,022 | 0,014 | 0,013 | 0,014 | 0,015 | 0,019 | 0,019 | 0,018 | |
| S | 0,028 | 0,0089 | 0,0062 | 0,0054 | 0,0059 | 0,0062 | 0,0061 | 0,0058 | |
| Cr | 18,20 | 12,2 | 14,2 | 15,0 | 16,6 | 17,8 | 19,6 | 18,3 | 17,7 |
| Ni | 8,38 | 12,3 | 10,9 | 10,1 | 9,84 | 9,62 | 9,11 | 9,71 | 8,71 |
| Mo | 0,29 | 0,030 | 0,032 | 0,032 | 0,035 | 0,036 | 0,038 | 0,036 | |
| Cu | 0,23 | 0,016 | 0,015 | 0,014 | 0,014 | 0,014 | 0,012 | 0,012 | |
| Al | - | 0,012 | 0,0056 | 0,0041 | 0,0085 | 0,0016 | 0,0016 | 0,0010 | |
| V | - | 0,079 | 0,095 | 0,100 | 0,110 | 0,120 | 0,130 | 0,120 | |
| Ti | 0,005 | 0,0052 | 0,0050 | 0,0047 | 0,0053 | 0,0050 | 0,0060 | 0,0050 | |
| Nb | 0,009 | 0,0053 | 0,0046 | 0,0046 | 0,0048 | 0,0044 | 0,0044 | 0,0038 | |
| Sn | 0,013 | 0,0029 | 0,0030 | 0,0030 | 0,0037 | 0,0032 | 0,0033 | 0,0027 | |
| Fe | - | 74,2 | 73,4 | 73,5 | 71,6 | 70,6 | 69,0 | 70,5 | 70,0 |

(ii) Slag

| | | | | | | | | |
|-------------------|------|------|------|------|------|------|------|------|
| Cr total | 16,6 | 16,8 | 17,5 | 16,4 | 15,6 | 16,4 | 18,3 | 19,2 |
| Cr acid leachable | 3,3 | 2,5 | 2,6 | 2,4 | 2,4 | 6,5 | 6,4 | 1,3 |
| Fe total | 3,4 | 4,1 | 3,6 | 3,7 | 2,9 | 2,9 | 7,4 | 11,6 |

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THREE PHASE A.C. OPEN-ARC FURNACE TESTS

In this example tests were conducted in a 300kVA three phase a.c. open-arc furnace manufactured by the applicant. The furnace was of a known type employing 3 graphite electrodes with a P.C.D. of 500mm located

centrally above the bath. A three phase alternating current power supply was applied to the molten bath by means of the electrodes.

The furnace had an outside diameter of 965mm and a composite refractory lining thickness of 155mm made up from an outer lining of magnesia and an inner lining of high alumina refractory bricks (90 percent Al_2O_3). The hearth was lined with a high alumina castable, the base of which being located flush with the tap-hole to minimise the quantity of material retained in the furnace between tests and so eliminating any dilution effects.

The feed materials consisted of steelscrap, nickel and composite pellets. The composite pellets were made from chromite fines and ferrosilicon utilising either bentonite or sodium-silicate as a binder.

The bentonite pellets were air dried for 24 hours and further indurated for 4 hours at 800 °C, whilst the sodium-silicate pellets were air dried for 12 hours and then oven dried at 120 °C for a further 12 hours. The compositions of the chromite, ferrosilicon and scrap are given in Table 5 and the pellet composition for each test is given in Table 6.

Table 5

| Composition of raw materials used for the a.c. arc-furnace tests | | | | | |
|--|------------|------------|-----------------|-----------------|------------|
| Composition Mass % | Chromite 1 | Chromite 2 | Ferro-Silicon 1 | Ferro-Silicon 2 | Scrap Iron |
| Cr_2O_3 | 40,14 | 46,90 | - | - | - |
| FeO | 15,00 | 12,10 | - | - | - |
| Fe_2O_3 | 12,40 | 10,80 | - | - | - |
| SiO_2 | 4,61 | 7,00 | - | - | - |
| CaO | 0,57 | 0,58 | - | - | - |
| MgO | 10,25 | 10,80 | - | - | - |
| Al_2O_3 | 16,10 | 11,90 | - | - | - |
| TiO_2 | 0,95 | 0,45 | - | - | - |
| MnO | - | - | - | - | - |
| Na_2O | - | - | - | - | - |
| S | 0,006 | 0,006 | - | - | 0,02 |
| P | 0,004 | 0,004 | 0,03 | 0,03 | 0,02 |
| C | <0,01 | 0,013 | 0,08 | 0,07 | 0,015 |
| Si | - | - | 80,7 | 74,60 | - |
| Fe | - | - | 18,5 | 24,90 | 99,5 |
| Al | - | - | 0,39 | 0,39 | - |
| Mn | - | - | - | - | 0,35 |
| Total | 100,0 | 100,6 | 99,7 | 100,0 | 99,0 |

As with the 200kVA d.c. plasma-arc tests each heat or test consisted of two stages viz: a melt-down followed by the smelt-down. During the melt-down the steel scrap and nickel were hand fed over a half hour period following which the composite pellets were charged by way of an automatic feed system over a period of approximately 1 hour. The power input into the furnace was adjusted such that an operating temperature of 1550°C was maintained.

The furnace was tapped after each test, most of the material being removed, the masses and analysis of which are given in Table 6.

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55**TABLE 6**

Summary of the a.c. electric arc-furnace tests and results

| | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Test 7 | Test 8 | Test 9 | Test 10 |
|---------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|
| 1. Charge mass in kg: | | | | | | | | | | |
| (a) Chromite 1 | 80,3 | 80,3 | 80,3 | - | - | - | - | - | - | - |
| (b) Chromite 2 | - | - | - | 78,8 | 78,8 | 78,8 | 78,8 | 78,8 | 78,8 | 78,8 |
| (c) FeSi 1 | 18,7 | 18,7 | 18,7 | - | - | - | - | - | - | - |
| (d) FeSi 2 | - | - | - | 18,3 | 18,3 | 24,3 | 18,3 | 18,3 | 18,3 | 18,3 |
| (e) Bentonite | 1,0 | 1,0 | 1,0 | - | - | - | - | - | - | - |
| (f) Sodium Silicate | - | - | - | 2,9 | 2,9 | 2,9 | 2,9 | 2,9 | 2,9 | 2,9 |
| (g) Steel Scrap | 20,0 | 17,5 | 17,5 | 45,0 | 45,0 | 45,0 | 36,7 | 35,0 | 35,0 | 36,0 |
| (h) Nickel | 4,5 | 4,5 | 4,5 | 7,5 | 7,5 | 7,5 | 7,5 | 6,0 | 6,0 | 6,5 |
| 2. Results | | | | | | | | | | |
| (1) Masses in kg: | | | | | | | | | | |
| Metal | 22,4 | 53,1 | 34,8 | 68,1 | 80,1 | 98,0 | 79,0 | 59,8 | 74,3 | 95,6 |
| Slag | 20,6 | 90,2 | 67,6 | 76,4 | 45,0 | 94,4 | 65,6 | 55,2 | 73,4 | 62,2 |
| (2) Yields, % | | | | | | | | | | |
| (a) Metal (FeCr) recovery | 31,64 | 78,48 | 51,26 | 69,67 | 82,22 | 96,95 | 86,87 | 68,90 | 86,18 | 109,11 |
| (b) Cr Recovery | 10,63 | 25,20 | 18,86 | 37,43 | 46,24 | 58,90 | 53,42 | 45,88 | 57,29 | 74,09 |
| (c) Cr Accountability | 30,85 | 111,78 | 87,22 | 94,85 | 78,44 | 120,59 | 90,81 | 79,27 | 100,91 | 111,89 |
| (d) Si Utilisation | 99,23 | 98,72 | 99,60 | 98,36 | 96,25 | 79,96 | 87,34 | 91,86 | 92,17 | 90,90 |

55 50 45 40 35 30 25 20 15 10 5

| Cont: | Test 11 | Test 12 | Test 13 | Test 14 | Test 15 | Test 16 | Test 17 | Test 18 | Test 19 | Test Dig-out* | |
|-----------------------|-----------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------------|-------|
| 1. Charge mass in kg: | | | | | | | | | | | |
| (a) | Chromite 1 UG-2 | - | - | - | - | - | - | - | - | - | |
| (b) | Chromite 2 G-M | 78,8 | 78,8 | 78,8 | 78,8 | 78,8 | 78,8 | 78,8 | 78,8 | 52,0 | |
| (c) | FeSi 1 | - | - | - | - | - | - | - | - | - | |
| (d) | FeSi 2 | 18,3 | 18,3 | 18,3 | 18,3 | 18,3 | 18,3 | 18,3 | 18,3 | 12,1 | |
| (e) | Bentonite | - | - | - | - | - | - | - | - | - | |
| (f) | Sodium Silicate | 2,9 | 2,9 | 2,9 | 2,9 | 2,9 | 2,9 | 2,9 | 29 | 1,9 | |
| (g) | Steel Scrap | 36,0 | 39,0 | 40,0 | 40,0 | 40,0 | 35,0 | 35,0 | 31,0 | 20,0 | |
| (h) | Nickel | 6,5 | 7,0 | 6,5 | 6,5 | 6,5 | 6,5 | 6,0 | 6,0 | 4,0 | |
| 2. Results | | | | | | | | | | | |
| (1) Masses in kg: | | | | | | | | | | | |
| | Metal | 71,9 | 61,4 | 42,8 | 123,4 | 107,8 | 59,7 | 91,7 | 66,8 | 47,5 | 16,0 |
| | Slag | 48,4 | 20,7 | 129,4 | 69,8 | 54,0 | 58,8 | 51,3 | 55,6 | 84,3 | 80,0 |
| (2) Yields, % | | | | | | | | | | | |
| (a) | Metal (FeCr) recovery | 82,43 | 67,50 | 46,69 | 134,92 | 117,60 | 68,86 | 106,72 | 81,59 | 88,75 | 83,94 |
| (b) | Cr Recovery | 57,72 | 44,67 | 31,65 | 84,91 | 69,48 | 42,02 | 63,82 | 48,60 | 52,65 | 49,78 |
| (c) | Cr Accountability | 87,26 | 58,42 | 119,33 | 134,83 | 107,38 | 81,71 | 99,27 | 87,33 | 141,26 | 99,18 |
| (d) | Utilisation | 91,58 | 95,82 | 97,62 | 94,58 | 95,19 | 96,94 | 94,97 | 96,38 | 96,00 | 94,15 |

* Yields reflected here are totals for the 19 tests including dig-out

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Test 1 Test 2 Test 3 Test 4 Test 5 Test 6 Test 7 Test 8 Test 9 Test 10

3. Composition (In Mass %) :
(i) Metal

ASTM 304

| | | | | | | | | | | |
|----|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| C | 0,05 | 0,11 | 0,17 | 0,19 | 0,12 | 0,10 | 0,13 | 0,30 | 0,19 | 0,20 |
| Si | 0,51 | 0,36 | 0,17 | 0,33 | 0,64 | 3,71 | 2,19 | 1,86 | 1,44 | 1,30 |
| Mn | 1,59 | 0,029 | 0,028 | 0,034 | 0,044 | 0,065 | 0,067 | 0,065 | 0,061 | 0,065 |
| P | 0,022 | 0,016 | 0,021 | 0,017 | 0,016 | 0,016 | 0,017 | 0,016 | 0,014 | 0,013 |
| S | 0,028 | 0,0083 | 0,2900 | 0,0100 | 0,0086 | 0,0087 | 0,0080 | 0,0080 | 0,0080 | 0,0078 |
| Cr | 18,2 | 10,6 | 12,1 | 13,9 | 14,6 | 15,2 | 17,1 | 19,4 | 19,5 | 19,6 |
| Ni | 8,38 | 11,2 | 10,6 | 9,80 | 9,34 | 8,28 | 10,4 | 8,45 | 8,27 | 8,73 |
| Mo | 0,29 | 0,025 | 0,028 | 0,032 | 0,033 | 0,033 | 0,037 | 0,040 | 0,040 | 0,040 |
| Cu | 0,23 | 0,022 | 0,500 | 0,090 | 0,019 | 0,017 | 0,017 | 0,015 | 0,015 | 0,015 |
| Al | - | 0,0038 | 0,0017 | 0,0110 | 0,0030 | 0,0032 | 0,0020 | 0,0030 | 0,0020 | 0,0010 |
| V | - | 0,053 | 0,056 | 0,057 | 0,055 | 0,053 | 0,066 | 0,071 | 0,074 | 0,074 |
| Ti | 0,005 | 0,0042 | 0,0050 | 0,0110 | 0,0042 | 0,0078 | 0,0050 | 0,0050 | 0,0050 | 0,0050 |
| Nb | 0,009 | 0,0055 | 0,0044 | 0,0056 | 0,0054 | 0,0049 | 0,0050 | 0,0040 | 0,0040 | 0,0050 |
| Sn | 0,013 | 0,0035 | 0,0027 | 0,0036 | 0,0040 | 0,0076 | 0,0060 | 0,0050 | 0,0050 | 0,0050 |
| Fe | - | 77,3 | 75,9 | 75,4 | 75,0 | 72,4 | 69,8 | 69,7 | 70,2 | 69,8 |

(ii) Slag

| | | | | | | | | | | |
|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Cr (total) | 21,92 | 21,43 | 22,58 | 19,01 | 18,09 | 16,52 | 14,42 | 15,30 | 15,03 | 15,37 |
| Cr acid leachable | | 1,5 | 1,6 | 3,0 | 6,9 | 11,6 | 1,5 | 0,6 | 1,9 | 1,3 |
| Fe (total) | 7,5 | 6,4 | 4,7 | 1,4 | 1,3 | 1,0 | 1,0 | 0,8 | 0,8 | 0,6 |

55 50 45 40 35 30 25 20 15 10 5

Cont: Test 11 Test 12 Test 13 Test 14 Test 15 Test 16 Test 17 Test 18 Test 19 Dig-out *

(3) Composition (In Mass %):
(i) Metal

ASTM 304

| | | | | | | | | | | | |
|----|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|------|
| C | 0,05 | 0,25 | 0,17 | 0,17 | 0,21 | 0,31 | 0,22 | 0,15 | 0,14 | 0,17 | 0,19 |
| Si | 0,51 | 1,60 | 0,76 | 0,60 | 0,60 | 0,61 | 0,70 | 0,75 | 0,74 | 0,73 | 0,70 |
| Mn | 1,59 | 0,064 | 0,056 | 0,054 | 0,054 | 0,049 | 0,050 | 0,054 | 0,055 | 0,015 | - |
| P | 0,022 | 0,013 | 0,014 | 0,016 | 0,016 | 0,016 | 0,016 | 0,016 | 0,015 | 0,015 | - |
| S | 0,028 | 0,0084 | 0,0089 | 0,0080 | 0,0080 | 0,0079 | 0,0070 | 0,0070 | 0,0080 | 0,0070 | - |
| Cr | 18,2 | 20,3 | 18,7 | 17,4 | 17,4 | 16,3 | 17,8 | 17,6 | 18,4 | 18,5 | 19,5 |
| Ni | 8,38 | 7,99 | 8,98 | 8,84 | 8,84 | 8,94 | 9,57 | 8,77 | 9,16 | 9,14 | 7,07 |
| Mo | 0,29 | 0,040 | 0,038 | 0,037 | 0,037 | 0,035 | 0,037 | 0,038 | 0,039 | 0,039 | - |
| Cu | 0,23 | 0,014 | 0,016 | 0,018 | 0,018 | 0,018 | 0,016 | 0,016 | 0,015 | 0,015 | - |
| Al | - | 0,0010 | 0,0027 | 0,0017 | 0,0017 | 0,0210 | 0,0016 | 0,0026 | 0,0120 | 0,0020 | - |
| V | - | 0,076 | 0,068 | 0,063 | 0,063 | 0,059 | 0,064 | 0,063 | 0,065 | 0,066 | - |
| Ti | 0,005 | 0,0049 | 0,0046 | 0,0044 | 0,0044 | 0,0042 | 0,0046 | 0,0044 | 0,0050 | 0,0050 | - |
| Nb | 0,009 | 0,0050 | 0,0040 | 0,0038 | 0,0038 | 0,0041 | 0,0047 | 0,0048 | 0,0050 | 0,0040 | - |
| Sn | 0,013 | 0,0043 | 0,0041 | 0,0039 | 0,0039 | 0,0038 | 0,0038 | 0,0039 | 0,0040 | 0,0040 | - |
| Fe | - | 69,5 | 71,1 | 72,6 | 72,6 | 73,5 | 71,4 | 72,4 | 71,2 | 71,1 | 72,4 |

(ii) Slag

| | | | | | | | | | | |
|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Cr (total) | 15,44 | 16,80 | 17,14 | 18,09 | 17,75 | 17,07 | 17,48 | 17,61 | 17,54 | 17,41 |
| Cr acid leachable | 1,5 | 1,6 | 2,5 | 2,7 | 2,2 | 2,3 | 5,4 | 4,0 | 3,7 | 1,4 |
| Fe (total) | 0,6 | 0,9 | 1,7 | 1,0 | 1,3 | 0,8 | 0,8 | 0,8 | 0,9 | 2,7 |

The results of the tests conducted in the 200kVA plasma arc furnace and the 300kVA electric arc furnace while serving to describe the process of the invention also indicate a lower recovery of chromium in the melt than was expected on the basis of the initial crucible tests. It is postulated that the answer for this lies in the difference in the operational conditions between the plasma arc and electric arc furnaces on the one hand
5 and the tube furnace used for the crucible tests on the other.

In the plasma arc and electric arc furnaces, maximum temperatures were higher and also achieved more rapidly than in the tube furnace. The faster formation of a melt reduced the solid phase reaction time in the pellets with a larger proportion of the chromium finding its way into the slag phase than was the case with the tests in the tube furnace.

10 For the above reasons it is believed that the benefits of the invention will be maximised using a two stage process in which the agglomerated material is initially treated at a lower temperature to promote solid phase reduction prior to being charged to a high temperature electric arc furnace for example. Rotary kilns or rotary hearth kilns would be suitable. In such a process a higher proportion of the alloying metal would find its way into the melt.

15 It will be clear from the results shown that good quality stainless steel can be produced with the direct use of chromite as the source of chromium when it is used in the manner provided by this invention.

It is to be understood that the scope of this invention is not limited to the entire process but is intended to include, as an intermediate product for sale to steel producers, an agglomerate of chromium oxide together with a suitable reductant and, optionally, a binder. Furthermore the invention may be applied in similar manner
20 to the production of other alloy steels including chromium, manganese, vanadium, nickel, cobalt or molybdenum either simply or in combination.

Claims

- 25
1. A process for the production of an alloy steel from iron and an alloy metal selected from the group comprising chromium, manganese, vanadium, nickel, cobalt and molybdenum, wherein the selected alloy metal is provided for reaction in the form of an agglomerate comprising an intimate mixture of a finely divided oxide of the selected alloy metal and a finely divided reductant.

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 2. A process as claimed in claim 1, wherein said agglomerate further comprises at least one other finely divided alloy metal oxide in intimate mixture with said finely divided reductant.

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 3. A process for the production of steel in which at least one of the alloy metals of the steel chosen from the group comprising the required chromium, manganese, vanadium, nickel, cobalt and molybdenum is characterised by providing the alloy metal in the form of a finely divided oxide of the alloy metal intimately mixed with a finely divided reductant with the mixture of oxide and reductant being in an agglomerated form.

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 4. A process as claimed in any of claims 1 to 3, wherein the finely divided oxide has a maximum particle size of 1mm.
 5. A process as claimed in claim 4, wherein the maximum particle size of the reductant is 1mm.

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 6. A process as claimed in any of claims 1 to 5, wherein the maximum particle size of the oxide is seventy five microns.
 7. A process as claimed in claim 6, wherein the maximum particle size of the reductant is seventy five microns.

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 8. A process as claimed in any of the preceding claims, wherein the reductant is present in an amount of at least 0,4 times the stoichiometric amount required to reduce all the chrome and iron oxides in the oxide.
 9. A process as claimed in any of the preceding claims, wherein the reductant is present in an amount of 1,3 times the stoichiometric amount required to reduce all the chrome and iron oxides in the oxide.

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 10. A process as claimed in any of the preceding claims, wherein the oxide is an ore.
 11. A process as claimed in any of the preceding claims, wherein the agglomerated form of the mixture of

oxide and reductant is one of briquettes, pellets and the like.

- 5
12. A process as claimed in any of the preceding claims, wherein the agglomerated oxide and reductant is added to a bath of molten iron.
- 10
13. A process as claimed in any of claims 1 to 11, wherein the agglomerated oxide and reductant is heated together with the solid iron with which the metal alloy is to be alloyed.
14. A process as claimed in any of claims 1 to 11, wherein the agglomerated oxide and reductant are initially treated at a lower temperature to promote solid phase reductions prior to being charged to a bath of molten iron.
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15. A process as claimed in any of the preceding claims, wherein the oxide is chromite ore.
16. A process as claimed in any of the preceding claims, wherein the reductant comprises ferrosilicon or ferro-alumino-silicon.

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EUROPEAN SEARCH REPORT

Application Number
EP 93 30 6349

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| X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document | | | |

EPO FORM 1503 03.82 (PM/C01)



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EUROPEAN SEARCH REPORT

Application Number
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