US 20140290230A1

(19) **United States**

(12) **Patent Application Publication**

Ekstrom et al.

(10) **Pub. No.: US 2014/0290230 A1**

(43) **Pub. Date: Oct. 2, 2014**

(54) CAST IRON ALLOY AND EXHAUST COMPONENT MANUFACTURED THEREBY

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(21) Appl. No.: **14/009,248**

(22) PCT Filed: **Mar. 21, 2012**

(86) PCT No.: **PCT/SE2012/050307**

§ 371 (c)(1),
(2), (4) Date: **Dec. 24, 2013**

(30) **Foreign Application Priority Data**

Apr. 1, 2011	(SE)	1150286-1
Feb. 10, 2012	(SE)	1250101-1

Publication Classification

(51) **Int. Cl.**

C22C 37/06	(2006.01)
F01N 13/10	(2006.01)
C22C 37/04	(2006.01)

(52) **U.S. Cl.**

CPC ***C22C 37/06*** (2013.01); ***C22C 37/04*** (2013.01); ***F01N 13/10*** (2013.01)

USPC **60/323**; 420/15

(57) ABSTRACT

The invention relates to a cast-iron alloy comprising (in wt %) C: 3.0-3.5 Si: 4.1-4.8 Mn: ≤0.4 Mg: 0.02-0.08 Cr: 0.4-1.0 Cu: ≤0.15 Mo: 0.8-1.2 P: <0.05 S: <0.015 the remainder comprising Fe and any impurities. The invention relates also to an exhaust-conducting component for truck engines which comprises the alloy according to the invention.

alloy	**C**	**Si**	**Mn**	**Mg**	**Cr**	**Cu**	**Mo**	**P**	**S**	**Ti**	**Nb**	**Ni**
SiMo51	3,17	4,15	0,4	0,052	0,10	0,14	0,86	0,02	0,008	0,01	0,01	0,04
SiMoCr	3,28	4,19	0,36	0,048	0,94	0,11	0,86	0,02	0,007	0,01	0,01	0,52
SiMoCr0,5	3,28	4,23	0,35	0,052	0,52	0,10	0,78	0,02	0,007	-	-	0,055

Table 1: Compositions of alloys

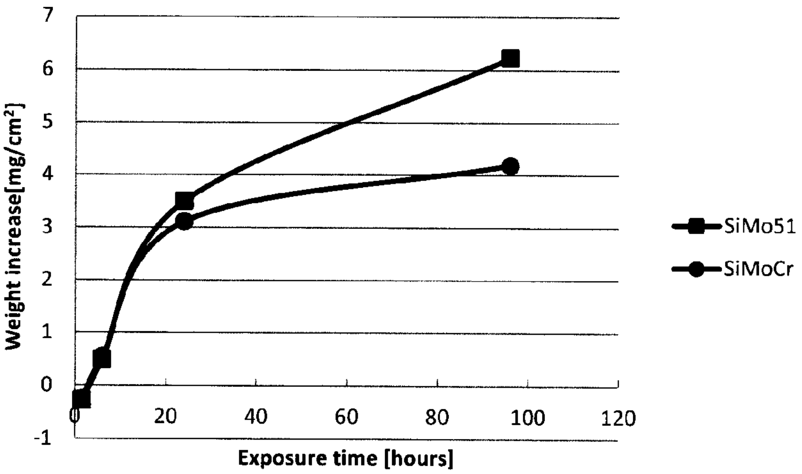

Figure 2

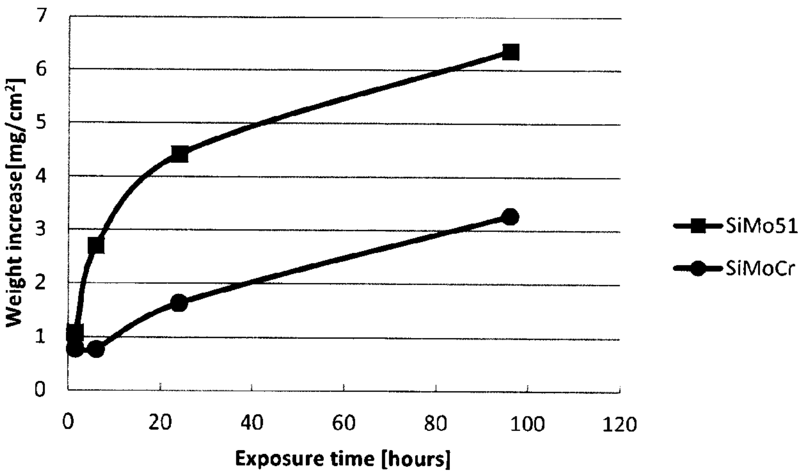

Figure 3

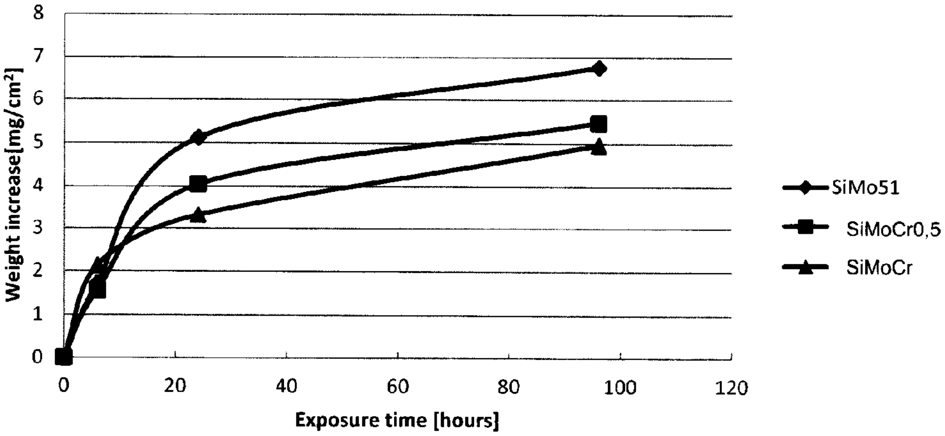

Figure 4

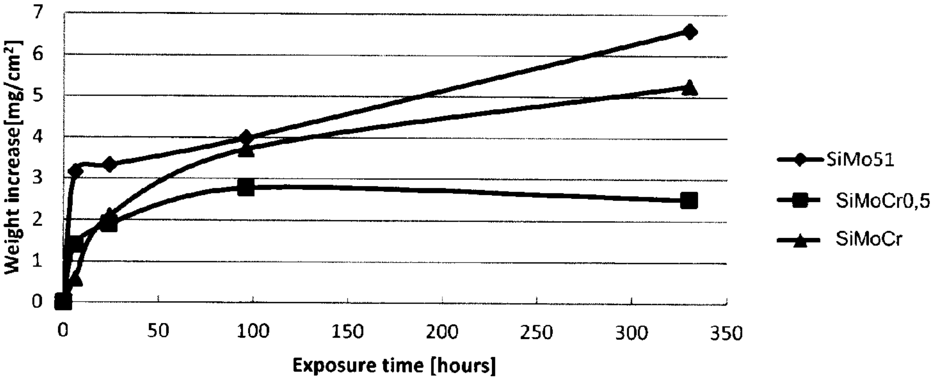

Figure 5

CAST IRON ALLOY AND EXHAUST COMPONENT MANUFACTURED THEREBY

TECHNICAL FIELD

[0001] The present invention relates to a cast-iron alloy according to the preamble of claim **1**. The invention relates also to an exhaust-conducting component intended for a truck engine and comprising the cast-iron alloy according to the invention.

BACKGROUND

[0002] Components used in truck engines to conduct exhaust gases away from the cylinders are subject cyclically to substantial thermal and mechanical loads during operation of the engine. Examples of such components comprise turbo manifolds, exhaust manifolds and turbine housings for turbos. The components are also subject to corrosion in the oxidising environment caused by the hot exhaust gases ejected from the cylinders. The corrosion concerned is so-called high-temperature corrosion in which the most important reaction mechanism is oxidation. Oxidation involves the metal being consumed by the formation of metal ions which can react with oxygen and form metal oxide. The oxidation of the metal surface increases with rising temperature, as chemical reactions and diffusion of the alloy substance are promoted by high temperatures.

[0003] A known practice is for example to make turbo manifolds from nodular iron, a type of cast-iron in which the structure consists of spheroidal graphite, so-called nodules, in a ferritic matrix. A type of nodular iron used in turbo manifolds is SiMo51. A further alloy of this type is indicated in DE 19636808.

[0004] The stringent emission requirements set for the engines of heavy vehicles and the market's demand for higher engine powers and lower fuel consumption have resulted in the development trend in engines being towards increased power output per engine unit volume, a trend known as "downsizing". Increased power output per engine unit volume does however mean that the temperature of the exhaust gases rises. In the new type of engines, the exhaust temperature may be up to 800° C. as against about 730° C. in conventional engines.

[0005] A problem with the known types of nodular iron is that they do not have enough corrosion resistance at high exhaust temperatures and are therefore not suitable for use in engines with increased power output per engine unit volume.

[0006] An object of the present invention is therefore to propose a cast-iron alloy which is corrosion-resistant at high exhaust temperatures and can be used in exhaust-conducting components. A further object of the present invention is that the alloy be cost-effective.

SUMMARY OF THE INVENTION

[0007] This object is achieved according to the invention by a cast-iron alloy containing (in wt %):

[0008] C: 3.0-3.5
[0009] Si: 4.1-4.8
[0010] Mn: ≤0.4
[0011] Mg: 0.02-0.08
[0012] Cr: 0.4-1.0
[0013] Cu: ≤0.15
[0014] Mo: 0.8-1.2
[0015] P: <0.05
[0016] S: <0.015

the remainder comprising Fe and any impurities.

[0017] Adding chrome in conjunction with other carefully balanced contents of alloy substances results in a cast-iron alloy of nodular iron type with high corrosion resistance and good high-temperature strength.

[0018] The surface of a component made of the alloy according to the invention forms, upon exposure to oxygen, e.g. in the air, a dense layer of chrome oxide. This layer of chrome oxide in conjunction with further oxide layers on the surface of the component, e.g. silicon oxides and iron oxides, then effectively protects the component from corrosion by preventing oxygen and other oxidising substances such as water vapour and carbon monoxide from reaching its surface.

[0019] Experiments have shown that the formation of the protective chrome oxide layer is promoted by high temperatures. This characteristic means that the alloy according to the invention is very usable in engines with increased power output per unit volume in which the exhaust temperature may be up to 800° C. At this temperature the protective chrome oxide layer forms very quickly and therefore provides the underlying component with effective protection against corrosion.

[0020] Using the alloy in exhaust-conducting components in conventional engines in which the temperature may be up to about 730° C. lengthens the service life of the components as compared with those which for example consist of SiMo51.

[0021] According to an alternative, the carbon content is 3.0-3.3 wt %.

[0022] According to an alternative, the silicon content is 4.2-4.4 wt %.

[0023] According to an alternative, the chrome content is 0.50-1.0 wt %.

[0024] According to an alternative, the chrome content is 0.6-1.0 wt %.

[0025] According to an alternative, the chrome content is 0.60-0.75 wt %.

[0026] According to an alternative, the molybdenum content is 0.8-1.0 wt %.

[0027] There should preferably be no nickel in the alloy according to the invention.

[0028] The cast-iron alloy according to the invention is primarily intended for exhaust-conducting components in diesel engines for heavy vehicles, e.g. trucks. Such components, also called exhaust-gathering components, comprise for example exhaust manifolds, turbo manifolds and turbine housings for turbos.

DESCRIPTION OF THE INVENTION

[0029] A cast exhaust-conducting component, e.g. a turbo manifold made of the cast-iron alloy of nodular iron type according to the invention, has a structure mainly consisting of spheroidal graphite in a matrix of ferrite.

[0030] The cast-iron alloy according to the invention comprises the following alloy substances:

[0031] Carbon (C)

[0032] Carbon increases the fluidity of the melt, which is important in casting the alloy, since it affects how well the casting mould is filled. In a specific solidification process, the amount of carbon in conjunction with added inoculant also affects the number and size of the graphite nodules which precipitate in the alloy's matrix. A large number of nodules counteract the formation of carbides and promote the formation of graphite in the matrix, reducing the brittleness of the alloy. As the density of the graphite nodules is lower than that of the iron, the formation of graphite nodules during solidification of the alloy will also lead to expansion which counteracts the shrinkage on solidification.

[0033] For the cast-iron alloy to have good fluidity and a favourable structure after solidification, the carbon content needs to be at least 3.0 wt %.

[0034] Too high a carbon content may however cause primary precipitation of graphite and consequent flotation, leading to non-homogeneous structure in the cast-iron and consequently inferior characteristics. The carbon content of the cast-iron alloy according to the invention should therefore be not more than 3.5 wt %.

[0035] The cast-iron alloy according to the invention has a high silicon content which reduces the solubility of the carbon in the melt. To prevent this from causing primary precipitation of graphite, the carbon content should preferably be between 3.0 and 3.3 wt %.

[0036] Silicon (Si)

[0037] Silicon promotes the formation of graphite and stabilises ferrite. In completely ferritic iron a high silicon content results in solution hardening of the ferrite, increasing the strength of the iron and its resistance to thermal cycling. Silicon also increases the oxidation resistance at high temperatures in that a thin but dense oxide layer forms on the surface of the alloy and hinders further oxidation. The oxidation resistance increases with increasing silicon content. The transformation temperature (A1), i.e. the temperature at which ferrite changes to austenite, is also raised by increasing silicon content. Relatively large changes of volume take place in the material at this temperature, causing local stresses and strains which may in the worse case lead to cracks in and failure of components. The transformation temperature (A1) is therefore usually indicated as the highest transformation temperature for ferritic cast-iron.

[0038] The silicon content for thin to medium-thick castings, typically up to 10 mm wall thickness, should be between 4.1 and 4.8 wt %.

[0039] At high silicon contents, brittle intermetallic phases which reduce the ductility of the material may form. High silicon contents may also disrupt the formation of graphite nodules in cast-iron. As segregation of the material increases with longer solidification time, both the formation of intermetallic phases and the degenerated disrupted graphite shape tend to be more pronounced in thick-walled castings, i.e. those with wall thicknesses over 10 mm.

[0040] To cater for high temperatures during operation and ensure good oxidation resistance and satisfactory ductility in thick-walled castings, the silicon content should be between 4.2 and 4.4 wt %.

[0041] Magnesium (Mg)

[0042] Adding magnesium results in the carbon in the melt forming spheroidal graphite nodules during solidification. To achieve a structure of spheroidal graphite nodules in the cast-iron alloy, the magnesium content should be between 0.02 and 0.08 wt %.

[0043] Molybdenum (Mo)

[0044] Molybdenum is added to improve the cast-iron alloy's mechanical characteristics, i.e. ultimate tensile strength, yield point and creep resistance, for use at high temperatures. For maximum strength at high temperatures the molybdenum content should be at least 0.8 wt %. Adding too much molybdenum may however cause the formation of a continuous network of intercellular carbides with consequent substantial reduction in ductility. The molybdenum content in the cast-iron alloy according to the invention should therefore be not more than 1.20 wt %. Owing to the larger segregations which occur in thick-walled castings, i.e. thicker than 10 mm, the molybdenum content should preferably be kept between 0.8 and 1.0 wt % to ensure maximum strength and good ductility of thick-walled castings.

[0045] Manganese (Mn)

[0046] Manganese stabilises austenite and perlite and is usually present in the scrap used in making the cast-iron alloy. At high temperatures, the perlitic phase breaks down to ferrite and graphite. The precipitated graphite then causes expansion of the material, potentially causing deformation of and cracks in the material and cracking of the anticorrosive oxide layer. To minimise perlite formation in components made of the alloy according to the invention, the manganese content should be kept as low as possible and be not more than 0.4 wt %.

[0047] Chrome (Cr)

[0048] Chrome increases the cast-iron alloy's oxidation resistance at high temperatures by forming a dense protective oxide layer on the surface of a component made of the alloy according to the invention. The oxide layer effectively prevents oxygen from reaching the component's surface and causing further oxidation. It is important that the alloy according to the invention contain enough chrome to make it possible for the protective oxide layer to form, so the chrome content needs to be not less than 0.4 wt %. To ensure the formation of a dense protective oxide layer, the chrome content is preferably at least 0.5 wt %. Increasing chrome content makes the chrome oxide layer form more quickly and become denser. The chrome content should therefore preferably be at least 0.6 wt %.

[0049] Chrome is also carbide-stabilising, so too much chrome increases the brittleness of the material, owing to the formation of chrome carbides. To ensure good ductility of and avoid cracks in the alloy according to the invention, the chrome content should be not more than 1.0 wt %.

[0050] Carbide-stabilising substances have a tendency to concentrate in the melt as a result of segregations during solidification. Long solidification times such as in the case of thick-walled castings therefore make it possible for continuous networks of carbides to form in intercellular regions in the solidified component. To prevent this, the chrome content should preferably be kept between 0.6 and 0.75 wt % when using the alloy according to the invention to make thick-walled castings.

[0051] Copper (Cu)

[0052] Copper is perlite-stabilising and often accompanies the scrap used for making the cast-iron alloy. At high temperatures, perlite breaks down to ferrite and graphite. The precipitated graphite causes expansion of the material, potentially causing deformation and cracks and potentially cracking the anticorrosive oxide layer. To prevent perlite formation in components made of the cast-iron alloy according to the invention, the copper content should be kept as low as possible and be not more than 0.15 wt %.

[0053] Phosphorus (P)

[0054] Phosphorus is an impurity in the cast-iron alloy which may cause brittle phosphorus inclusions with consequent negative effects on the toughness and notch toughness of the material. Phosphorus should therefore be limited to less than 0.05 wt %, preferably less than 0.025 wt %

[0055] Sulphur (S)

[0056] Sulphur is an impurity in the cast-iron alloy. Sulphur inhibits the spheroidisation of the graphite during the alloy's solidification. High sulphur contents may cause degenerated graphite, e.g. the cast-iron's graphite nodules may be flake-like because of sulphur binding to magnesium. It is therefore important that the sulphur content be kept below 0.015 wt %.

DESCRIPTION OF FIGURES

[0057] FIG. **1**: Table showing the composition of a cast-iron alloy according to the invention according to a first embodiment (SiMoCr) and a second embodiment (SiMoCr0.5) and the composition of a comparable cast-iron alloy (SiMo51).

[0058] FIG. **2**: Diagram showing the results of an oxidation experiment carried out at 700° C. on the cast-iron alloy according to the invention according to the first embodiment (SiMoCr) and the comparable cast-iron alloy of the SiMo51 type.

[0059] FIG. **3**: Diagram showing the results of an oxidation experiment carried out at 800° C. on a cast-iron alloy according to the invention according to the first embodiment (SiMoCr) and the comparable cast-iron alloy of the SiMo51 type.

[0060] FIG. **4**: Diagram showing the results of an oxidation experiment carried out at 700° C. on a cast-iron alloy according to the invention according to the first embodiment (SiMoCr) and a cast-iron alloy according to the invention according to the second embodiment (SiMoCr0.5) and the comparable cast-iron alloy of the SiMo51 type.

[0061] FIG. **5**: Diagram showing the results of an oxidation experiment carried out at 800° C. on a cast-iron alloy according to the invention according to the first embodiment (SiMoCr) and a cast-iron alloy according to the invention according to the second embodiment (SiMoCr0.5) and the comparable cast-iron alloy of the SiMo51 type.

EXAMPLES

[0062] The cast-iron alloy according to the invention is described below on the basis of specific examples.

[0063] As a first step, cast-iron alloys according to the invention were made, called SiMoCr and SiMoCr0.5. For comparison purposes, a cast-iron alloy of SiMo51 type was also made. Table 1 shows the compositions of the respective SiMoCr, SiMoCr0.5 and SiMo51 alloys. It shows that the alloys according to the invention contain small amounts of impurities in the form of titanium and niobium. Nickel also occurs as an impurity in the alloys according to the invention. The nickel content of SiMoCr is 0.52 wt %. The nickel content of 0.055 wt % in SiMoCr0.5 may be regarded as negligible. Nickel may accompany the addition of chrome, e.g. in the form of stainless steel scrap. There should however be no nickel at all in the alloy according to the invention, since it lowers the transformation temperature for ferrite to austenite. The transformation of a cast-iron material from ferrite to austenite involves a volume change causing local stresses and strains which in the worst case lead to cracks in and failure of components made from the cast-iron. The volume change also results in cracking of the oxide layer formed on the material, leading to increased amounts of oxygen reaching the pure metal. This lowers the oxygen resistance.

[0064] The alloys were made in a conventional industrial way by methods appropriate to series production and were used to make solid castings from which testpieces measuring 2×2×0.5 cm were taken.

[0065] The surfaces of the samples were ground mechanically in water and then cleaned in ethanol, followed by cleaning in deionised water, before being dried with lint-free paper and being weighed and measured.

[0066] To determine the respective alloys' corrosion resistance, the samples were then subjected to oxidation testing in air, the material being oxidised at a predetermined temperature for a predetermined time. The weight of the material was determined before and after oxidation and the weight increase was calculated. Large weight increase means poor corrosion resistance since a relatively large proportion of the sample has oxidised. Small weight increase means that a thin but dense oxide layer with good adhesion has formed on the surface of the sample. This oxide layer then protects the sample from further oxidation. Small weight increase therefore means good oxidation resistance and consequently good corrosion resistance.

[0067] The oxidation test was carried out in air in a Naber furnace (model N60/HR) at 700° C. and 800° C. Two separate test batches were conducted.

[0068] As a first test batch 1, testpieces of the alloy according to the invention (SiMoCr) and the comparable material (SiMo51) were oxidation-tested at both 700° C. and 800° C. The exposure times set for the testpieces were 1.5, 6, 24 and 96 hours at both 700° C. and 800° C.

[0069] As a second test batch 2, testpieces of the alloy according to the invention (SiMoCr), the alloy SiMoCr0.5 according to the invention and the comparable material (SiMo51) were oxidation-tested at both 700° C. and 800° C. During the test at 700° C., the exposure times set for the testpieces were 1.5, 6, 24 and 96 hours. During the test at 800° C., the exposure times set for the testpieces were 1.5, 6, 24, 96 and 326 hours.

[0070] The oxidation tests of the respective batches involved a number of testpieces of each alloy being placed in the furnace and heated from room temperature to 700° C. or 800° C. so that their surface oxidised by reaction with the furnace atmosphere. The exposure time was counted from when the furnace reached the respective temperature, and when each of the predetermined times had elapsed a testpiece was taken out of the furnace and cooled to room temperature. The oxidised testpieces were weighed again and the weight increase per surface area was calculated in mg/cm^2.

[0071] The results of the oxidation tests are presented in the form of mean values for three testpieces. FIGS. **2** and **3** show the results from the first test batch and FIGS. **4** and **5** those from the second batch.

[0072] Test Batch 1

[0073] In the oxidation test at 700° C., see FIG. **2**, the weight increase of the SiMoCr alloy according to the invention and the comparable SiMo51 alloy turned out to be the same at exposure times of 1.5, 6 and 24 hours, but at the longer time of 96 hours the weight increase of the SiMoCr alloy according to the invention was significantly lower than that of the comparable SiMo51.

[0074] A probable explanation of this is as follows:

[0075] Heating of the SiMo51 samples resulted in the formation of iron oxides and silicon oxides on their surface. These oxides, particularly silicon oxide, protect the iron in the surface of the samples from further oxidation, but upon longer exposure, i.e. beyond 24 hours, oxygen manages to diffuse through the layer of iron oxide and silicon oxide and corrode the underlying iron surface. The oxide layer therefore grows, resulting in the weight increase measured.

[0076] In contrast, the SiMoCr samples form not only the layer of iron oxide and silicon oxide but also, after a time, a dense layer of chrome oxides. The layer of chrome oxides in conjunction with the layer of iron oxide and silicon oxide effectively prevents diffusion of oxygen through the oxide layer to the surface of the iron and therefore protects the sample of the alloy according to the invention from corrosion by further oxidation. From the corrosion perspective this means that an exhaust-conducting component, e.g. a turbo manifold, made from the alloy according to the invention and used at conventional exhaust temperatures, i.e. up to 730° C., has a significantly longer service life than a component made of the comparable alloy.

[0077] In the oxidation test at 800° C., the weight of the samples of the SiMoCr alloy according to the invention turns out to increase considerably less at all exposure times than those of the comparable SiMo51 alloy. The weight increase at 800° C. is also lower than that at 700° C. at similar exposure times. A probable explanation is that the formation of the chrome oxide layer on the surface of the SiMoCr alloy according to the invention is promoted by the higher temperature 800° C., presumably because the diffusion rate of chrome towards the surface of the sample increases with rising temperature. The chrome oxide layer therefore forms more quickly at 800° C. than at 700° C. and also becomes denser. When a layer of chrome oxide has formed, it prevents continued diffusion of oxygen to the metallic surface, thereby preventing further growth of the oxide layer.

[0078] The SiMo51 samples subjected to oxidation testing at 800° C. show considerable weight increase both relative to the SiMoCr material according to the invention and relative to the SiMo51 samples at 700° C. As mentioned above, chemical reactions at the metal surface and diffusion of alloy elements are promoted by rising temperature. This affects the layer of silicon oxides and iron oxides formed on SiMo51 to such an extent that it becomes porous and thick and therefore does not sufficiently protect the underlying surface from further corrosion.

[0079] Test Batch 2

[0080] FIG. **4** shows results from the oxidation testing of the second batch at 700° C. They show that the results for the SiMoCr alloy according to the invention and the comparable SiMo51 alloy are substantially the same in the second test batch as in the first. Any differences observable in the results from test batch 1 and test batch 2 between SiMoCr and SiMo51 may be assumed to be due to factors relating to sample preparation, sample taking and measurement.

[0081] FIG. **4** shows that the SiMoCr0.5 alloy according to the invention has a somewhat larger weight increase at 700° C. than the SiMoCr alloy according to the invention. This is assumed to be because SiMoCr0.5 contains less chrome than SiMoCr and the protective chrome oxide layer therefore takes longer to form on it than on SiMoCr.

[0082] FIG. **4** does however show that at 700° C. both of the SiMoCr and SiMoCr0.5 alloys according to the invention have less weight increase and consequently higher oxidation resistance than the comparable SiMo51 alloy.

[0083] FIG. **5** shows the results from the second batch at 800° C. These show that the SiMoCr alloy according to the invention and the comparable SiMo51 alloy largely exhibit the same oxidation behaviour as the first batch at 800° C. The differences observable between test batches 1 and 2 are due to factors pertaining to sample taking, sample preparation and measurement.

[0084] FIG. **5** shows that the SiMoCr0.5 alloy according to the invention has a very low increase weight increase at 800° C. and no weight increase at all at exposure times beyond 96 hours.

[0085] The very good oxidation resistance of SiMoCr0.5 at 800° C. is assumed to be due to its chrome content in combination with very low nickel content. As described above, at 800° C. chrome very quickly forms a dense layer of chrome oxide which protects the underlying material from further oxidation. Moreover, SiMoCr0.5 at the test temperature is in a stable ferritic phase state promoted by its substantial lack of nickel content. As described above, nickel lowers the transformation temperature for ferrite to austenite. This transformation involves a volume change which may cause oxide layers formed on the surface of the material to crack, increasing the amount of oxygen reaching the metal. However, SiMoCr0.5 undergoes no phase transformation and consequently no volume expansion.

[0086] This relationship is supported by comparison between the SiMoCr0.5 and SiMoCr alloys according to the invention at 800° C., at which the weight of SiMoCr with a nickel content of 0.52 continues to increase during the oxidation test.

[0087] As previously mentioned, comparing the oxidation tests at 700° C. and 800° C. shows that the weight of the SiMoCr0.5 alloy according to the invention completely ceases to increase in the test at 800° C. but continues to increase somewhat during the test at 700° C. This is because the chrome oxide layer which forms at 800° C. forms more quickly and is denser than that formed at 700° C. and therefore provides the underlying metal with better protection from further oxidation.

1. A cast-iron alloy comprising (in wt %):
C: 3.0-3.5
Si: 4.1-4.8
Mn: ≤0.4
Mg: 0.02-0.08
Cr: 0.4-1.0
Cu: ≤0.15
Mo: 0.8-1.2
P: <0.05
S: <0.015
the remainder comprising Fe and any impurities.

2. The cast-iron alloy according to claim **1**, which in solidified state has a structure of spheroidal graphite nodules in a mainly ferritic matrix.

3. The cast-iron alloy according to claim **1**, wherein the C content is 3.0-3.3 wt %.

4. The cast-iron alloy according to claim **1**, wherein the Si content is 4.2-4.4 wt %.

5. The cast-iron alloy according to claim **1**, wherein the Cr content is 0.5-1.0 wt %.

6. The cast-iron alloy according to claim **1**, wherein the Cr content is 0.6-1.0 wt %.

7. The cast-iron alloy according to claim **1**, wherein the Cr content is 0.60-0.75 wt %.

8. The cast-iron alloy according to claim **1**, wherein the Mo content is 0.8-1.0 wt %.

9. An exhaust-conducting component for truck engines, comprising a cast-iron alloy according to claim **1**.

10. An exhaust-conducting component for truck engines according to claim **9**, wherein the exhaust-conducting component is in the form of a turbo manifold, an exhaust manifold or a turbine housing for a turbo.

* * * * *