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(71) Applicant: **Outokumpu Oyj**
00180 Helsinki (FI)

(72) Inventors:
- **Wu, Rui**
  19163 Sollentuna (SE)
- **Falkland, Marie Louise**
  77440 Avesta (SE)

(54) AUSTENITIC STAINLESS STEEL

(57) Austenitic stainless steel with improved heat resistant and corrosion resistance, where the steel contains in weight %

Carbon	0.03 - 0.20
Chromium	20.00 – 26.00
Nickel	10.00 – 22.00
Silicon	0.50 – 2.50
Maganese	0.50 - 2.00
Nitrogen	0.10 – 0.40
Sulphur	<0.015
Phosphous	<0.040

Rare earth metals, mainly cerium and lanthanum 0.00 - 0.10 and the rest being iron (Fe) and inevitable impurities.

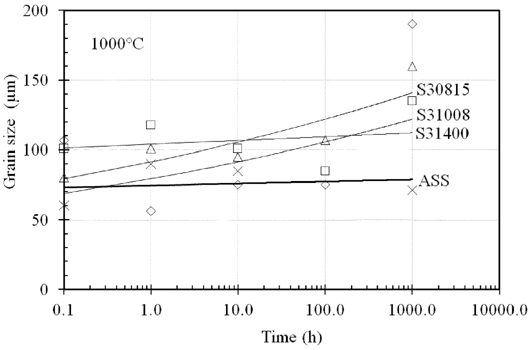

Fig. 2

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to an austenitic heat and creep resistant stainless steel. It also relates to the use of this austenitic stainless steel, especially in oxidizing and carburizing environments. Further, the present invention relates to products made of this austenitic heat and creep resistant stainless steel.

BACKGROUND

[0002] S31008 is the most commonly used high temperature stainless steel for applications in the temperature range of 800 - 1050°C. It is however outperformed by S30815 both in regards to creep resistance and oxidation resistance in cyclic temperatures. It is however so that S31008 performs better in reducing or carburizing environments.

SUMMARY OF THE INVENTION

[0003] There is a strong need for a steel which has excellent high temperature oxidation and corrosion resistance in combination with very good mechanical like creep properties. Existing high temperature steels lack this combination of features. An object of the design and development of this alloy, an austenitic heat resistant stainless steel, is to produce a combination of high creep strength and good oxidation and corrosion resistance at high temperatures. Heading for a creep strength as excellent as that of S30815 and exceeding that of S31008 and S31400 and an oxidation resistance that is superior to that of the aforementioned commercial grades. This alloy is aimed at fulfilling the requirement of load bearing applications in oxidizing and carburizing environments.

[0004] It is an aim of the present invention to provide an austenitic stainless steel that combines excellent creep resistance and oxidation resistance, in isothermal as well as cyclic conditions, with good resistance, in particular in reducing environments. These are requirements often demanded of materials used in applications such as muffle furnaces.

[0005] The present invention relates to an austenitic heat resistant stainless steel, intended to replace the existing heat resistant stainless grades S30815 and S31008 for special high temperature applications like muffle and heat treatment furnaces where both oxidizing and reducing environments exist. By means of the invention an austenitic heat resistance stainles steel is provided having even better high temperature corrosion resistance and creep properties, being cost effective and easy to produce.

[0006] Surprisingly, it has been found that the austenitic stainless steel according to embodiments provides high temperature corrosion resistance and creep properties and is particularly suitable for high temperature applications in aggressive environments such as heat treatment equipment e.g. muffle furnaces. The austenitic stainless steel according to embodiments can be economically manufactured in a practical and environmentally sound manner.

DETAILED DESCRIPTION

[0007] According to embodiments an austenitic stainless steel has a composition utilizing the benefits of several alloying elements in order to combine good oxidation resistance through the formation of a tight and adhesive oxide layer and to, at the same time, be alloyed in a way to resist carburizing. Furthermore, it is designed in a way to have excellent creep resistance.

[0008] A well-defined and balanced alloying with carbon and nitrogen increases the creep strength through the formation of intra- and to some extent intergranular carbides and nitrides; so-called precipitation strengthening.

[0009] Chromium and silicon are added in order to have a high oxidation resistance. The amount is carefully balanced in order to not have a negative influence on the structure stability, since both these elements promote the formation of intermetallic and brittle phases such as sigma phases.

[0010] Rare earth metals, e.g. cerium has in earlier micro alloyed (MA) grades shown to have an excellent effect on the cyclic oxidation resistance. Thus, rare earth metals are added in an amount optimized to get the benefits of a more elastic and adhesive oxide layer. The amount, however, is limited since it has been shown that a surplus amount of rare earth metals is no longer beneficial for oxidation resistance and that it might cause clusters of oxide inclusions having a negative effect on mechanical properties and formability.

[0011] The nickel content is at a level known from other well-known commercially-available high temperature stainless steels but different from other high temperature grades micro alloyed with rare earth metals. Thus, the combination of the elements is utilized in a novel way. The nickel in combination with silicon promotes resistance to carburization.

[0012] Total of 15 test melts have been produced, see Table 1. The melts 1-8 are produced using a Mullite crucible and heated up to melt in an Ar protection atmosphere using a high frequency coil. The melt process takes about 10 to

15 min. Each melt is weighed about 600 grams. The melts are forged by using the hydraulic press Interlaken. An in-house software program has been developed that presses the ingot in short bursts to the desired thickness over a predetermined number of steps. The melt is heated to about 1250°C between each step. The thickness of the final piece is 8 mm.

[0013] The test melts 9-15 are produced using a Leybold-Heraeus vacuum induction furnace having minimum pressure of 4 x 10-4 bar. The melts are tapped to metal mound in vacuum for producing 65 kg ingots. Heating up to 1250°C, the Frohling rolling mill with furnaces on both sides is used to hot roll 38 mm thick slab to 10 and 6 mm thick plates, respectively. The rolling speed is 45 m/min. The rolling passes are 7 and 9 for 10 mm thick plate and for 6 mm thick plate, respectively.

[0014] Annealing temperature and holding time have been chosen to bring about a fully recrystallized austenite, proper hardness and grain size. Annealing temperature and holding time cover from 1100°C to 1200°C and from 0 min to 30 min, respectively.

Melt	C	Si	Mn	P	S	Cr	Ni	Mo	Ti	Nb	Cu
1	0.089	1.69	1.40	0.021	0.003	24.80	20.62	0.16	0.007	0.004	0.12
2	0.066	1.17	1.51	0.016	0.001	25.46	20.56	0.14	0.004	0.004	0.11
3	0.066	1.63	1.63	0.020	0.001	24.96	20.14	0.14	0.006	0.006	0.14
4	0.070	1.63	1.81	0.021	0.001	25.23	21.17	0.16	0.005	0.008	0.14
5	0.069	1.64	1.63	0.025	0.001	24.77	20.35	0.40	0.010	0.009	0.15
6	0.074	1.59	1.54	0.021	0.002	24.78	20.39	0.16	0.005	0.008	0.15
7	0.077	1.71	1.63	0.024	0.002	24.70	20.69	0.16	0.008	0.008	0.15
8	0.073	1.67	1.62	0.024	0.002	24.90	20.45	0.16	0.002	0.008	0.15
9	0.051	1.60	1.52	0.006	0.008	23.63	18.78	0.01	0.006	0.002	0.006
10	0.046	0.62	0.94	0.006	0.007	25.67	19.01	0.01	0.007	0.002	0.006
11	0.048	1.72	0.62	0.008	0.007	21.18	11.27	0.01	0.006	0.003	0.008
12	0.049	1.78	0.55	0.007	0.002	21.06	11.01	0.01	0.007	0.003	0.007
13	0.047	1.59	1.43	0.006	0.007	25.10	20.03	0.01	0.006	0.003	0.006
14	0.047	1.67	1.43	0.006	0.005	25.07	19.99	0.01	0.007	0.003	0.007
15	0.05	1.61	1.4	0.007	0.002	25.05	20.08	0	0.004	0.002	0.005

Table 1**:** Chemical composition of austenitic stainless heats (wt%).

Melt	Co	N	Sn	As	W	V	Al	B	Ce	N+3×(C+REM)
1	0.10	0.218	0.005	0.002	0.017	0.050	0.010	0.0005	0.009	0.512
2	0.10	0.340	0.004	<0.003	0.016	0.051	0.16	0.0003	0.032	0.634
3	0.12	0.404	<0.002	<0.003	0.028	0.055	0.009	0.0004	0.10	0.902
4	0.12	0.347	0.005	<0.003	0.031	0.059	0.009	0.0003	0.078	0.791
5	0.12	0.322	0.006	<0.003	0.031	0.061	0.009	0.0004	0.070	0.739
6	0.12	0.151	0.005	<0.003	0.033	0.059	0.006	0.0004	0.092	0.649
7	0.12	0.154	0.008	0.000	0.030	0.060	0.007	0.0003	0.044	0.517
8	0.12	0.145	0.005	0.000	0.032	0.060	0.009	0.0003	0.048	0.508
9	0.003	0.044	0.003	<0.003	0.006	0.007	0.025	0.0031	0.01	0.227
10	0.003	0.022	<0.002	<0.003	0.006	0.007	0.02	0.0004	0.008	0.184
11	0.008	0.142	0.001	<0.003	0.007	0.008	0.027	0.0003	0.007	0.307
12	0.009	0.162	0.002	<0.003	0.009	0.009	0.029	0.0002	0.027	0.39
13	0.003	0.172	0.002	<0.003	0.005	0.008	0.009	0.0004	0.008	0.337
14	0.004	0.172	0.003	<0.003	0.008	0.01	0.027	0.0004	0.040	0.433
15	0.005	0.144	0.003	<0.003	0.007	0.009	0.029	0.0003	0.047	0.435

Table 1: Continued

[0015] Not all melts listed in Table 1 fulfill the basic idea behind this austenitic stainless steel to chemically combine main elements like chromium, nickel, silicon, nitrogen and REM of S31008 and S30815. Therefore, the chemical compositions obtained in above test melts result in a target and preferred chemical composition as described below in Table 2. The microstructure investigation, oxidation and carburisation tests, as well as creep test are performed in the most cases using the melts 7, 8, 14 and 15.

Table 2: Proposed chemical composition of austenitic stainless steel (wt%).

Main target composition	Broad range	Preferred range
Carbon	0.03 - 0.20	0.05 - 0.10
Chromium	20.00 - 26.00	24.00 - 26.00
Nickel	10.00 - 22.00	19.00 - 22.00
Silicon	0.50 - 2.50	1.20 - 2.50
Mangness	0.50 - 2.00	0.50 - 2.00
Nitrogen	0.10 - 0.40	0.12-0.20
Sulphur	<0.015	<0.010
Phosphous	<0.040	<0.040
Cerium	0.00 - 0.10*	0.03 - 0.08*
*Sum of rare earth metals, mainly Cerium and Lanthanum		

PRODUCTION PROCESS AND PRODUCTS

[0016] The austenitic stainless heat resistant steel as defined hereinabove and herinafter is intended to be used for manufacturing of objects such as semis, plate, sheet, coil, strip, par, pipe, tube and/or wire. The methods used for manufacturing these products include conventional manufacturing processes such as, but not limited to, melting, refining, casting, hot rolling, cold rolling, forging, extrusion and drawing.

BRIEF DESCRIPTION OF THE ILLUSTRATIONS

Microstructure

[0017]

- Figure 1 shows microstructure of the austenitic stainless steel (ASS).
- Figure 2, Figure 3, Figure 4, Figure 5 and Figure 6 show grain growth behavior for the austenitic stainless steel (ASS) in comparison to commercial grades like S31008, S30815 and S31400 at given times at 1000°C, at 1050°C, at 1100°C, at 1150°C and at 1200°C, respectively.
  Environmental testing
- Figure 7 and Figure 8 exhibit cyclic oxidation test in dry air at 1150°C/90 h and at 1175C/50 h, respectively, for the austenitic stainless steel (ASS) in comparison to commercial grades like S31008, S30815 and S31400.
- Figure 9, Figure 10 and Figure 11 display isothermal oxidation test in dry air at 1000°C/250 h, at 1100°C/250 h and at 1150C/250 h, respectively, for the austenitic stainless steel (ASS) in comparison to commercial grades like S31008, S30815 and S31400.
- Figure 12 shows carburization test result for the austenitic stainless steel (ASS), S31008, S30815 and S31400.and S31400.
  Mechanical testing
- Figure 13, Figure 14, Figure 15 and Figure 16 show creep properties for the austenitic stainless steel (ASS) at 900°C comparing to those for S30815 and S31008.

EMBODIMENTS ILLUSTRATING THE INVENTION

Microstructure

Figure 1 illustrates

[0018]

- Microstructure for the as-produced austenitic stainless steel. Production process has been melting, metallurgical treatment, casting and hot rolling followed by optimized annealing process.
- The microstructure consists of austenite and few oxide inclusions. This is common for MA grade.
- The grain size is approximately 70 μm (ASTM 5 - 5.5) and the hardness is 170 (HV5).

Figure 2 illustrates

[0019]

- Grain growth behavior at 1000°C shown as the mean grain size in μm as a function of time in hours.
- The grain growth study includes heat treatment, metallographic sample preparation and grain size measurement. The size of the test samples is approximately 15x25x6 mm. The heat treatment is conducted in a chamber furnace in open air. After heat treatment, the samples are cooled in water. The grain size is measured on the etched samples according to the standard ASTM E112. The mean grain size is determined by three to five measurements. The positions for the grain size measurements are randomly selected to cover entire cross section.
- The austenitic stainless steel shows superior microstructure stability in terms of grain growth to other commercial grades.
- The austenitic stainless steel has more stable microstructure than S31008, S30815 and S31400. Finer grain size improves oxidation and corrosion resistance, as well as ductility.

Figure 3 illustrates

[0020]

- The same relation as Figure 2, but at 1050°C.
- The austenitic stainless steel shows superior microstructure stability in terms of grain growth to other commercial grades.

Figure 4 illustrates

[0021]

- The same relation as Figure 2, but at 1100°C.
- The austenitic stainless steel shows superior microstructure stability in terms of grain growth to other commercial grades.

Figure 5 illustrates

[0022]

- The same relation as Figure 2, but at 1150°C.
- The austenitic stainless steel shows superior or similar microstructure stability in terms of grain growth to other commercial grades.

Figure 6 illustrates

[0023]

- The same relation as Figure 2, but at 1200°C.
- The austenitic stainless steel shows superior or similar microstructure stability in terms of grain growth to other

commercial grades.

Environmental testing

Figure 7 illustrates

[0024]

- Cyclic oxidation test in dry air at 1150°C for 90 h, illustrated as the mass change per unit area (W/A) related to time t, where W is the mass change in mg, A the total surface area prior to test in cm2 and t in hour.
- The test has been performed using Setaram TGA 96 thermogravimetry set-up. A single cycle includes 1) heating up to target temperature, 2) holding two hours at target temperature, and 3) cooling down to room temperature and holding for 10 min.
- The samples are prepared is in accordance with the standard ISO 21608:2012. Cuboid sample is used. The sample size is approximately 20x20x2.5 - 6 mm. Prior to the test, the total surface area and weight are carefully measured and recorded.
- The chamber is first heated up to target temperature. Then, the sample is put into the chamber and the temperature is allowed to be harmonized and stabilized.
- Two parameters, namely maximum value of mass change and the corresponding time called the breakaway time are usually considered. The mass change is the sum of mass gain due to oxide formation and mass loss due to evaporation of volatile species plus spallation. The breakaway time accounts actually for the time when mass loss is larger than mass gain, or spallation. Generally speaking, the longer the breakaway time and the lower the maximum value of mass change, the better the cyclic oxidation resistance. The weight (mass) change is monitored and measured continuously using a Setaram TG 96 microbalance during testing. In total, there are approximately 4900 measurements for each test.
- The longer the time, the more the oxidation. This is true for all materials. No oxidation breakaway has been observed at the given test conditions for the austenitic stainless steel, whereas, oxidation breaks always away for S31008, S30815 and S31400.
- Austenitic stainless steel has an adherent oxide layer with high oxide spallation resistance resulting in a cyclic oxidation resistance superior to S31008, S30815 and S31400.

Figure 8 illustrates

[0025]

- The same relation as Figure 7, but at 1175°C for 50 h,
- Austenitic stainless steel has an adherent oxide layer with high oxide spallation resistance resulting in a cyclic oxidation resistance superior to S31008, S30815 and S31400.

Figure 9 illustrates

[0026]

- Isothermal oxidation testing in dry air at 1000°C for 250 h, illustrated as the mass change per unit area related to time.
- The sample preparation, test equipment and test methodology for isothermal oxidation test are the same as those for cyclic oxidation test, except that there is no temperature variation. The test is constantly kept at target temperature for 250 hours.
- Oxidation increases with increasing time at the same temperature. This is the case for all materials. Usually, the larger the value of mass change per unit area, the more the material oxidizes. At given test condition, the austenitic stainless steel shows less oxidation comparing to S31008, S30815 and S31400.
- Austenitic stainless steel has an adherent oxide layer with high oxide spallation resistance resulting in an isothermal oxidation resistance equivalent or superior to S31008, S30815 and S31400.

Figure 10 illustrates

[0027]

- The same relation as Figure 9, but at 1100°C for 250 h

- Austenitic stainless steel has an adherent oxide layer with high oxide spallation resistance resulting in an isothermal oxidation resistance superior to S31008, S30815 and S31400.

Figure 11 illustrates

[0028]

- The same relation as Figure 9, but at 1150°C for 250 h.
- Austenitic stainless steel has an adherent oxide layer with high oxide spallation resistance resulting in an isothermal oxidation resistance superior to S31008, S30815 and S31400.

Figure 12 illustrates

[0029]

- Resistance to carburization for the austenitic stainless steel, S31400, S31008 and S30815.
- Carburization test is carried out at 1000°C/4 h in 5%CH4 + Ar using a tube furnace with constant running gas flow. CH4 is used to generate carbon according to: CH4 -> 2H2 + C.

[0030] The carbon activity ac is calculated according to:

$$ac = (K \times pCH4)/p2H_2 \qquad (1)$$

where pCH4 is the CH4 partial pressure, in the present case content of CH4 in the gas mixture. p2H2 is assumed to be very low, i.e. 0,00001, since the running gas flow and constant supply of CH4 will minimize H2 in the reaction. K is the equilibrium constant and is calculated using standard free energy of formation for the reaction ΔG at temperature T (K) of 1273K (1000°C).

- The calculated ac is far greater than unity, ac >> 1, ensuring that the carburization takes place.
- Cuboid sample is used. The sample size is approximately 20x20x6 mm. Before the test the samples are ground to 1200.
- After test, the samples are sectioned and ground to 0.25 μm. The cross section is examined in scanning electron microscope (SEM).
- SEM examination of the coss section of the austenitic stainless steel, S31400, S31008 and S30815 samples after exposure in 5%CH4 at 1000°C/4 h shows that there are hardly any intra- or intergranular carbides in the austenitic stainless steel, while other commercial grades show both intra- and intergranular carbides and carbide penetration from surface deep inside the matrix.
- Austenitic stainless steel shows hardly any intra- or intergranular carbides, while other commercial grades show both intra- and intergranular carbides and carbide penetration from surface (left hand side) deep inside the matrix.
- The austenitic stainless steel shows superior carburization resistance to S31400, S31008 and S30815.

Mechanical testing

Figure 13 illustrates

[0031]

- Creep strain in % as a function of time in hour for the austenitic stainless steel at given stresses at 900°C.
- Cylindrical specimens with 5 mm diameter and 50 mm gauge length are used for the creep test.
- The creep test is performed according to the standards ASTM E139 - 2011 and SS-EN 10291:2000.
- Using single specimen and a deadweight lever creep machine, all the specimens are uniaxially tested to rupture in air at 900°C at different stresses from 10 to 30 MPa. Two calibrated thermal couples are mounted on the gauge length of the specimens. The maximum temperature variations with time are controlled within $\pm$3°C. The strain (elongation) of the specimens is measured continuously during the test using analogue clock with an accuracy of 1 μm. Creep data such as time, surrounding temperature and specimen elongation at given time intervals are recorded and saved. From these data, creep strain and the corresponding time to given strain and to failure can be obtained.

- The elongation at failure is measured on the failed specimens.
- The test at 10 MPa is stopped due to extra long duration. × refers to the elongation at rupture.

Figure 14 illustrates

[0032]

- Creep behavior of the austenitic stainless steel compared to S30815 tested in air at 900°C. One reference point is also given to S31008.
- Testing procedure as described in Figure 13.
- Stress in MPa as a function of rupture time in h at 900°C.
- One reference point is also given to S31008.
- Rupture time increases with decreasing stress.
- The rupture time of the austenitic stainless steel is similar to that of S30815.
- The rupture strength for the austenitic stainless steel indicates a considerably higher level than that for S31008 at the same given rupture time.

Figure 15 illustrates

[0033]

- Minimum creep strain rate $\acute{\varepsilon}$ in 1/h as a function of stress in MPa for the austenitic stainless steel at 900°C, so-called Norton's law.
- Testing procedure as described in Figure 13.

Figure 16 illustrates

[0034]

- The relative 100,000 hour creep rupture resistance of some stainless high temperature grades.
- It is seen that S30815 is superior to other commercial grades. Since the austenitic stainless steel is on par with S30815, the austenitic stainless steel is thus also superior to other commercially available high temperature steels.

SUMMARY OF FINDINGS

[0035]

- The austenitic stainless steel has utilized the advantages of elements of C, Cr, Ni, Si, N as well as rare earth elements.
- The austenitic stainless steel has combined the above mentioned elements and optimized them to a preferred range.
- The austenitic stainless steel has received appropriate hot rolling process and annealing treatment to provide fully recrystallized austenite, favorable grain size and hardness.
- The austenitic stainless steel has more stable microstructure than S31008, S30815 and S31400. Finer grain size improves oxidation and corrosion resistance, as well as ductility.
- The austenitic stainless steel shows superior cyclic oxidation resistance to S31400, S31008 and S30815.
- The austenitic stainless steel shows superior isothermal oxidation resistance to S31400, S31008 and S30815.
- The austenitic stainless steel shows superior carburization resistance to S31400, S31008 and S30815.
- The austenitic stainless steel shows a creep resistance on par with S30815 and superior to S31400 and S31008.

[0036] According to embodiments the austenitic stainless steel is provided with improved heat resistance and corrosion resistance. According to an embodiment the austenitic stainless steel has finer grain size which improves oxidation and corrosion resistance as well as ductiliy. In a preferred embodiment the austenitic stainless steel has superior cyclic oxidation reistance. In a particular embodiment the steel has superior isothermal oxidation reistance. In a suitable embodiment the steel has superior carburization resistance. In a particularly preferred embodiment the steel has a creep resistance comparable with commercial grades.

[0037] In an embodiment the steel contains in weight % carbon <0.20, chromium 20.00 - 26.00, nickel 10.00 - 22.00, silicon 0.50 - 2.50, manganese < 2.00, nitrogen 0.10 - 0.40, sulphur <0.015, phosphous <0.040, rare earth metals 0.00 - 0.10, and the rest being iron (Fe) and inevitable impurities.

[0038] For the stainless steel, carbon is a strong austenite former that also significantly increases the mechanical strength by the formation of carbides. On the other hand, carbon also reduces the resistance to intergranular corrosion just due to the carbide formation, indicating the low carbon content. In embodiments described herein, the austenitic stainless steel contains < 0.20 carbon in weight %. Keeping the carbon content < 0.20%, preferably at least 0.05% but not more than 0.10% provides an optimization between austenite, mechnical strength and intergranullar corrosion resistance.

[0039] Chromium is the most important alloying element for the stainless steels. Chromium gives stainless steels their fundmental oxidation and corrosion resistance. All stainless steels have a Cr-content of at least 10.5% and the oxidation and corrosion resistance increases with increasing chromium content. In addition, chromium carbide and nitride improve mechanical strength. On the other hand, chromium promotes a ferritic microstructure. High chromium also contributes to intermetallic sigma phase formation. In a preferred embodiment the chromium content is at least 24.0 but not more than 26.0% for the austenitic stainless steel.

[0040] Nickel is present in all of the austenitic stainless steels since nickel promotes an austenitic microstructure. When added to a mix of iron and chromium, nickel increases ductility, high temperature strength, and resistance to both carburization and nitriding because nickel decreases the solubility of both carbon and nitrogen in austenite. On the other hand, high nickel is bad for sulphidation resistance. In a preferred embodiment the chromium content is at least 19.0 but not more than 22.0 w-% for the austenitic stainless steel.

[0041] Silicon improves both carburization and oxidation resistance, as well as resistance to absorbing nitrogen at high temperature. On the other hand, silicon tends to make the alloy ferritic, and promotes to intermetallic sigma phase formation. In a preferred embodiment the amount of silicon in the austenitic stainless steel is further controlled so that the silicon content is at least 1.20 but not more than 2.50 w-%.

[0042] Manganese is usually considered an austenitizing element and can also replace some of the nickel in the stainless steel. Manganese improves hot workability, weldability, and increases solubility for nitrogen to permit a substantial nitrogen addition. On the other hand, manganese is mildly detrimental to oxidation resistance, so it is limited to 2 w-% maximum in most heat resistant alloys. In a preferred embodiment the amount of manganese in the austenitic stainless steel is at least 0.50 but not more than 2.00 w-%.

[0043] Nitrogen is a very strong austenite former that also significantly increases the mechanical strength. Nitrogen tends to retard or prevent ferrite and sigma formation. On the other hand, high content nitrigen impairs toughness and causes embrittlement. In a preferred embodiment the amount of nitrogen in the austenitic stainless steel is at least 0.12 but not more than 0.20 w-%.

[0044] Sulphur and phosphorus are normally regarded as impurities. Sulphur is commonly below 0.010 w-%, while phosphorus is usually not specified. In a preferred embodiment the sulphur and phosphorus content in the austenitic stainless steel is not more than 0.010 w-% and 0.040 w-%, respectively.

[0045] Small amount of the rare earth elements (REM) are used singly or in combination to increase oxidation resistance by forming a thinner, tighter and more protective oxide scale in austenitic stainless alloys. Residual REM oxides in the metal may also contribute to creep-rupture strength. On the other hand, a surplus amount of rare earth metals might cause clusters of oxide inclusions having a negative effect on mechanical properties and formability. In a preferred embodiment the REM content in the austenitic stainless steel, maninly cerium and lanthanum, is at least 0.03 w-% but not more than 0.08 w-%. In a particularly preferred embodiment the REM is cerium and is present in the range of 0.03% to 0.08 w-%

[0046] In a particular embodiment the N, C and rare earth metal (REM) contents in the austenitic stainless steel satisfy the relationship:

$$0.40\% \leq N + 3xC + 3xREM \leq 0.60\% \qquad (2)$$

[0047] As described above the stainless steel comprises inevitable impurities. In an embodiment the austenitic stainless steel comprises one or more of the inevitable impurities contains in weight %:

trace amounts V ≤ 0.20%
trace amounts Co ≤ 0.60%
trace amounts Sn ≤ 0.05%
trace amounts As ≤ 0.05%
trace amounts W ≤ 0.40%
trace amounts B ≤ 0.0050%
trace amounts Nb ≤ 0.060%
trace amounts Cu ≤ 0.50%
trace amounts Zr ≤ 0.1%.

[0048] Further embodiments relate to objects formed from the stainless steel according to embodiments of the present invetion. In one embodiment is provided an object comprising the stainless steel according to any of the embodiments described herein.

[0049] The stainless steel according to embodiments of the present invention has a diverse range of uses. In one embodiment is provided a use of the stainless steel according to any of the embodiments described herein in the formation of an object. In a further embodiment the object formed and/or used according to embodiments is selected from the group consisting of plate, sheet, strip, tube, pipe, bar and wire. Further embodiments relates to uses of objects formed in heat treatment applications. Such object are apt for use in difficult environments. Thus, in an embodiment the object may be used in aggressive high temperature environments, which have oxidazing and reducing carburizing atomspheres, like in muffle funace and in metal manufacturing process applications.

Claims

1. Austenitic stainless steel with improved heat resistant and corrosion resistance, **characterized in that** the steel contains in weight %

Carbon	0.03 - 0.20
Chromium	20.00 - 26.00
Nickel	10.00 - 22.00
Silicon	0.50 - 2.50
Maganese	0.50 - 2.00
Nitrogen	0.10 - 0.40
Sulphur	<0.015
Phosphous	<0.040

Rare earth metals, mainly cerium and lanthanum 0.00 - 0.10 and the rest being iron (Fe) and inevitable impurities.

2. The austenitic stainless steel according to claim 1, wherein the carbon content is at least 0.05 but not more than 0.10 w%.

3. The austenitic stainless steel according to claim 1 and 2, wherein the silicon content is at least 1.20 but not more than 2.50 w%.

4. The austenitic stainless steel according to any of claims 1 to 3, wherein the nitrogen content is at least 0.12 but not more than 0.20 w%.

5. The austenitic stainless steel according to any of the preceding claims, wherein the sum of rare earth metals, mainly cerium and lanthanum, is at least 0.03 w% but not more than 0.08 w%.

6. The austenitic stainless steel according to any of the preceding claims, wherein the chromium content is at least 24.0 but not more than 26.0 w%.

7. The austenitic stainless steel according to any of the preceding claims, wherein the nickel content is at least 19.0 but not more than 22.0 w%.

8. The austenitic stainless steel according to any of the preceding claims, wherein nitrogen, carbon and rare earth metal (REM) contents satisfy the relationship: $0.40\% \leq N + 3xC + 3xREM \leq 0.60\%$.

9. The austenitic stainless steel according to any of the preceding claims, wherein the manganese content is at least 0.50 but not more than 2.00 w%.

10. The austenitic stainless steel according to any of the preceding claims, wherein the sulphur and phosphorus content is not more than 0.010% and 0.040%, respectively.

11. The austenitic stainless steel according to any of the preceding claims, comprising one or more of the inevitable

impurities contains in weight %

trace amounts V ≤ 0.20%
trace amounts Co ≤ 0.60%
trace amounts Sn ≤0.05%
trace amounts As ≤0.05%
trace amounts W ≤0.40%
trace amounts B ≤0.0050%
trace amounts Nb ≤ 0.060%
trace amounts Cu ≤ 0.50%
trace amounts Zr ≤ 0.1%.

12. An object comprising the stainless steel according to any of claims 1 to 11.

13. Use of the stainless steel according to any of claims 1 to 11 in the formation of an object according to claim 12.

14. The use according to claim 13, wherein the object is selected from the group consisting of plate, sheet, strip, tube, pipe, bar and wire.

15. Use of an object comprising the austenitic stainless steel according to the claims 1-11 in applications relating to heat treatment applications.

16. Use of an object according to claim 12 in aggressive high temperature environments.

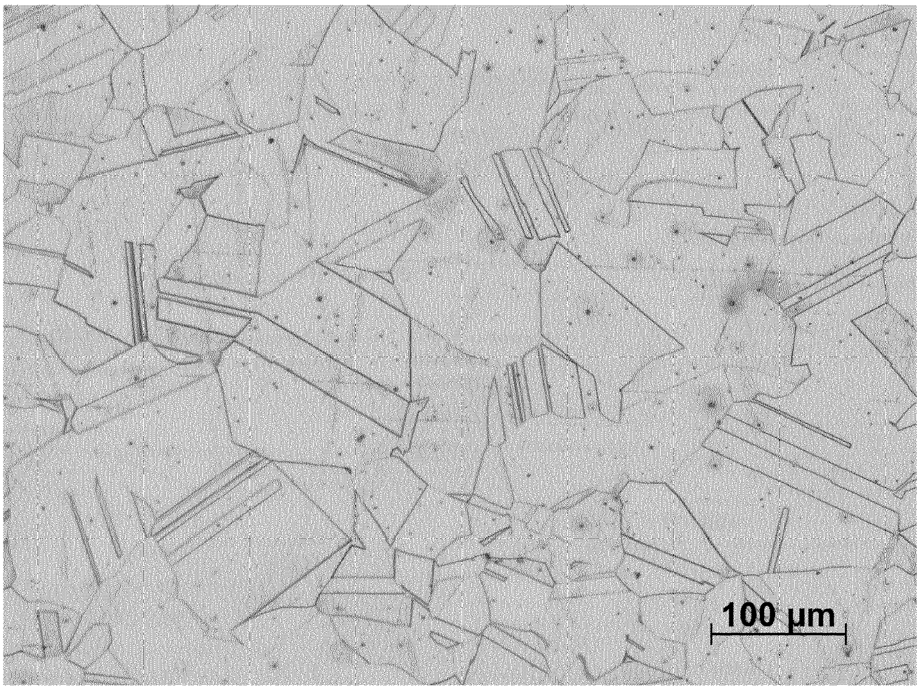
100 µm

Fig. 1

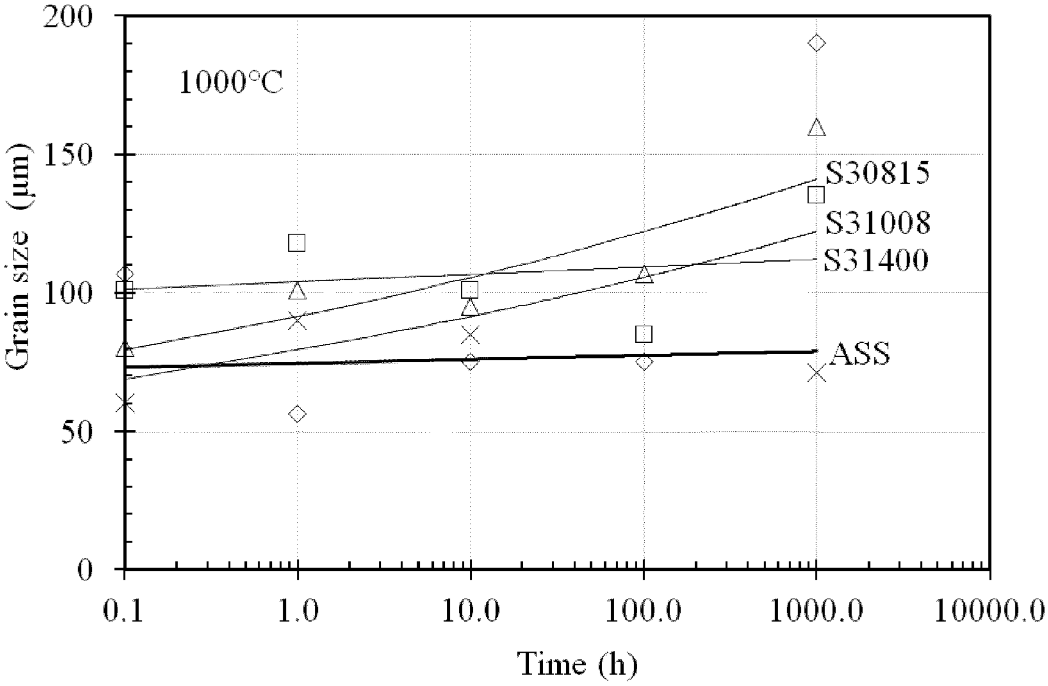
1000°C
Grain size (µm)
Time (h)
0
50
100
150
200
0.1
1.0
10.0
100.0
1000.0
10000.0
S30815
S31008
S31400
ASS

Fig. 2

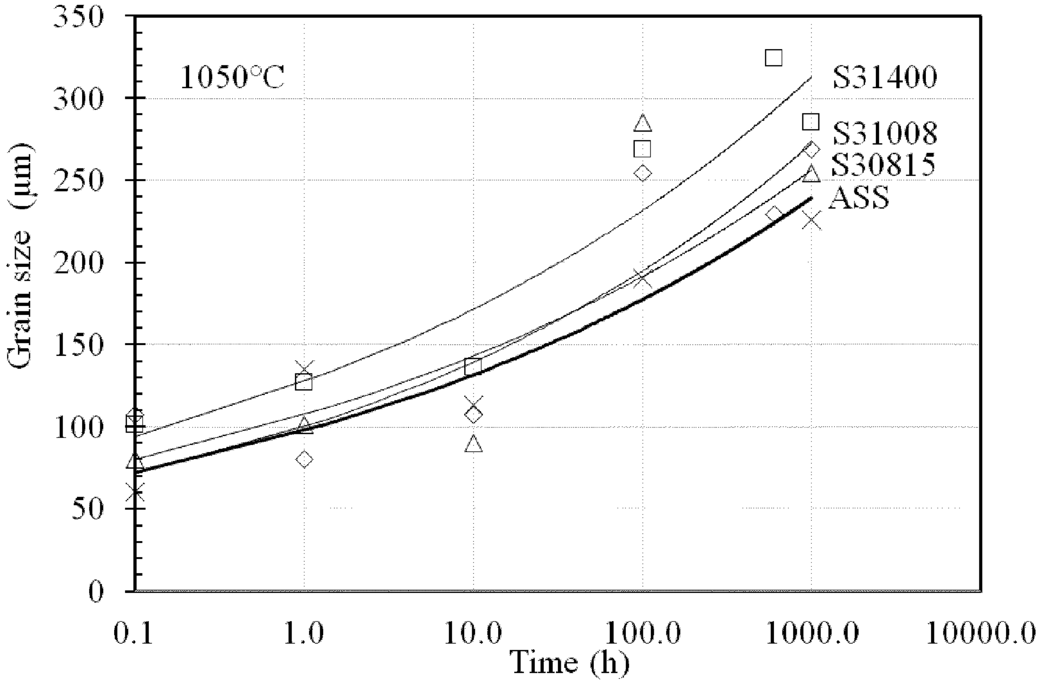
1050°C
S31400
S31008
S30815
ASS
Grain size (μm)
Time (h)
0
50
100
150
200
250
300
350
0.1
1.0
10.0
100.0
1000.0
10000.0

Fig. 3

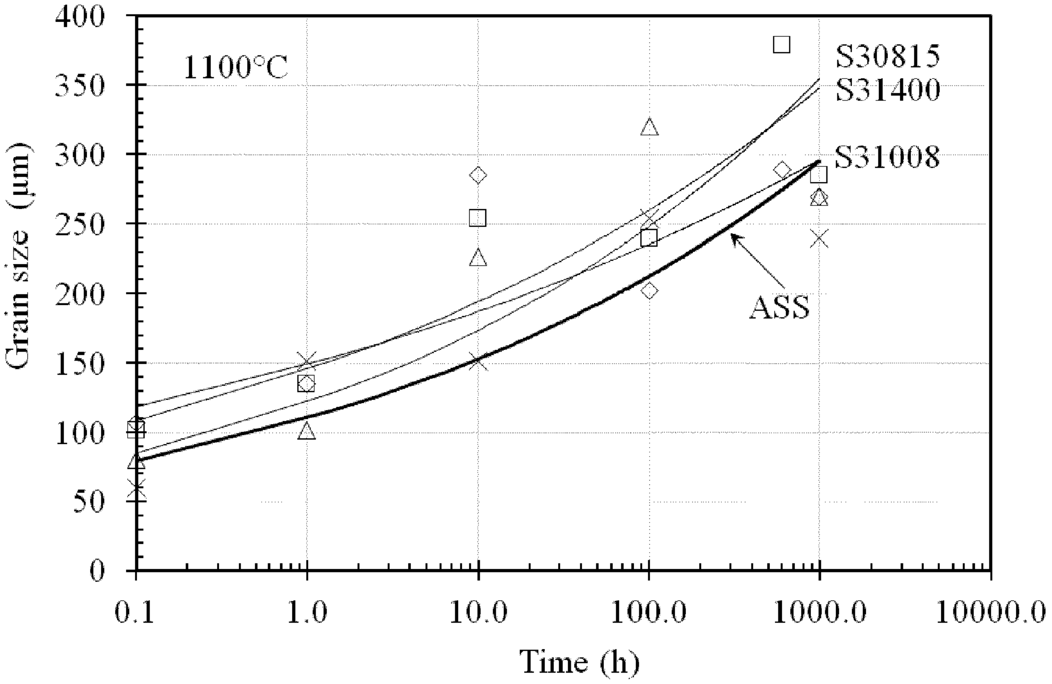
1100°C
S30815
S31400
S31008
ASS
Grain size (μm)
Time (h)
0
50
100
150
200
250
300
350
400
0.1
1.0
10.0
100.0
1000.0
10000.0

Fig. 4

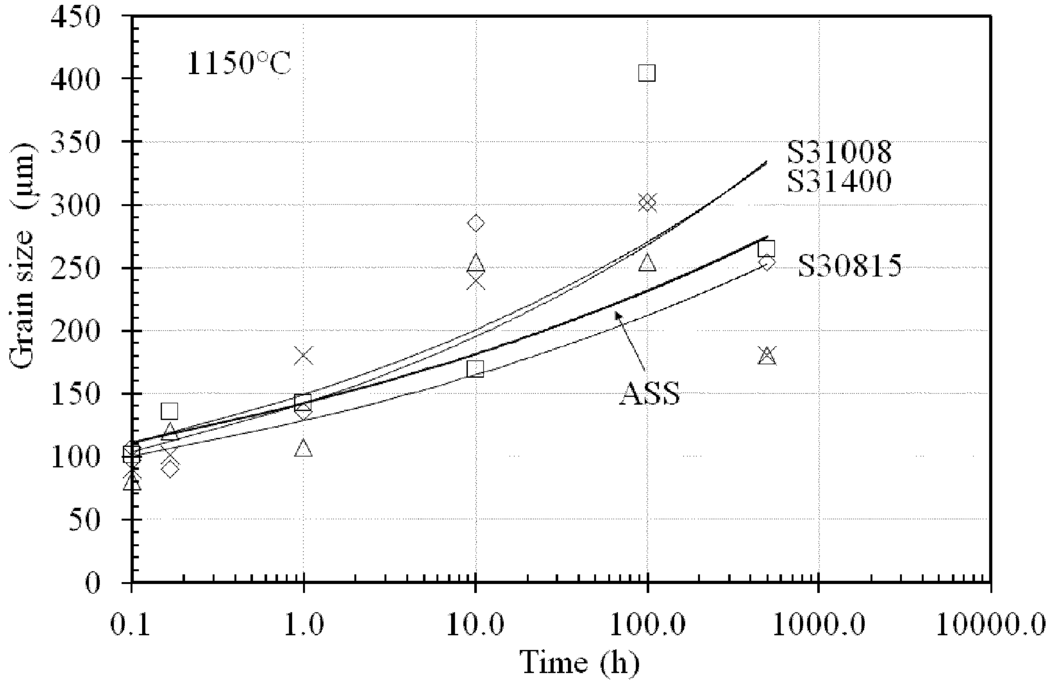
1150°C
Grain size (μm)
Time (h)
S31008
S31400
S30815
ASS
0
50
100
150
200
250
300
350
400
450
0.1
1.0
10.0
100.0
1000.0
10000.0

Fig. 5

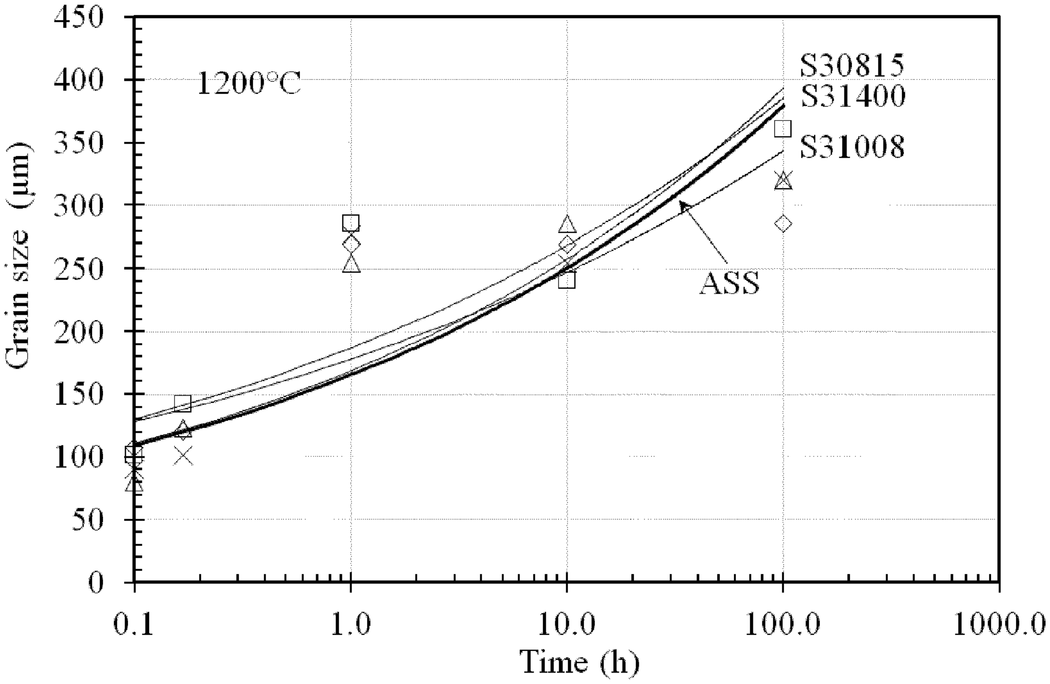
1200°C
Grain size (μm)
Time (h)
S30815
S31400
S31008
ASS
0
50
100
150
200
250
300
350
400
450
0.1
1.0
10.0
100.0
1000.0

Fig. 6

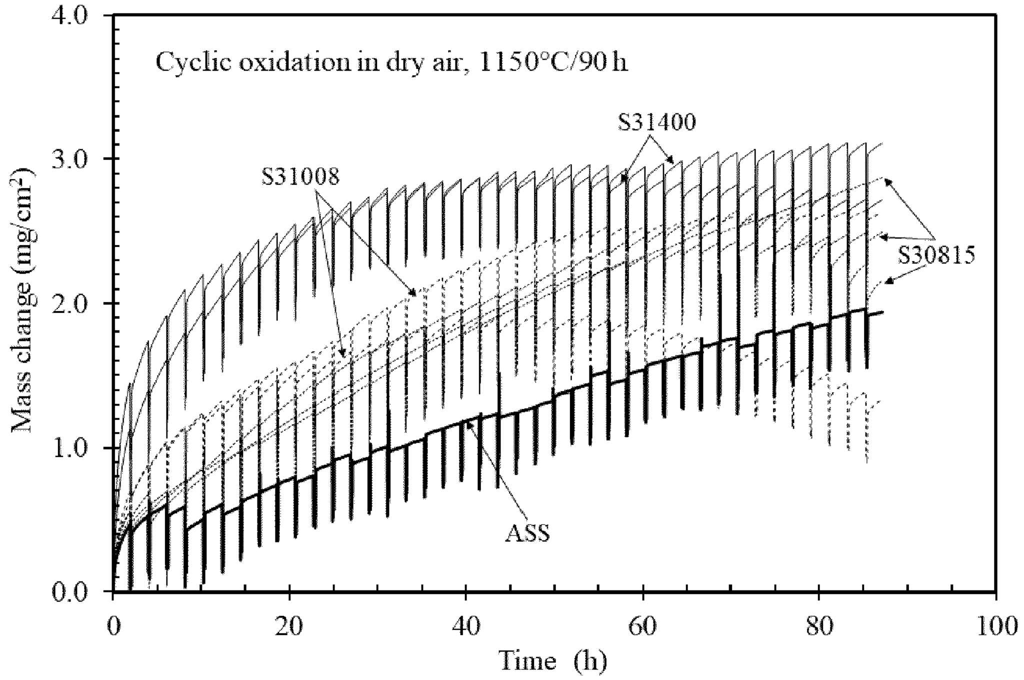
Cyclic oxidation in dry air, 1150°C/90 h
S31400
S31008
S30815
ASS
Mass change (mg/cm²)
Time (h)
4.0
3.0
2.0
1.0
0.0
0
20
40
60
80
100

Fig. 7

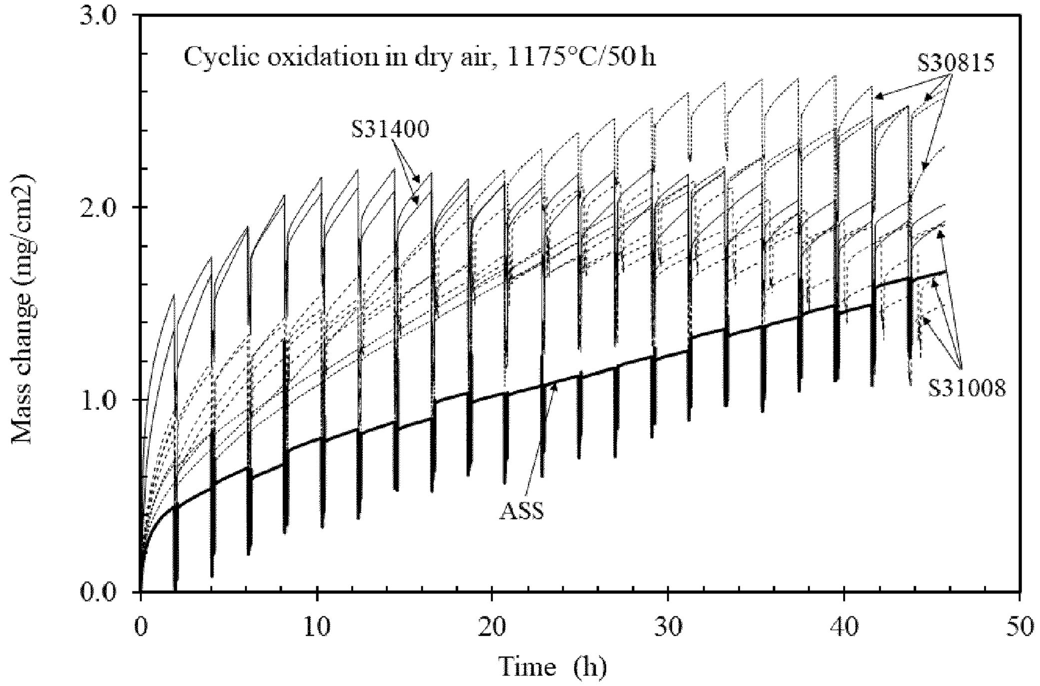
Cyclic oxidation in dry air, 1175°C/50 h
S30815
S31400
S31008
ASS
Mass change (mg/cm2)
Time (h)
3.0
2.0
1.0
0.0
0
10
20
30
40
50

Fig. 8

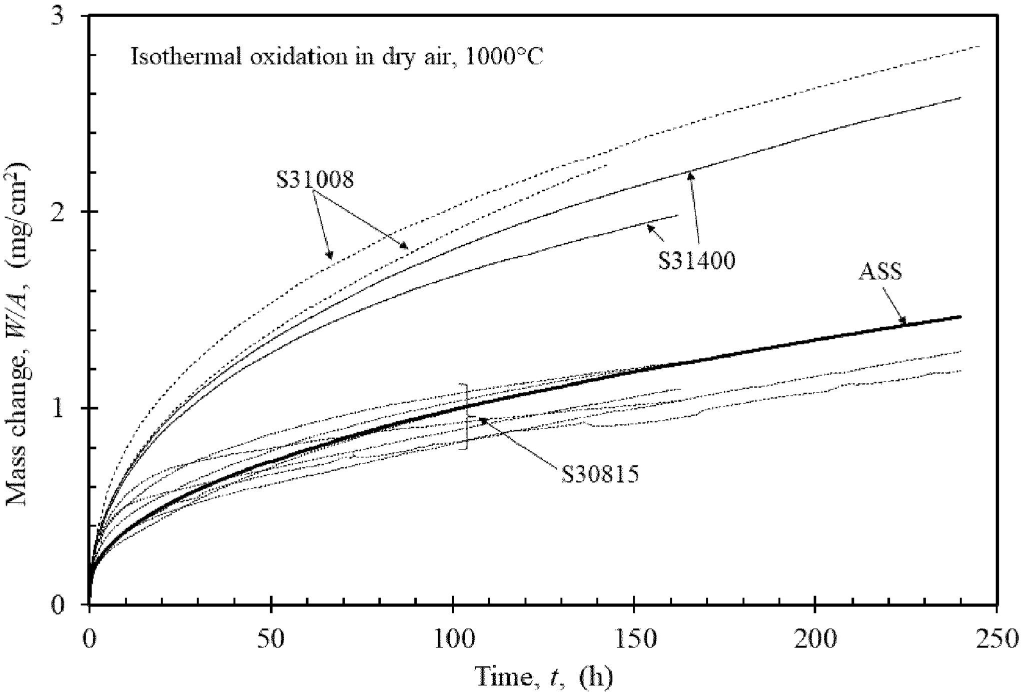
Isothermal oxidation in dry air, 1000°C
S31008
S31400
ASS
S30815
Mass change, W/A, (mg/cm²)
Time, t, (h)
0
1
2
3
0
50
100
150
200
250

Fig. 9

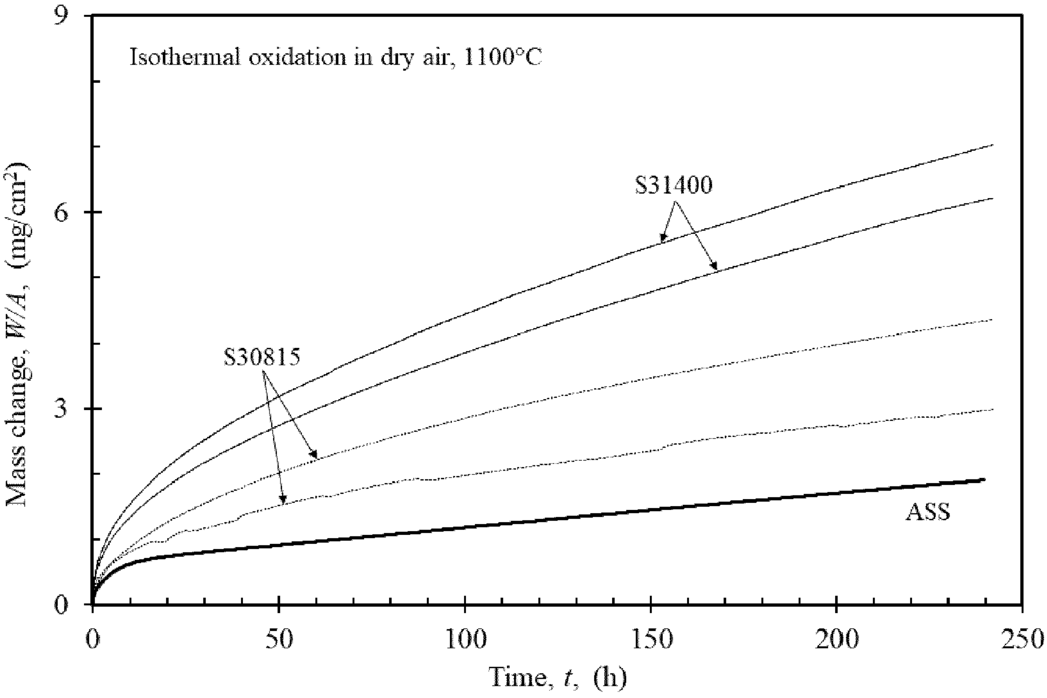
Isothermal oxidation in dry air, 1100°C
S31400
S30815
ASS
Mass change, W/A, (mg/cm²)
Time, t, (h)
0
3
6
9
0
50
100
150
200
250

Fig. 10

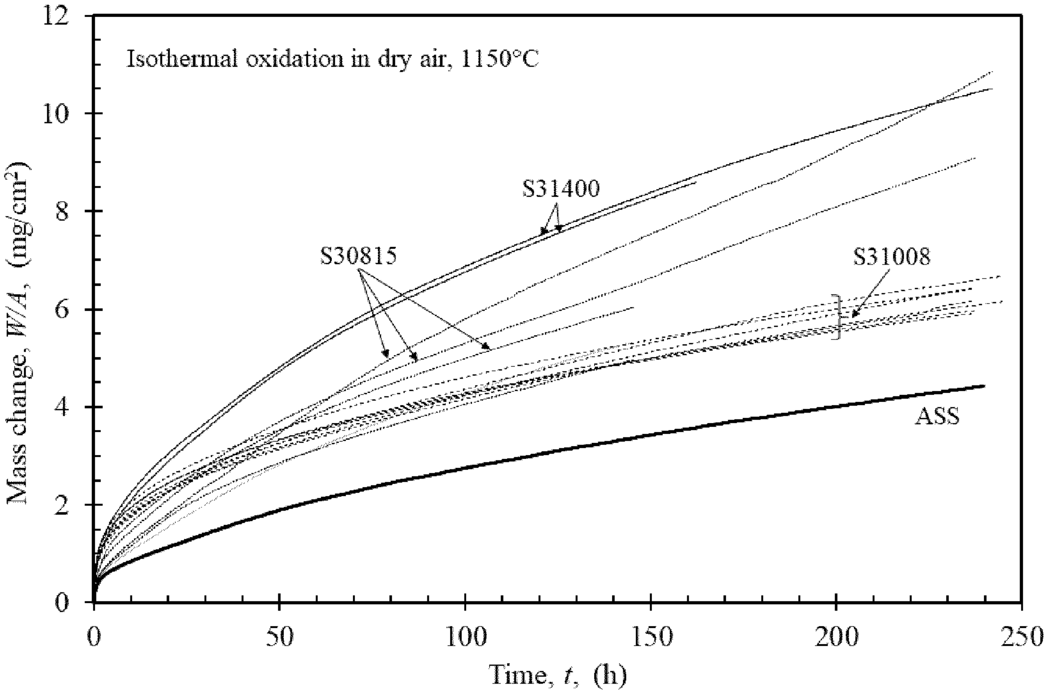
Isothermal oxidation in dry air, 1150°C
S31400
S30815
S31008
ASS
Mass change, W/A, (mg/cm²)
Time, t, (h)
0
2
4
6
8
10
12
0
50
100
150
200
250

Fig. 11

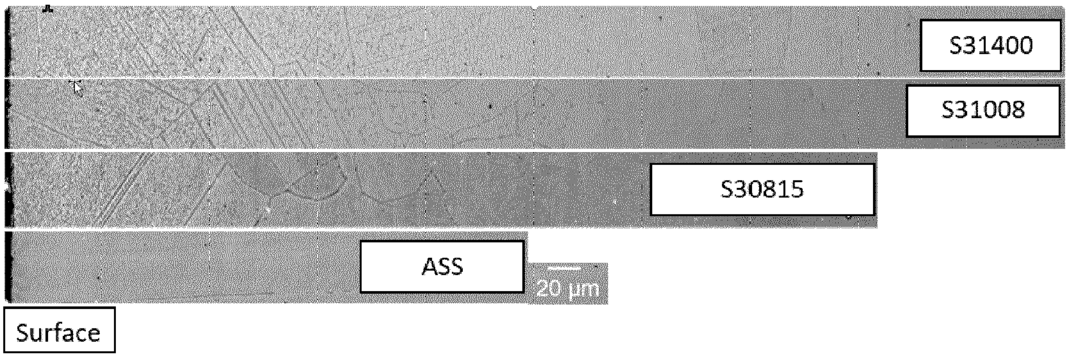
S31400
S31008
S30815
ASS
20 µm
Surface

Fig. 12

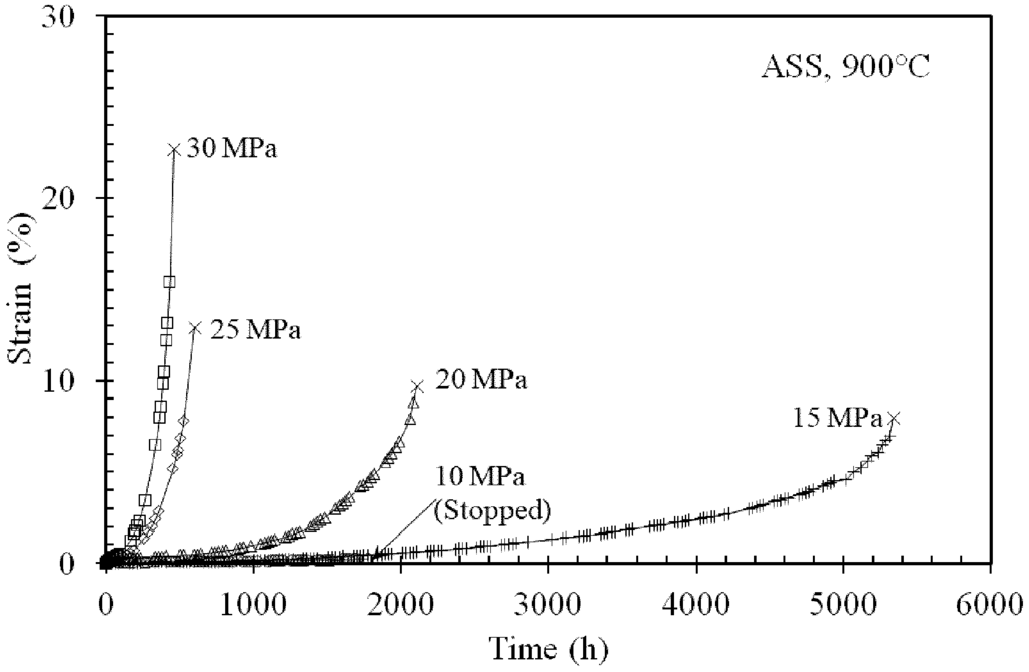
ASS, 900°C
30 MPa
25 MPa
20 MPa
15 MPa
10 MPa
(Stopped)
Strain (%)
0
10
20
30
0
1000
2000
3000
4000
5000
6000
Time (h)

Fig. 13

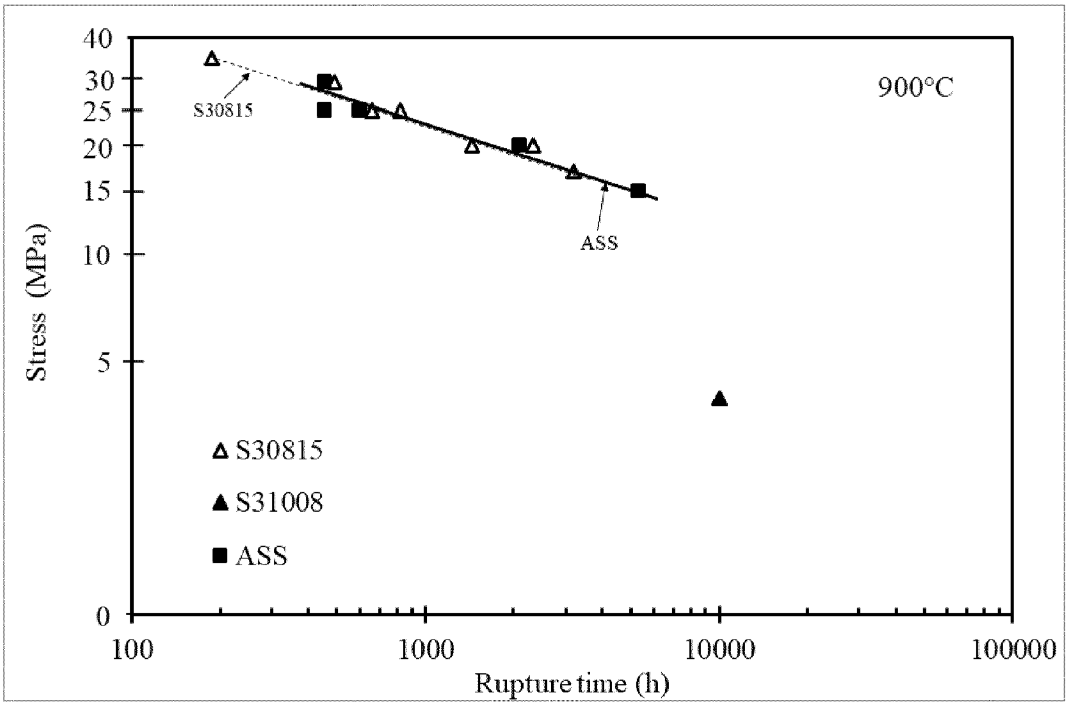
900°C
S30815
ASS
△ S30815
▲ S31008
■ ASS
Stress (MPa)
40
30
25
20
15
10
5
0
100
1000
10000
100000
Rupture time (h)

Fig. 14

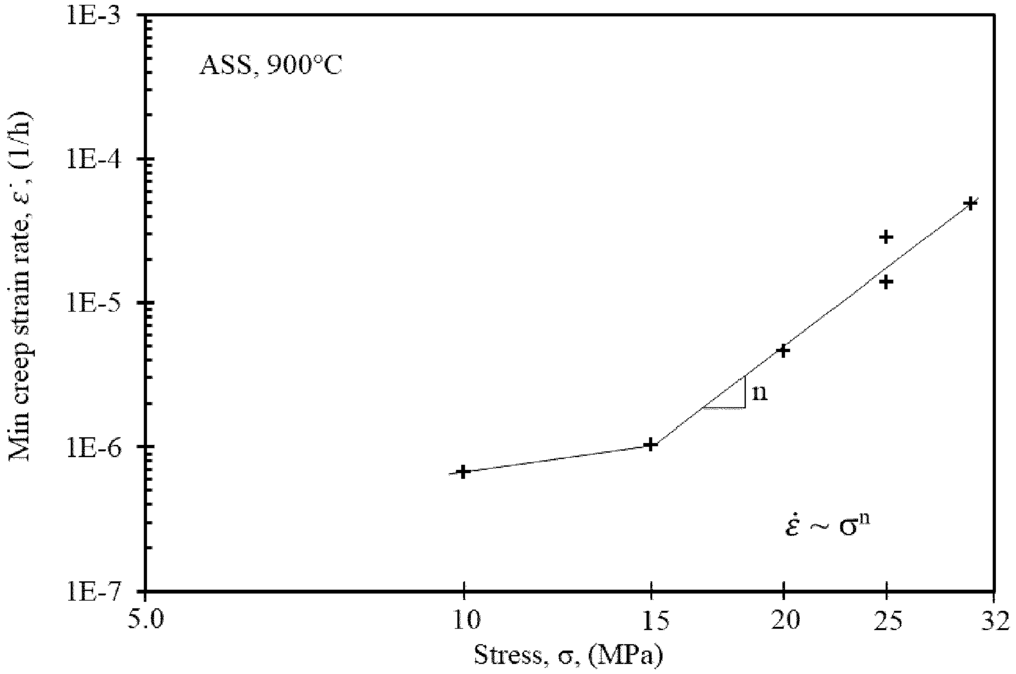
ASS, 900°C
Min creep strain rate, ε˙, (1/h)
1E-3
1E-4
1E-5
1E-6
1E-7
n
ε̇ ~ σⁿ
5.0
10
15
20
25
32
Stress, σ, (MPa)

Fig. 15

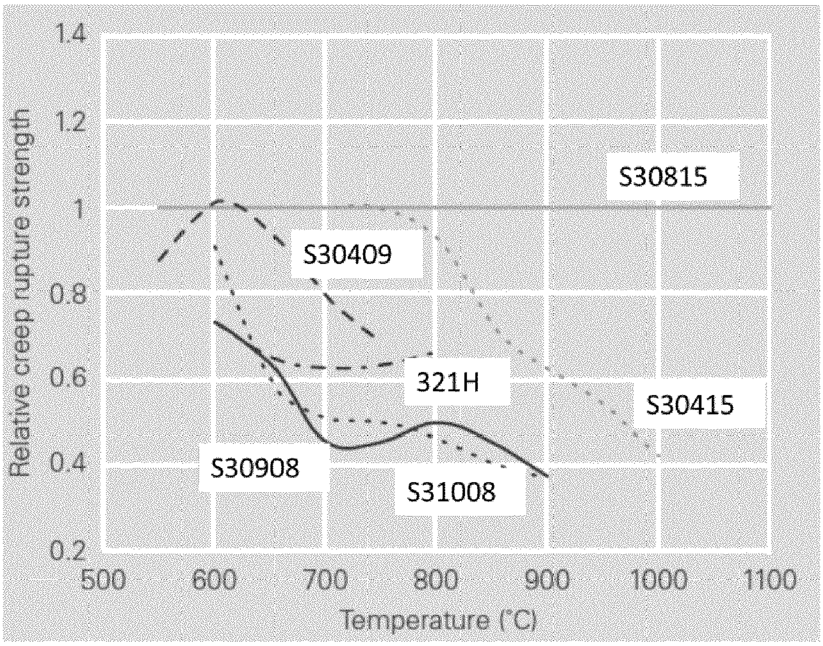
Relative creep rupture strength
1.4
1.2
1
0.8
0.6
0.4
0.2
500
600
700
800
900
1000
1100
Temperature (°C)
S30815
S30409
321H
S30415
S30908
S31008

Fig. 16

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Application Number
EP 20 20 6232

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 5 824 264 A (UNO HIDEKI [JP] ET AL) 20 October 1998 (1998-10-20) * claims 1-12 * * tables 1-5 * * columns 2-10 *	1-16	INV. C22C38/40 C22C38/42 C22C38/44 C22C38/00 C22C38/02 C22C38/04 C22C38/06 C22C38/34 C22C38/58 C22C38/46 C22C38/48 C22C38/50 C22C38/52 C22C38/54 C21D9/46 C21D8/02 C21D9/08
X	US 2008/107559 A1 (NISHIYAMA YOSHITAKA [JP] ET AL) 8 May 2008 (2008-05-08) * claims 1-7 * * paragraphs [0017] - [0117] * * tables 1-2 *	1-16	
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X	US 5 126 107 A (DARNFORS SVEN [SE]) 30 June 1992 (1992-06-30) * claims 1-12 * * tables 1-8 * * columns 2-7 *	1-16	

-/--

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	21 March 2021	Vlassi, Eleni

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Application Number
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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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			TECHNICAL FIELDS SEARCHED (IPC)

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	21 March 2021	Vlassi, Eleni

CATEGORY OF CITED DOCUMENTS

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21-03-2021

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		JP 2004083976 A	18-03-2004

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