

Heat resistance of Fe-Al intermetallics in the context of selected heat-resistant and high-temperature creep resistant steels

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Abstract

Results are hereby presented of heat-resistance tests of two Fe₃Al and FeAl intermetallic phase-based alloys in the context of St41k-type boiler steel and 50H21G9N4 high-temperature creep resistant steel. It has been ascertained that heat resistance of the 50H21G9N4 steel and of the Fe₃Al and FeAl intermetallic phase-based alloys significantly exceeds that of the boiler steel tested in the air atmosphere and the atmosphere of a flue gas with CO, CO₂, SiO₂ content alike. Improvement of these properties depends of exposure conditions. The largest differences have been observed when the tests were carried out in temperature 1023 K and in the flue gas atmosphere. The differences have been more and more noticeable as the exposition duration extended. A tendency has been also recorded of smaller mass decrements of the Fe₃Al and FeAl intermetallic phase-based alloys as compared to the 50H21G9N4 steel.

Key words: Fe-Al type intermetallics, heat resistance, heat resistant and high-temperature creep resistant steels

1. Introduction

Increasing intensity of industrial applications of new engineering materials makes the demand for relevant scientific research still significant. A number of research projects are now in progress concerning development of better and better structural materials capable of meeting stringent engineering requirements [1÷4].

At many world-wide leading scientific centres intensive research has been for many years in progress of a group of engineering materials nicknamed new generation materials. The group of materials includes, among others, alloys based on

intermetallic phases, including Fe-Al type phases. The R&D works in progress have focused mainly on these materials' application in industrial conditions in view of their suitability to replace traditional materials such as heat resistant and high-temperature creep resistant steels. In particular the research addresses the issue of optimisation of the process of intermetallics' manufacturing from the point of view of their properties' stabilisation and repeatability. It is a very difficult task however. Methodical solutions of the issue require profound specialist expertise. Regardless of the above, the development process itself, i.e. production of a very precisely preset chemical and phasing composition additionally requires high level of

engineering skills and very careful implementation of the metallurgic process [5, 6].

Engineering materials used in construction of machinery and equipment are specified with a number of qualitative parameters. And yet in order to confirm a material's quality such parameters must be selected for control tests that are relevant to the respective structure's (its main components') main functionality. And the applied research methodology must be so selected as to reflect the structure's major features [7]. It should be added here that in many cases one of the most important criteria that rule a material's applicability to the structure is feasibility of obtaining high strength properties with concurrent retaining good high resistance performance [8]. This has provided the main premise for the research that is reported hereby.

2. Research methodology

Some selected engineering materials have been subject to the experimental tests, such as: a Fe₃Al intermetallic phase-based alloy (hereafter referred to as No 1.), and a FeAl intermetallic phase-based alloy (hereafter referred to as No 2.). The following two steels have been selected for reference: K41-type boiler steel (No 3.) and 50H21G9N4 steel (No 4.).

The alloys No 1 and No 2 have been produced by way of vacuum remelting of clean powder alloy components. The samples have been cast into special 100x100x80 moulds. Details of the remelting process have been already presented in these authors' earlier papers, [9 ÷10] among others. The intermetallic alloys so produced have been subjected to control tests of their chemical composition – Fig. 1.

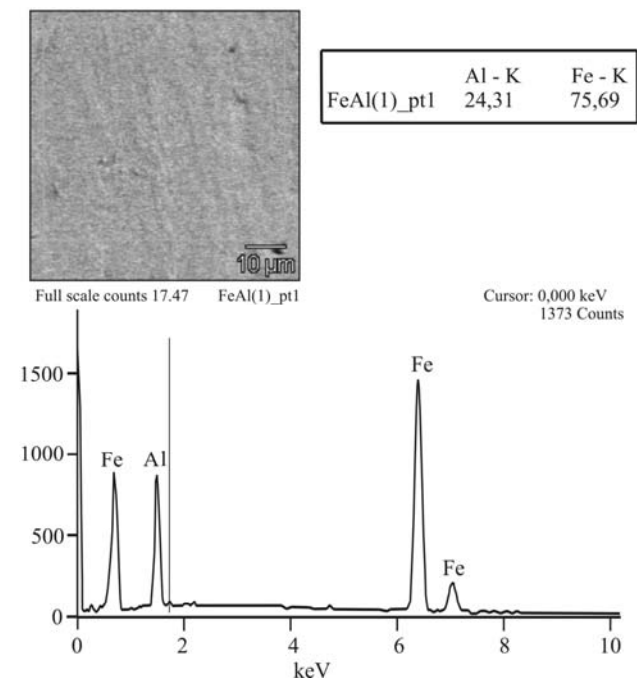


Fig 1. Analysis of Fe₃Al alloy's chemical composition after casting

The samples for heat resistance tests had been prepared by way of material removing processing (grinding), their diameters were 40 mm and thickness ca. 5 mm.

Heat resistance tests of selected alloys and steels were conducted in temperatures 823, 923, and 1023 K in atmospheres of air and the flue gas of an industrial boiler installed at the facilities of Bartosz company in Białystok, Poland for 300 hours. During the experiment, after expiration of preset exposure times, the samples were taken off and changes in their masses were recorded. During the tests, after the samples had been taken out of the furnace, adhesion of the oxide films was also analysed by the qualitative method. Loosely bounded products were brushed off the samples' surfaces (with a soft hair brush) and then such preliminarily cleaned samples were subject to the process of washing in an ultrasound washer. The testing procedures have been already described in details, in [8, 11, 12] among other publications.

3. Test results

Literature details [12] indicate that there are many types of engineering materials' possible behaviour in increased and high temperatures. The most common symptom of the oxidation process is an increment of the sample's mass resulting from production of an oxides layer. Sometimes the oxide layer so produced during the process may be spalling off, which is recorded as a decrement of the sample mass. Regardless of the composition's behaviour during the process of heating the material however, its mass ultimately decreases – Fig. 2. Intense accretion of the oxide layer in the beginning of the oxidation process followed by its stabilisation resulting in constant decreasing of the mass loss increment down to zero is commonly considered the most advantageous behaviour of the material.

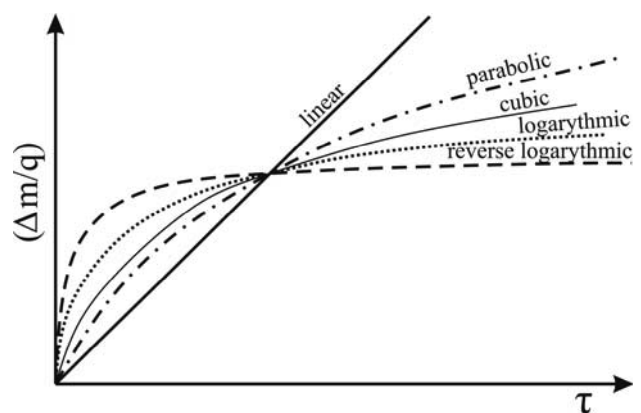


Fig. 2. Metal oxidation process [10] (Δm – mass gain of bound oxidant, q – metal sample surface, τ - time)

Preliminary reconnaissance tests had confirmed that the oxidation process of the materials selected for the research was relatively complex. This has been reconfirmed by relatively large fluctuations of the sample mass changes' intensity during the heat resistance tests. Also literature details indicate large complexity of

the oxidation process, in particular changes in its kinematics within the temperature range adopted by these authors for the tests (823 – 1023 K) and the oxidation kinematics' dependence of the experiment duration -12 – 15].

Changes in the mass of the samples tested in temperature range 823 – 1023 K in atmospheres of air and of flue gas are presented on Fig. 3, 4.

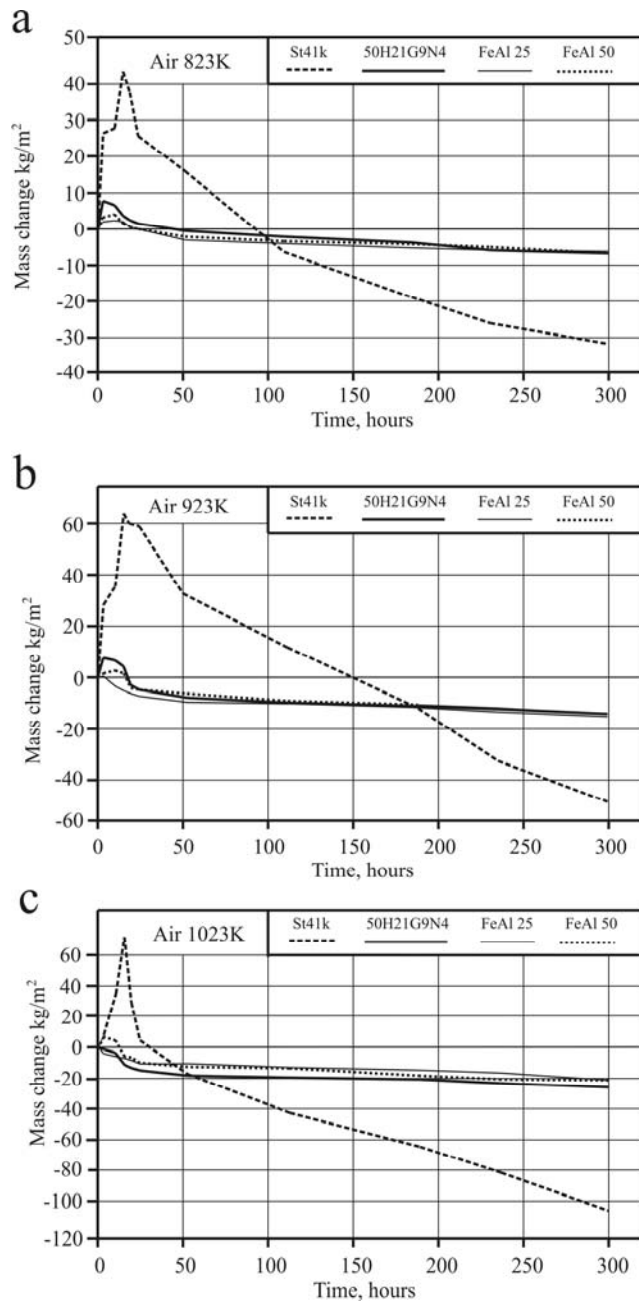


Fig. 3. Changes in mass of samples tested in air atmosphere in temperatures: a – 823 K, b – 923 K, c – 1023 K

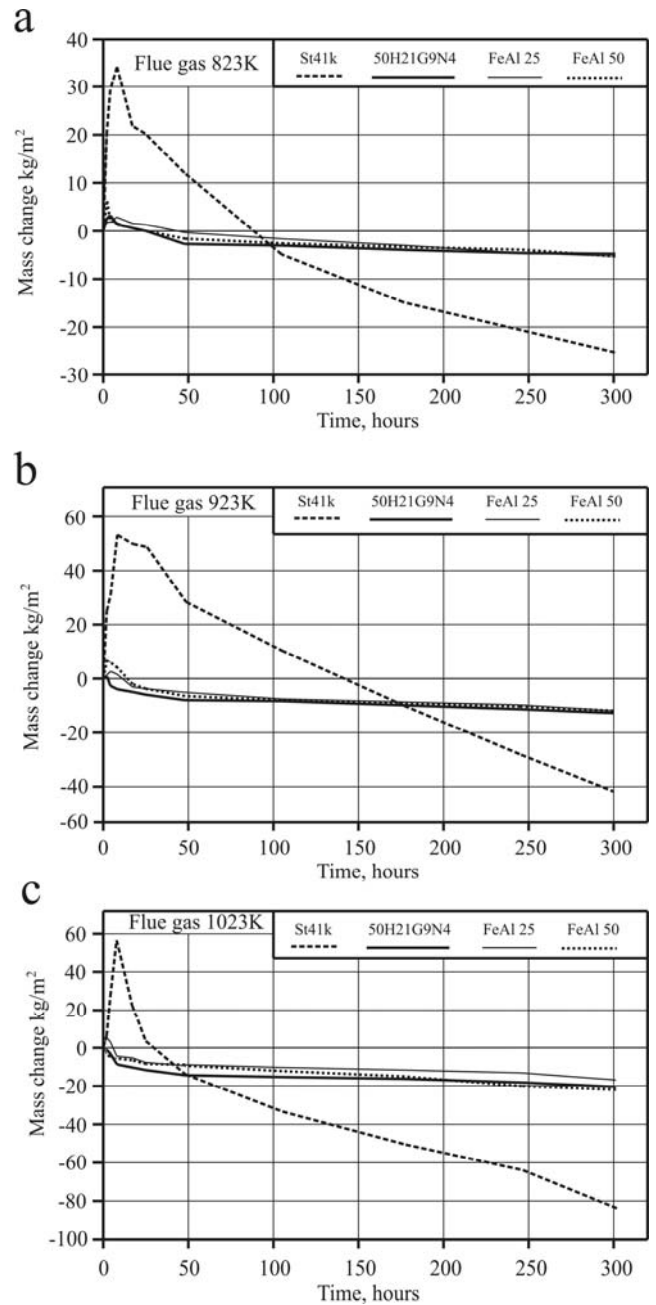


Fig. 4. Changes in mass of samples tested in flue gas atmosphere in temperatures: a – 823 K, b – 923 K, c – 1023 K

Analysis of the results indicates that oxidation of St41k boiler steel definitely differs from those of 50H21G9N4 steel and of the FeAl and Fe₃Al intermetallic phase-based alloys. At the oxidation initiation stage the St41k steel samples were gathering a scale layer and absorbing corrosion-supportive substances from the surrounding atmosphere, which resulted in the samples' evident mass gains. As time went by the process intensified, while

the scale so gathered was subject to adhesive exfoliation – especially during the cycles of temperature changes caused by the need to take the samples out and to measure their masses. The foregoing mechanism caused a definitely larger loss of the mass of St41k steel samples compared to the other materials.

The mass changes of 50H21G9N4 steel and of the FeAl and Fe₃Al intermetallic phase-based alloys tested in temperature range 823 – 1023 K were similar. This concerns the tests carried out in both atmospheres, of air and of the flue gas. Nevertheless an obvious tendency has been observed of slightly larger mass losses of 50H21G9N4 samples than those of the intermetallic alloys, especially in 1023 K. This concerns the tests in the both atmospheres.

4. Recapitulation

The test results allow formulation of the following final conclusions:

1. Mass loss of St41k boiler steel tested in temperature range 823 – 1023 K was definitely larger than those of 50H21G9N4 steel and of the Fe-Al alloys.
2. Unit mass changes of 50H21G9N4 steel, and of the FeAl and Fe₃Al intermetallic phase-based alloys tested in temperature range 823 – 1023 K were comparable in the atmospheres of air and of the flue gas alike.
3. A tendency was however recorded of increased heat resistance in the tests carried out in the atmospheres of air and of the flue gas alike in temperature range 823 – 1023 K for the intermetallic phase-based alloys, especially as regarded the FeAl alloy.

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5. Literature

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