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Hot rolling of intermetallics FeAl phase based alloys

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ABSTRACT

Purpose: The one of major problem restricting universal employment of intermetallic phase base alloy is their low plasticity which leads to hampering their development as construction materials. The following work concentrates on possibilities to form through rolling process the alloys with various aluminium content.

Design/methodology/approach: After casting and annealing, alloy specimens were subjected to axial-symmetric compression at temperatures ranging from 900 to 1200°C at 10 s-1 strain rates. In order to analyse the processes which take place during deformation, the specimens after deformation were intensely cooled with water. Structural examination was carried out using light microscopy. The process was conducted on the K -350 quarto rolling mill used for hot rolling of flat products. The process was conducted in some stages in at temperatures ranging from 1200-900°C:

Findings: The research carried out enabled the understanding of the phenomena taking place during hot rolling of the investigated alloy. An alloy with 38%at. aluminium concentration can be plastically formed at a temperature of up to 900°C, which has been also confirmed in plastometric studies conducted in the form of hot compression tests.

Research limitations/implications:

Practical implications: The obtained sheets can be used as constructional elements working in complex stress fields, at a high temperature and corrosive environments

Originality/value: The tests have shown that it is possible to form the investigated alloys through rolling processing only where shields are applied. Rolling of the alloys without shields led to the occurrence of a grid of cracks.

Keywords: Plastic forming; Iron aluminides; Hot rolling; Microstructure

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Alloys based on the intermetallic phases from the Fe-Al system belong to a group of high-temperature creep resisting materials with advantageous physicochemical and mechanical properties at an elevated and high temperatures [1-4]. The position of alloys representing the Fe-Al system against other constructional materials is increasingly better as the research on the capacities for their fabrication and application advances. Properties Fe-Al alloys, such as: low density, high melting temperature, high strength and good oxidizing resistance, coupled with good crack resistance, create wide prospects for their industrial applications, for components of machines working at a high temperature and corrosive environment [6-9].

In general, limitation on the capacity for a broad application of Fe-Al intermetallics system, e.g. as an alternative to expensive alloy steels of specific properties, is their insufficient plasticity, which is a factor inhibiting further their development as constructional materials [10,12].

The following work concentrates on possibilities to form through rolling process the alloys with various aluminium content. The materials for the research were cast specimens were characterized by contents of 38%atAl and 42%at.Al with additional of Zr, B and C. The displayed results may form the basis for designing the technology of plastic working of the investigated alloy.

The obtained sheets can be used as constructional elements working in complex stress fields, at a high temperature and corrosive environments.

2. Research methodology

2.1. Research material

The bars composed of intermetallic-phase-based Fe-Al alloy, whose chemical content is presented in Table 1, were chosen as the material for the research. The alloy was prepared by casting in graphite forms. The following contents were used for smelting: ARMCO iron, aluminium 99,98% wt. minimum, amorphous boron and technically pure molybdenum powder compact. Having undergone the casting, the samples were annealing at 1000°C for 48h with furnace cooling.

Table 1.
Chemical composition of the investigated alloy (at.- %)

Al	Zr	C	B	Fe
38	0.05	0.10	0.01	61.84
42	0.05	0.10	0.01	57.84

2.2. Plastometric compression test

Following the annealing, the material was used for the preparation of the samples for the compresion test, which consisted of axisymmetrical strain on GLEEBLE 3800 simulator, with simultaneous structure-freeze by rapid quenching. The compression sampless were deformd at temperatures ranging from 700 to 1200°C at a rate of $\dot{\varepsilon}$ =10s^{-1}. The methodology was described in papers [13,14].

2.3. Hot rolling

Cast specimens, 20 mm in height and 40mm in width, were used as an initial material for the hot rolling process . The process was conducted at the Institute of Modelling and Control of Forming Processes in the Czech Republic on the K 350 quarto rolling mill used for hot rolling of flat products [15]. The process was conducted in the following stages:

- preliminary rolling at a temperature of 1200-1100°C with the use of ferritic steel spacers separating cold rollers from the rolled material, with a 20% draft in each pass;
- rolling at a temperature of 1100-1000°C in a ferritic steel shield separating cold rollers from the rolled material, with a 20% draft in each pass;
- finishing rolling was conducted at a temperature of 1000°C, with applying 25% reverse drafts and interoperation annealing;
- finishing rolling, forming the microstructure at a temperature of 900°C, with applying 25% reverse drafts and interoperational annealing (for the Fe-38%Al alloy only) and cooling in oil after the last pass;
- annealing for 30 minutes at 800°C.

The calculated strain rate during rolling amounted to 10s^{-1}.

3. Results

The microstructures of the cast and heat treated alloys are shown in Fig. 1, 2. The alloy composed of Fe-38% Al and Fe-42% Al with an intermetallic FeAl phase matrix had a single-phase, coarse-grained structure, with a comparable grain size of 220μm and 205μm, respectively.

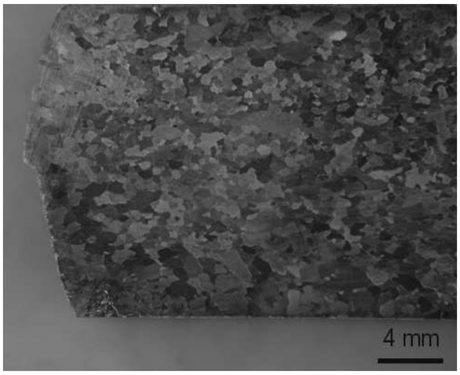

Fig. 1. Cross section of the ingot with Fe-42%at. Al alloy after casting (20 mm in height / 40mm in width)

The axisymmetrical hot compression tests made for the studied alloys with type B2 structure and aluminium content in the range from 38 to 42at.-% enabled determining the flow curves in the stress-deformation system (Fig. 2 and 3). A wide range of deformation strengthening with a diversified course was identified, depending on the temperature. The obtained compression tests results show that an increase of the deformation temperature in the range of 900-1200°C entails an intensive decrease in the maximum yield stress σ_p, causing at the same time a decrease in the corresponding strain ε_p, which, in consequence, leads to fast strengthening of the alloys. A higher flow resistance was found for the alloy with a 42 at.-% aluminium content at a deformation temperature of 900 and 1000°C. The alloy samples' compression at a temperature of 900°C and strain rate of 10 s^{-1} to a strain ε= 1 led to the sample's cracking on the lateral side of the barrel being formed for the alloy with a higher aluminium concentration.

Based on the structural studies carried out [2], the processes taking place in the orderly alloys' structure during high-temperature deformation were detected. The determination of the technological plasticity as well as structural studies enabled selecting the optimal rolling conditions.

Rolling on the quarto rolling mill proceeded in several stages. Both the studied alloys were subjected to the first stage of rolling, during which ferritic steel spacers were used. The application of the spacers was indispensable since first trials demonstrated a grid of cracks on the surface, even in the case of minor deformations. (Fig.4).

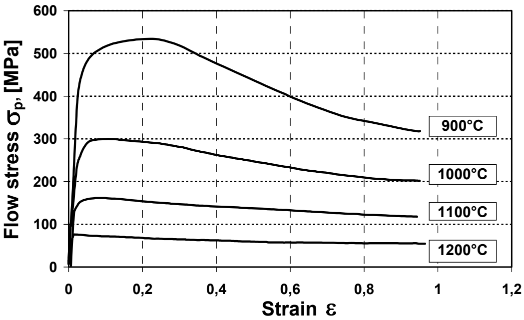

Fig. 2. The stress-strain curves of Fe-38%Al alloy deformed at the strain rate $10s^{-1}$

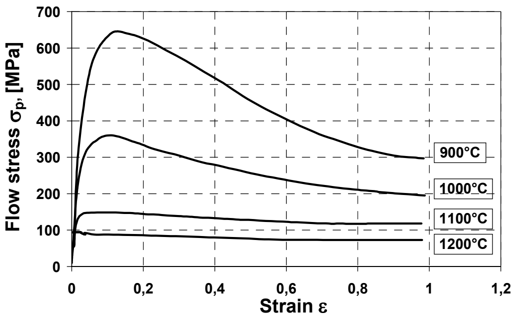

Fig. 3. The stress-strain curves of Fe-42%Al alloy deformed at the strain rate $10s^{-1}$

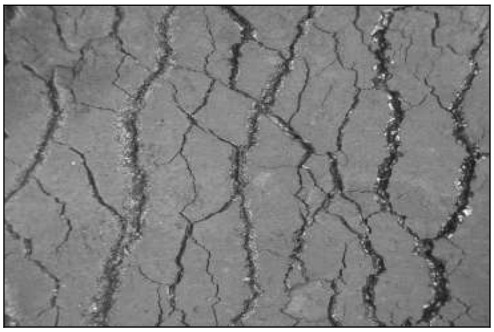

Fig. 4. A grid of cracks on the surface of of hot rolled alloy at a temperature of 1200-1100°C at alloy without spacers

The spacers separated cold rollers from the alloys' surface. The first stage in a temperature range of 1200-1000°C, with applying two reverse drafts, enabled reducing the height by 50% (10mm) 10 s^{-1}. At this stage of rolling, no cracks were identified on the external surface of the sheet.

Further deformation was performed using a complete shield made of ferritic steel sheets. The application of a lower process temperature (1100-1000°C) caused material cracking on its lateral surfaces, while longitudinal surfaces, protected by the shield, were free of any defects.The strips rolled at 1100-1000°C with a 50% total draft (5mm sheet) are shown in Figure 5. The effect of this stage of rolling for both the studied alloys were microstructural changes in the form of grain size reduction caused by the recrystallization process (Fig. 6).

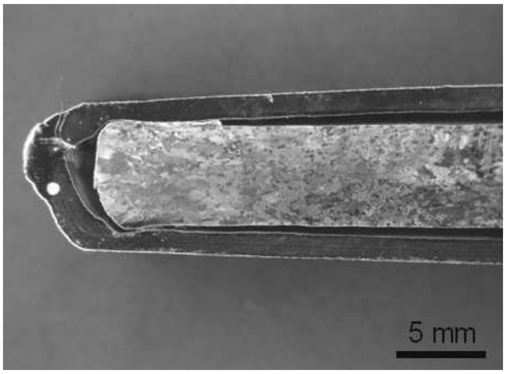

Fig. 5. Cross section of the flat with Fe-42% at. Al alloy after rolling with ferritic steel shield at temperature 1100-1000°C

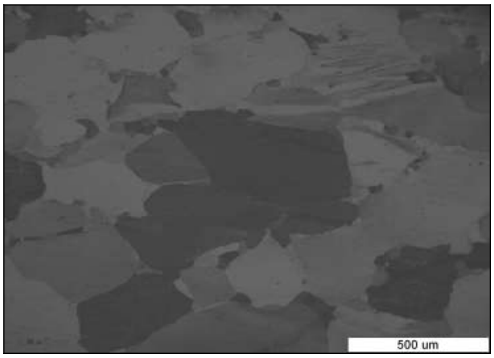

Fig. 6. Structure of the sample from Fe-42 %at.Al alloy after rolling at 1100-1000°C with air cooling

Next deformation was performed at a temperature of 1000°C, with reducing the height to 2.5mm. That stage of rolling brought positive results for the Fe-38% Al alloy only. The alloy with a higher aluminium concentration showed cracks, indicating the necessity of its rolling at a higher temperature. A flat bar of the Fe-38% Al alloy was subjected to further deformation at a temperature of 1000°C to a thickness of 2 mm. Consequently, a further grain size reduction was obtained.

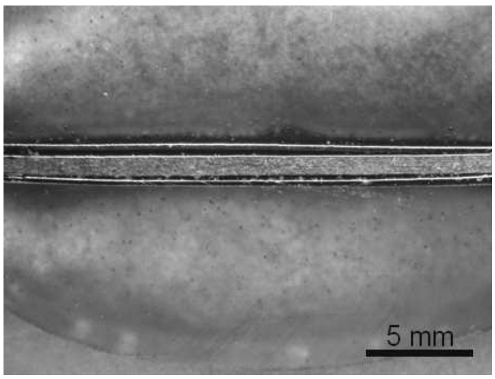

Fig. 7. Cross section of the flat with Fe - 38%at. Al alloy after rolling with ferritic steel shield at temperature 900°C

The finishing rolling of the alloy with a 38% Al content, forming the microstructure, was conducted at a temperature of 900°C using 25% reverse drafts and interoperation annealing. The obtained final sheets (Fig. 7), 1 mm in thickness , had no cracks and were characterized by a fine-grain structure with average grain size 56µm (Fig. 8).

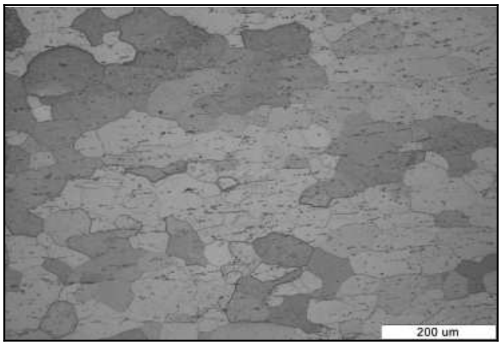

Fig. 8. Structure of the sample from Fe-38%at.Al alloy after rolling at 900°C with annealing at 800°C per one hour

4. Conclusions

Specimens of FeAl phase-based alloys were subjected to hot compression, which enabled determining the influence of hot deformation parameters on the materials' technological plasticity and structure. An analysis of the compression process indicates a significant increase in flow resistance at a temperature of 900°C and rate of 10 s^{-1} as well as cracking of the alloy with a 42% aluminium content in case of a considerable strain. Similar results are observed for the Fe-38% alloy after compression at a temperature of 800°C. This prevents forming these alloys at lower temperatures, at a strain rate during rolling of ca. 10s^{-1}. The necessity of applying high rates results from the technical capacities of rolling mills.

The tests have shown that it is possible to form the alloys through thermoplastic processing only where ferritic steel shields of appropriate thickness are applied. Rolling of the alloys without shields led to the occurrence of a grid of cracks. An alloy with a lower aluminium concentration can be plastically formed at a temperature of up to 900°C, which has been also confirmed in plastometric studies conducted in the form of hot compression tests. Thus, there seems to be a capacity for improvement of the studied alloy's properties by means of thermoplastic treatment.

The obtained 1 mm thick sheets can be used as constructional elements working in complex stress fields, at a high temperature and corrosive environments.

Acknowledgements

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