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Kinetics of static recrystallization in the coarse-grained Fe–40 at.%Al–Zr–B alloy

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ABSTRACT

The aim of works was to describe mathematically the kinetics of static recrystallization of the alloy type Fe–40 at.%Al–Zr–B (with 24.6 Al–0.01 B–0.18 Zr–0.01 C in wt.%) with the coarse-grained structure. The microstructure of the laboratory castings made of this extremely brittle alloy was homogenized by hot rolling of the material in the protective capsules and by the long-term annealing at 1200 °C. An initial microstructure with average grain size 0.77 ± 0.27 mm was obtained. Based on the isothermal plastic deformation tests and EBSD analysis, the static recrystallization kinetics of the prepared coarse-grained B2 iron aluminide after strain 0.20 was mathematically described. Recrystallized fraction depends on deformation/annealing temperature (900–1100 °C) as well as on annealing time. The activation energy of static recrystallization was calculated as 255 kJ mol^{-1}. Competition between dynamic recovery and static recrystallization was proved after strain 0.35 and annealing temperature 1100 °C. Static recrystallization starts relatively easily in the studied alloy, but a very long-term annealing is quite necessary for the complete course of recrystallization. The mean size of recrystallized grains falls with the decreasing annealing temperature (0.47 ± 0.15 mm for temperature 1100 °C, and 0.22 ± 0.04 mm for 900 °C). Even at a temperature of 1200 °C the annealing after deformation should last approx. 1 min for obtaining the fully recrystallized microstructure. That is why the standard hot forming technologies should be combined by an interpass annealing in order to refine sufficiently the coarse grains.

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1. Introduction

Iron aluminides are potential replacements for heat-resistant steels due to their excellent high-temperature oxidation-corrosion resistance in aggressive environments [1]. They usually offer low density and potentially lower cost than stainless steels. The amount of aluminium present in aluminides (from 10 to 30 wt.%) is significantly higher than the aluminium concentrations present in conventional alloys and superalloys. The alumina layer formed on the surface of the materials is responsible for their excellent oxidation and carburization resistances even at temperatures over 1000 °C [2,3]. As a result, iron aluminides found their application e.g. as transfer rolls in hot strip rolling mills and air deflectors for burning high sulphur coal [4]. Larger expansion of iron aluminides is so far impeded by difficulties at their processing by conventional forming methods. From this perspective, the situation is better in the case of Fe_3Al type aluminides, enabling complex thermomechanical processes comprising hot forging, hot rolling, warm rolling and annealing producing grain refinement [5–10]. The hot workability of B2 iron aluminides (i.e. FeAl type alloys typically with 40 at.%, i.e. with approx. 24 wt.% Al) is much more problematic. These alloys are extremely susceptible to crack formation in the surface areas cooled by contact with the forming tool [11,12]. Generally, this behaviour can be attributed to the widely known bad grain boundaries cohesion at low temperatures and its additional lowering by atmosphere – hydrogen embrittlement – in B2 ordered alloys. These troubles with formability, which are evident particularly in the as-cast condition, are in laboratory conditions eliminated for example by resistant heated anvils at uniaxial compression [13]. The method of hot rolling in the sheathing [14] or protective capsules (welded of stainless steel with similar hot deformation behaviour [11,12,15,16] seems to be very promising.

Various powder methods thus bypass both the reason of the poor grain boundary cohesion and the reason of the easy crack spreading – the first mentioned by lowering the degree of long-range order and the second by reducing the grain size in compacted powders, which lowers the area of the brittle grain boundary. The use of hot extruded alloy powders produced by the gas-atomization or water-atomization techniques and subsequent hot extrusion was tested by many authors – see e.g. [17]. The best process was the water atomization followed by hot extrusion in steel cans [18], which was improved by special processes of compaction and cold rolling [19]. This process allows the cold rolling of thin sheets [20].

Interesting results were achieved by application of the shock-wave explosive deformation [3]. Additions of zirconium and boron improve tensile properties of the Fe-40 at.%Al-based intermetallic alloys at the room and elevated temperatures. The increase of the boron content changed the fracture mode from intergranular decohesion to cleavage, which correlates with significant increases in the fracture toughness. Boron was also found to increase the grain boundary strength and modify the formation of the second phase particles [21,22].

The aim of works was to describe mathematically the kinetics of static recrystallization of the alloy type Fe–40 at.% Al–Zr–B with the coarse-grained initial structure. The knowledge of such mathematic relation would be useful e.g. in the optimization of the rolling process of this material and the effective grain refining by repeated recrystallization.

2. Material for the research

The original objective was to study the kinetics of static recrystallization of the as-cast alloy Fe 40 at.%Al–Zr–B using the isothermal plastic deformation experiments and structural analyses. Iron aluminide with the average chemical composition 24.6 Al–0.04 Cr–0.01 B–0.18 Zr–0.01 C–0.14 Mn–0.01 Mo (remainder Fe–all in wt.%) served as experimental material. In the first stage [23], the cylindrical samples with diameter 10 mm and height 12 mm were manufactured directly from central parts of the laboratory castings of the cross section of approx. 19.5 mm (thickness) × 33 mm (width), prepared in the vacuum induction furnace. In spite of the application of the ultrasound vibrating mould during casting and solidification [24] the resulting cast structure was quite heterogeneous, mostly also very coarse-grained, with distinct dendrites (Fig. 1).

Heterogeneity of the initial cast structure caused fundamental problems at the subsequent structural analysis of samples after their uniaxial compression and isothermal annealing, especially in the quantification of the recrystallized grains fracture. For that reason, we tried to homogenize the initial structure by high-temperature annealing of the hot-formed laboratory castings [15]. The castings were covered by protective capsules welded of the ferritic stainless steel sheet and hot rolled to 2/3 of their thickness by 4 height reductions with the interstage heating. The heating temperature, as well as the interstage heating in the furnace after the second pass lasting 45 s, was 1200 °C. Free cooling of the rolled products was followed by the homogenization annealing of their cuts in a vacuum furnace heated to a temperature of 1200 °C. The structure after the high-temperature annealing lasting 7 h (Fig. 2) is the result of static recrystallization across the whole volume of the rolled product and the subsequent coarsening of the fine recrystallized grains in the surface areas. We have thus succeeded in achieving the sufficiently homogenized structure, although at the cost of partial grain coarsening. The

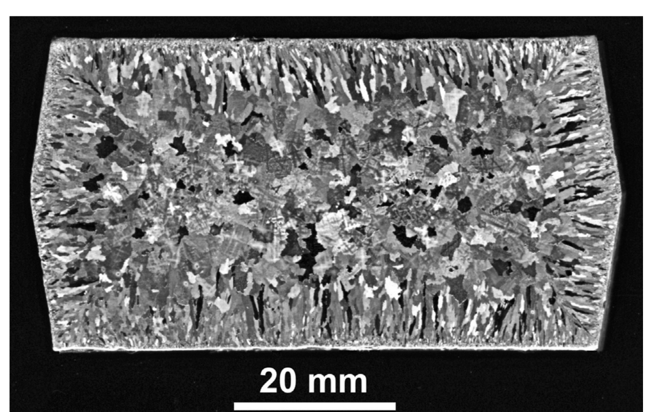

Fig. 1 – Heterogeneous macrostructure of the initial casting (complete cross section).