氏名	吉見享祐（よしみ きょうすけ）
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論文審査委員	東北大学教授 花田 修治　東北大学教授 及川 洪 東北大学教授 丸山 公一

論文内容要旨

Chapter 1 Introduction

In this doctoral dissertation, anomalous strengthening behavior and its mechanism in B2-type FeAl have been investigated. Since mechanical properties of this aluminide are strongly affected by excess vacancies, as mentioned in chapter 1, the influence of the excess vacancy strengthening has to be distinguished from apparent mechanical properties for understanding intrinsic strength and deformation behavior of B2－type FeAl. Furthermore, structural details on lattice defects and their roles on strength and deformation behavior should be experimentally clarified. The author could successfully give a common understanding for mechanical properties of B2-type FeAl through this study.

Chapter 2 Effect of Excess Vacancies on Hardness and Tensile Properties of Polycrystalline B2-type FeAl

Effects of excess vacancies on hardness and tensile properties of B2－type FeAl at elevated temperatures were investigated using polycrystals. Polycrystalline sheets containing 40 and 46mol% aluminum were prepared by arc-melting and hot-rolling. They were recrystallized at 1123K, and then air-cooled to room temperature. A part of those was further annealed at 713K to eliminate excess vacancies. Both the air-cooled and the vacancy-eliminated Fe-46mol% Al exhibit a negative temperature dependence of yield stress. In contrast, the vacancy-eliminated Fe-40mol% Al shows a positive temperature dependence of yield stress,so-called “strength anomaly”, between 673 and 873K, although the air-cooled Fe-40mol% Al shows a strong negative temperature dependence of yield stess. This result indicates that the strength anomaly is obscured by the excess vacancy strenthening. The difference in the yield stress between the air-cooled and the vacancy-eliminated specimens disappears at and above 873K for both Fe-40 and 46mol% Al alloys.

Chapter 3 Yielding and Plastic Flow Behavior of B2-type Fe-39.5mol% Single Crystals in Compression

Yielding and plastic flow behavior of B2 − type Fe-39.5mol% Al single crystal were investigated in the temperature range from room temperature to 1073K. Yield stress exhibits a distinct positive temperature dependence followed by a peak for all the orientations examined. The temperatures of the anomalous peak are located between 823K and 873K for all the orientations except near-<111> orientation. Only for the near-<111> orientation the peak temperature is located between 773K and 823K. Yield stress and critical resolved shear stress (CRSS) at 773K exhibit a strong orientation dependence. The larger the value of χ or ξ is, the higher the yield stress is for all the orientations examined except near-<100> orientation. The slip transition from<111> direction at low temperature to <100> at high temperature occurs around the peak temperatures. Specimens having compression axes of $\chi \geq 0°$ exhibit serrations in stress-strain curves below the peak temperatures, whereas serrations are not observed in those of $\chi < 0°$. In addition, a yield drop is observed around but above the peak temperatures for all the orientations examined. Below the peak temperatures, the yield stress hardly depends on the applied strain rate. This indicates that the motion of <111>-type superdislocations has very small strain-rate sensitivity in the temperature range. On the other hand, there is a strong strain-rate dependence at the peak temperature and above, indicating that the motion of <100>-type dislocations is strongly rate sensitive.

Chapter 4 Tensile Properties of B2-type Fe-39mol% Al Single Crystals at Elevated Temperature

Tensile properties of B2-type Fe-39mol% Al single crystals were investigated between room temperature and 923K. Positive temperature dependence of yield stress was also observed in all the orientations examined. Orientation-dependent phenomena in the temperature range where yield stess increases with temperature (stage II) viz., orientation dependences of yield stress and CRSS, peak stress and peak temperature, and serrated flow behavior, show trends opposite to those in compression obtained in chapter 3. Based on the results, it is concluded that those orientation-dependent phenomena represent intrinsic characteristics of deformation behavior associated with the strength anomaly. Elongation of more than 30% is obtained at room temperature for the orientation situated near center of the standard unit triangle, indicating B2 FeAl is intrinsically ductile.

Chapter 5 Transmission Electron Microscopic Observation of Thermally-introduced Planar Faults in Fe-35mol% Al Alloys

Thermally introduced planar faults were investigated both in an Fe-35mol% Al binary alloy and in B, Cr, Pd and W added ternary alloys using a transmission electron microscope. Air cooling of the alloys from 1273K followed by annealing at 698K for 120h introduces two types of planar faults. One type is the anti-phase boundary (APB), which is observed in all of the alloys. The other is the complex planar fault (CPF) having APB and stacking fault (SF) characters, which is observed in only the B- added alloy. The formation of the observed APBs is envisaged to be caused by a collapse of the lattice owing to vacancy condensation on *triple* layers of {111} planes. The APB formation on {111} planes is energetically reasonable becauase the energy surface calculation by Flinn predicted that the APB energy of the {111} plane is minimum. The size, distribution and planarity of the APBs are affected by the ternary element addition. The planarity of the APBs is reduced by the Cr addition, but enhanced by the Pd and W additions.

Chapter 6 TEM Observation of Deformation Microstructure in B2-type Fe-39.5mol% Al Single Crystals

Deformation behavior and microstructures associated with the strenght anomaly were studied using Fe-39.5mol %Al single crystals. It was found that, in the temperature range where yield stress increasse with temperature (stage II), the strain-rate sensitivity parameter estimated through compressive strain-rate change tests is almost zero, whereas the relaxation stress obtained by stress relaxation tests increases with increasing temperature. These results mean that a recovery process is gradually activated with temperature in this temperature range. By TEM observation, the dominant operative slip direction within a small strain comarable to a yield point was confirmed to be of <111>even at a peak temperature, whereas the slip direction drastically changes to <100>beyond the strain. Hence, the author concludes that the increase in yield stress with temperature in stage II is attributed to the temperature dependent barriers against <111>-type superdislocation motion. It was obseved that climb-dissociation of <111>-type superdislocations frequently occurs in stage II. Consequently, the strength anomaly in B2-type FeAl is explained in terms of the local climb lock (LCL) mechanism. An energetic driving force for the climb dissociation is given by the anisotropy of APB energy between the {110} glide plane and the {111} climb plane.

Chapter 7 Discussion on the Mechanism of the Stength Anomaly in B2 FeAl

The mechanism of the strength anomaly in B2 FeAl is discussed on the basis of the results obtained through the present work. The physical source of the strength anomaly in B2 FeAl is the local climb locking (LCL), which operates on <111>-type superedge dislocations. The driving force is the anisotropy of the APB energy between the {110} slip plane and the {111} climb plane. Since climbing is non-conservative motion of edge dislocations, the climb dissociation in B2 FeAl requires the assistance by local diffusion. Consequently, the strength anomaly induced by the LCL does not appear at lower temperatures, but only at the elevated temperatures where diffusivity is high enough to activate the climb dissociation. In B2 FeAl, the interaction torque due to elastic anisotropy, which would promote the climb events, is almost zero for superdislocations lying within a {110} slip plane, but once the climb dissociation begins, the torque force operates between the superartials in edge character as well as the interaction force due to self-stress field that would also promote also the climb events. These forces would be regarded as intrinsic forces. Line tension due to adjacent, cross-sliped nearscrew segments, and external stress are considered as the extrisic force, which would give rise to the orientation-dependent behavior in B2 FeAl. The anomalous strengthening behavior is roughly explained on the basis of those effects.

Chapter 8 Summary

The main results and conclusions of the present research work were summarized.

審 査 結 果 の 要 旨

近年，アルミナイドやシリサイドといった金属間化合物が，新しい軽量耐熱材料として，たいへん注目されている。特に鉄アルミナイドは，他のアルミナイドやシリサイドに比べて延性に富むことから，実用に最も近い金属間化合物の一つとして期待が寄せられている。本論文ではB 2 型 FeAl に着目しており，単結晶を用いた研究を中心に FeAl の基本的な力学特性と強度の異常性を明らかにするために行われた研究をまとめたもので，全編 8 章よりなる。

第 1 章は序論であり，本研究の背景と目的を述べている。

第 2 章では，熱処理過程で導入される過剰空孔が，多結晶 FeAl の力学特性とその温度依存性にどのような影響を及ぼすかを調査し，過剰空孔硬化現象と降伏強度の逆温度依存性現象を分離してとらえ，両者の関係を明らかにしている。

第 3 章では，Fe-39.5mol. %Al 単結晶を用いて圧縮試験によって降伏強度の異常性を詳細に調査し，すべりの遷移挙動や降伏応力の温度，方位および歪み速度依存性を明らかにしている。

第 4 章では，Fe-39.5mol. %Al の変形挙動を，単結晶を用いて引張試験によって調査し，すべりの遷移挙動や降伏応力の温度および方位依存性，また伸びの温度及び方位依存性などを明らかにしている。

第 5 章では，B，Cr，Pd，W を微量添加した三元系 Fe-35mol. %Al 合金中に熱的に導入された面欠陥を透過型電子顕微鏡を用いて観察し，{111} 面に熱空孔が凝集して形成される逆位相境界の形成機構と原子構造モデルを提案している。

第 6 章では，Fe-39.5mol. %Al 単結晶の変形組織を，透過型電子顕微鏡で観察している。その結果，＜111＞型超転位の上昇分解が異常強化の原因であることを指摘している。

第 7 章では，＜111＞型超転位の上昇分解機構に基づいて，本研究で得られた B 2 型 FeAl の異常強化現象を説明すると共に，上昇分解する熱力学的駆動力の存在を明らかにしている。

第 8 章は，総括である。

以上要するに本論文は，B2型 FeAl の力学特性に対する理解を大幅に前進させた基礎的研究であり，金属間化合物の変形機構に関する研究に対して重要な知見を与えたもので，材料工学の発展に寄与するところが少なくない。

よって，本論文は博士（工学）の学位論文として合格と認める。