CRYSTALLOGRAPHIC FRACTOMETRY OF TiAl FRACTURE SURFACES

T Hebesberger[1], C.O.A. Semprimoschnig[1], R. Pippan[1], O. Kolednik[1], H Clemens[2].

Two different microstructures of a Ti-48Al-2Cr alloy, one with a fully lamellar structure of $\gamma+\alpha_2$ and one with only the γ phase, were tested in the temperature range between -196°C and 700°C. It was found that both microstructures show an R-curve behaviour which is, however, more pronounced for the two-phase material. Although the two microstructures show a different fracture toughness the corresponding crack initiation toughness is very similar. Fractographic investigations revealed that the single phase material changes its fracture mode from transcrystalline to intercrystalline with increasing temperature whereas the two phase material fails mostly in a translamellar way. Examples of surveyed fracture surfaces with the method of the crystallographic fractometry are presented.

INTRODUCTION

Intermetallic materials based on γ-TiAl show very promising mechanical and physical properties which make them potential candidates as structural materials for space, aerospace and automotive applications. Beside the advantages of these materials (low density, good creep and oxidation resistance at elevated temperatures etc.) their low fracture toughness and their limited ductility at room temperature have so far prevented their commercial application. Furthermore this material has also been difficult to process and therefore it has been mainly investigated as a forged or cast material. This problem has been partly overcome by recent advances in processing technology which makes it possible to produce sheet material and permits superplastic forming (1-3).

Despite these progresses the intrinsic low fracture toughness remains. For engineering applications it is therefore important to better understand the fracture behaviour and to search for ways how to increase the fracture toughness of these alloys. From studies reported in literature it is well known that these alloys when tested at room temperature fail in a brittle manner with K_{IC} values typically about 10MPa√m (4).

---

[1] Erich-Schmid-Institute for Solid State Physics, Austrian Academy of Sciences, Leoben, Austria.

[2] Univ. of Stuttgart, Stuttgart, Germany. (formerly Plansee AG, Reutte, Austria).

EXPERIMENTAL DETAILS

In this work two different microstructures of a Ti-48Al-2Cr alloy, one with a fully lamellar microstructure of $\gamma + \alpha_2$, designated DFL (Designed Fully Lamellar), and the other with only the γ phase, designated NG (Near γ), were investigated. SEM-micrographs of the two microstructures are shown in Fig. 1 and Fig. 2. The DFL microstructure had a grain size of about 200 μm and the NG microstructure of about 10 μm. Details about the processing route followed can be found in (1).

Specimens of both microstructures were tested in three point bending tests according to ASTM E-399. The specimens were quadratic (width and thickness were 6 mm) and the distance S (support span) was 24 mm. The pre-crack was introduced by fatigue till it reached a length of 3 mm. The tests were performed displacement controlled with 0.02 mm/min. The crack growth was measured continuously with the DC-potential method. Tests were performed at four different temperatures, i.e. -196°C, 25°C, 500°C and 700°C. Two specimens of each microstructure were tested at each temperature.

RESULTS AND DISCUSSION

For both microstructures the load at which the first crack extension was observed was significantly lower than the maximum load of the toughness test. This is typical for materials with R-curve behaviour which means that the fracture resistance increases with crack extension. Fig 3 shows one R-curve of each microstructure tested at room temperature. As can be seen the crack initiation stress intensity factor of both microstructures is similar. However, the increase of the fracture toughness is more pronounced in the DFL microstructure. The reason for that is that the lamellar DFL microstructure promotes toughening effects such as crack bridging, crack deflection and crack branching.

The results of the initiation toughness, K_{iIc}, as a function of the test temperature is presented in Fig. 4. (The K_{iIc} values were determined assuming a crack extension of 10 μm.) Except at 700°C, the K_{iIc} value of both microstructures were nearly identical.

In contrast to that, the maximum value of the fracture toughness (K_{IC}) of the two microstructures are significantly different at all temperatures (See Fig. 5). At low temperatures the difference between the two microstructures was small but it increased with temperature. Pronounced crack bridging is the reason for the significant higher fracture toughness of the DFL microstructure.

The fracture surfaces of both microstructures were investigated with crystallographic fractometry. This method enables to crystallographically survey cleavage fracture surfaces and it is based on the combination of orientation measurement and the determination of the location in space of individual cleavage facets. Details about that method and its application to brittle fracture surfaces can be found in (7).

In Fig. 6 a typical fracture surface of a specimen with a DFL microstructure tested at 500°C is presented. As can be seen large flat areas constitute a major part of the fracture surface. By usual fractographic means it can not be decided in which phase or along which phase boundary the material fractured. With orientation measurements of homologue areas of both specimen halves it can, however, be decided whether the crack followed a phase boundary or not. In all investigations it was found that these flat areas resulted from a translamellar fracture of the hexagonal $\alpha_2 - Ti_3Al$ -phase. With the method of the crystallographic fractometry those areas were crystallographically surveyed. As presented in Fig. 7 which shows one flat area at a higher magnification the {0001} type cleavage plane was determined for the $\alpha_2 - Ti_3Al$ –phase. It is interesting to see that in the presented area of Fig. 7 a small cleavage area of the tetragonal $\gamma - TiAl$ –phase was also found. The cleavage plane of the phase was identified as a {111} type.

For the NG microstructure it was found that the fracture mode changed with increasing temperature. At low testing temperature a transcrystalline fracture was observed and at higher temperature (i.e. 500°C and 700°C) a predominantly intercrystalline fracture was found. This was determined by fractographic investigations of the fracture surface and by orientation measurements. At 700°C the material fractured nearly exclusively in an intercrystalline way. This may be the reason that the fracture toughness decreased at that temperature for the NG microstructure. The fractured grains of that microstructure were also surveyed with crystallographic fractometry. Surprisingly it was found that the fractured facets were not plane (it was bended) and thus no low indexed cleavage plane could be determined. This issue and further additional results achieved from this study will be more comprehensively addressed in a forthcoming paper.

CONCLUSIONS

In this work two different microstructures of a Ti-48A1-2Cr alloy have been tested in the temperature range between -196°C and 700°C. It has been found that the two phase material showed a more pronounced R-curve behaviour than the single phase material. This could be related to the lamellar structure of the two-phase material. Fractographic investigations revealed that the single phase material changed its fracture mode from transcrystalline to intercrystalline with increasing temperature. With the method of the crystallographic fractometry it was possible to crystallographically survey the fracture surfaces and to determine the type of the cleavage planes in the two phase material.

REFERENCES

(1) Clemens H., Glatz W., "Mikrostruktur und Eigenschaften von $\gamma - TiAl$ – Basislegierungen", Praktische Metallographie, Sonderband 26, 1995, pp 257-269.

(2) Kim Y.-W., "Ordered Intermetallic Alloys, Part III, Gamma Titanium Aluminides", JOM, Juli 1994, pp 30-39.

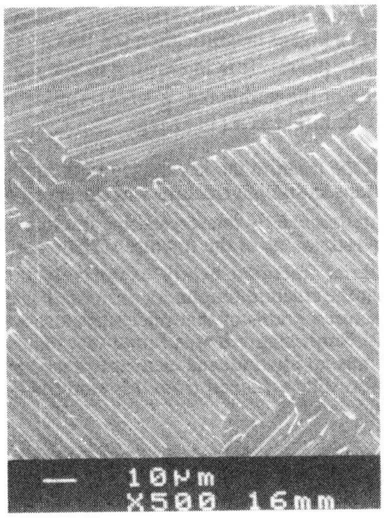
(3) Kim Y.-W., Dimiduk D.M.: "Progress in the Understanding of Gamma Titanium Aluminides", JOM, August 1991, pp.40-47.

(4) Chan K.S., Shih D.S.: Fundamental Aspects of Fatigue and Fracture in a TiA1 Sheet Alloy, Metall. And Mat. Trans. A, Vol. 29A, January 1998, pp.73-87.

(5) Appel F., Wagner R.: Deformation Mechanisms in TiAl/Ti_3A1 Structures", Gamma Titanium Aluminides, Eds., Y-W. Kim, R. Wagner, M. Yamaguchi, TMS, 1995, pp.231-244.

(6) Appel F. et al., "Microprocesses of Plasticity in Two-Phase Titanium Aluminides", Fatigue and Fracture in Ordered Intermetallic Materials, Eds,: W.O. Sobeyejo, T. S. Srivatsan, H. L Fraser, TMS, 1996, pp.123-139.

(7) Semprimoschnig C.O.A. et al, "A new powerful tool for surveying cleavage fracture surfaces", Fat. & Fract. Eng. Mats & Struct., Vol. 20 No 11, 1997, pp.1541-1550.



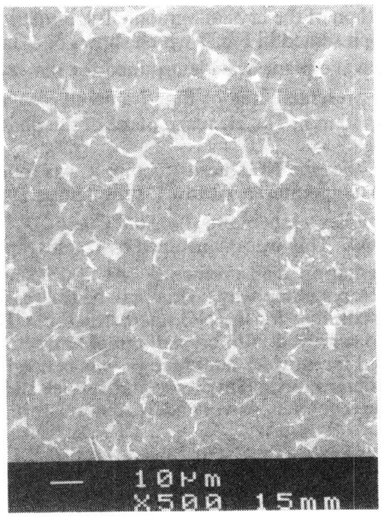


Fig. 1: SEM-image of the DFL-microstructure. Fig.2: SEM-image of the NG-microstructure.

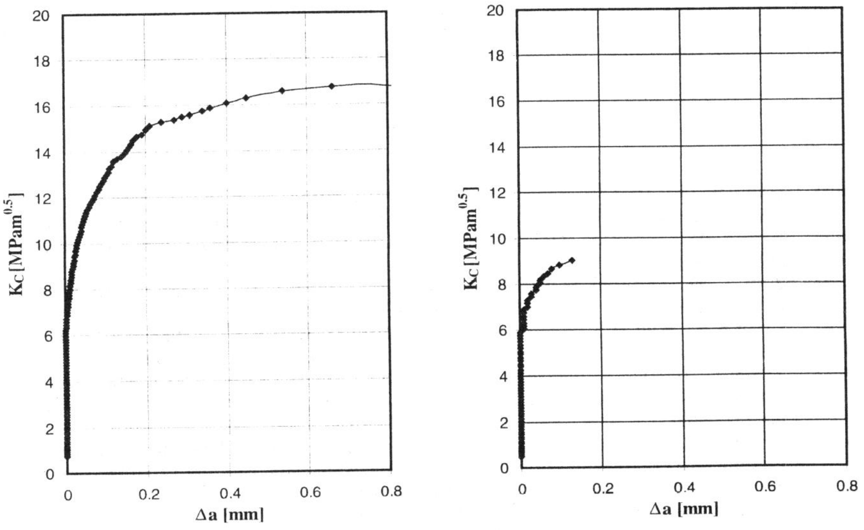


Fig. 3: R-Curves of tests at room temperature. Left DFL-, right NG-microstructure

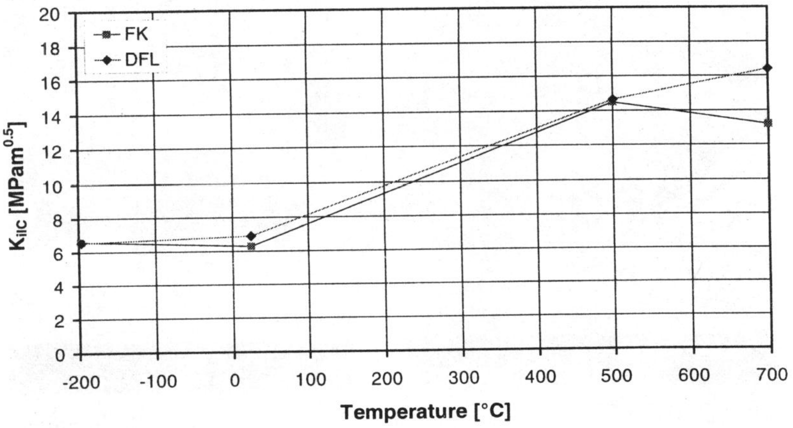


Fig. 4: Determined K_{IIc} values over temperature for both microstructures.

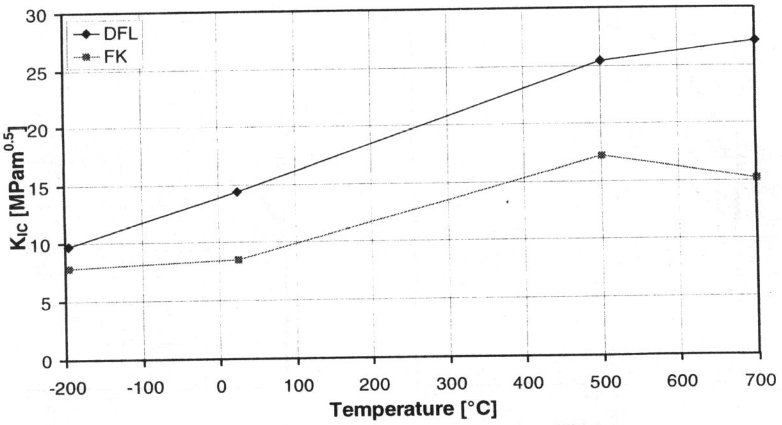


Fig. 5: Determined K_{IC} values over temperature for both microstructures.

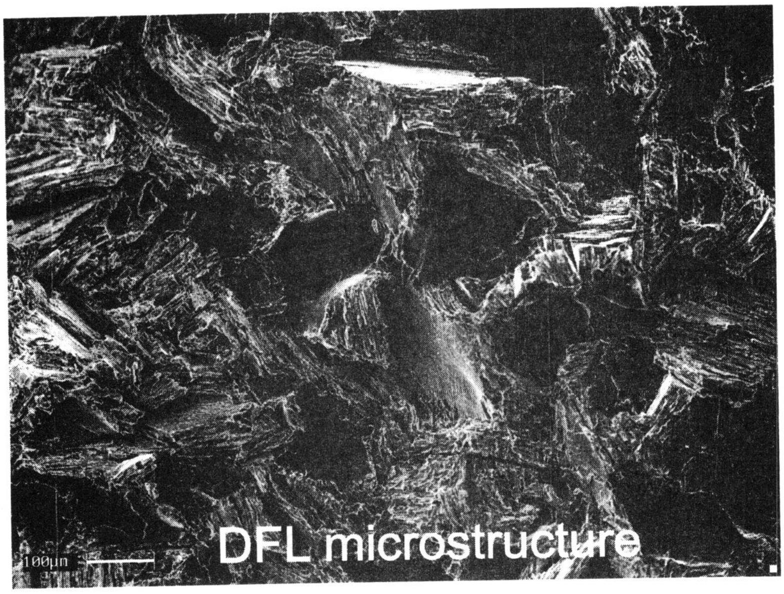


Fig.6: Fracture surface of $\gamma + \alpha_2$ microstructure tested at 500°C.

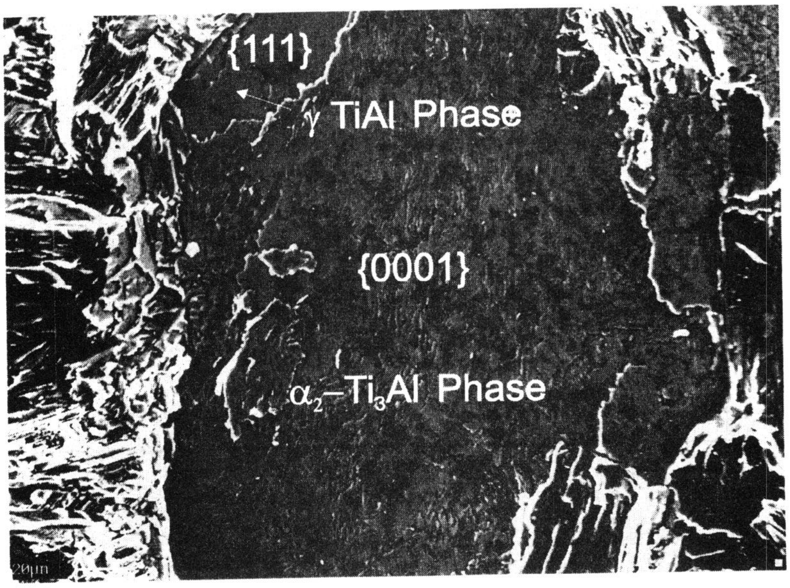


Fig. 7: as above, determined crystallographic indices superimposed on the image.