INFLUENCE OF MICROSTRUCTURE TO FRACTURE TOUGHNESS AND CRACK PROPAGATION OF TiAl6V4.

W.J.Oberparleiter*

Different quenching times in thick and thin sections of TiAl6V4 semiproducts cause different microstructure in these sections which may have an influence to fracture toughness, crack propagation and yield strength too. To study this effect relevant tests were done using specimen machined from different ranges of microstructure in three semiproducts of different manufactoring processes. The results were correlated to the microstructure.

INTRODUCTION

Fracture toughness and crack propagation for safe life design and fatigue life prediction of critical parts made from TiAl6V4 can be taken either from hand books or must be determined from the specimen taken from the critical part itsself or from the semiproduct. Normally, if the material is quite homogeneous like in sheet material or relatively thin rolled plates the scatter of these values is small and does not effect the calculations very much.

Thicker plates or forged semiproducts, with larger and smaller cross sections, however, show different microstructure due to different long quenching time of these sections. These different microstructures of TiAl6V4, eventually caused by different methods of production too, have a different effect to static strength, fracture toughness and crack propagation.

TEST PROCEDURE

To determine to effect of microstructure, to fracture toughness K_{Ic}, crack propagation and yield strength $\sigma_{0,2}$ tests were done using CT-specimen machined from different cross sections of three semiproducts

- a thick rolled plate (2000 x 800 x 78 mm)
- several die forgings (maximum thickness 54 mm), Fig. 1, and
- two hand forgings (maximum cross section 200 x 200 mm) Fig. 2

* Industrieanlagen Betriebsgesellschaft, Ottobrunn.

All semiproducts had been produced from the identical Ti-alloy TiAl6V4,

Al	V	Fe	O_2	N_2	C	H_2
6.2	4,0	0.09	0.19	0.02	0.01	0.004

but by different manufacturing processes.

Before machining the specimen, the microstructure of several large and/or small cross sections of the semiproducts was determined by macroetching to be sure to have different microstructure.

The specimen used - CT specimen according to ASTM standard E 399-78 (1) - had the advantage that K_{Ic} and crack propagation could be determined with the same specimen and nearly at the same location. Also after fracture tensile specimen to get $\sigma_{0,2}$ could be machined near the fracture surface.

Only in the thick plate specimen could be taken in the 3 orientations L-T, T-L and S-T, in the forgings specimen orientation was defined by normal or parallel to the grain flow.

RESULTS

Semiproducts from the identical TiAl6V4 material show different microstructure due to the manufacturing process and the geometry of the semiproduct. These different types of microstructure could not be characterized by the conventional parameters for analysis of microstructure like grain size, content and elongation of the primary alpha grains. All these parameters show nearly identical values (grain size 14 µm, elongation s = 1.1 - 1.55, content of ≈ 65 % primary alpha) for the obviously different types of microstructure found.

Therefore three other parameters were defined for a better description of the structures found:

- formation of the dark $\alpha + \beta$-component (coarse or fine)
- streakiness of the primary alpha (in %)
- turbulence of the primary alpha (globular or lamellar).

Large cross sections (especially the center of the 78 mm thick plate) show a very coarse $\alpha + \beta$-structure combined with a high percentage of primary alpha titanium, Fig. 3. The presence of such different microstructures may be explained by the different heat transfer from the center of the plate to the fringe. A very significant phenomena is the large elongation of the primary alpha grains in the center of the plate in rolling direction, Fig. 4. This elongation can be seen only from a micrograph in longitudinal direction (L), the microstructure looks like laminated.

Small sections (die forging, fringe sections of the plate and the connection between the two thick portions of the hand forging), however show a very fine $\alpha + \beta$ -structure with a small percentage of primary alpha and a more or less globular primary alpha (2).

The homogeneity of the microstructure increases with thinner cross sections. The largest differences in microstructure occur in the large thick plate (between the center and the fringe of 20 - 30 mm), smaller differences occur in the thick parts of the hand forging, while the small die forged discs show a very homogeneious microstructure where no differences were found.

Main indicator for different microstructure of TiAl6V4 is the fracture toughness value K_{Ic}. Central regions showing coarse $\alpha + \beta$ -structure indicate generally higher fracture toughness than thin sections with a fine $\alpha + \beta$-structure and globular-lamellar primary alpha grains.

In thick rolled plates K_{Ic} depends on specimen orientation too. The mean K_{Ic}-values determined with specimen take from the outer 20 - 30 mm thick fringe of the plate with a relatively fine $\alpha + \beta$ -structure, only 5-15 % percent streakiness and globular primary alpha are about 60 % lower in S-T direction than the K_{Ic} values determined with specimen taken from the center of the plate with a very coarse $\alpha + \beta$ -structure, a streakiness of 30 to 70 % and coarse lamellar primary alpha, Fig. 5. In the L-T direction however the differences in K_{Ic} are only 7 % which is identical to the natural scatter of K_{Ic} for titanium-alloys.

Concerning the hand forgings the differences between the center of the thick parts and the thinner parts are about 18 %. Compared to the plate the differences in the microstructure between thick parts and thin parts in the hand forgings is not so evident than between the center and fringe of the plate.

Finally the mean K_{Ic} -values of different parts of the small die forged discs with a relatively homogeneous fine $\alpha + \beta$ -structure differ only by 9 %. This is also in the range of normal scatter for K_{Ic} of TiAl6V4.

Both forgings show no influence of specimen orientation (normal or parallel to the grain flow) to K_{Ic}.

Opposite to fracture toughness K_{Ic} the same differences in the microstructure does effect the yield strength $\sigma_{0,2}$ only by 8 % respectively 3 %, Fig. 5. This is already known from literature (3) (4). There is no correlation between $\sigma_{0,2}$ and K_{Ic} in this case and the simple conventional tests like tensile tests ($\sigma_{0,2}$) cannot replace fracture toughness tests or examination of the microstructure to characterize the microstructure in different parts of TiAl6V4 semiproducts.

A similar trend may be noticed looking at the crack propagation behaviour, Fig. 6. There seems to be a favourable effect of the microstructure of the hand forged part but the scatter bands are close together or even intersecting.

CONCLUSIONS

From the parameters studied mainly fracture toughness K_{Ic} is sensitive to microstructure. Conventional parameters like yield strength are not suitable to characterize different microstructures.

In semiproducts containing thick sections and thin sections as well with different microstructure the scatter of K_{Ic} may be unusual large (5). This should be accounted for in calculations of critical crack length of parts machined from these semiproducts.

REFERENCES

1. Standard Test Method for Plane Strain Fracture Toughness of Metallic Materials. ASTM Annual Book of Standards, Designation E 399 - 78.

2. Oberparleiter, W.J. and Zeitler H., 1981, "Correlation between Microstructure and Mechanical Properties of TiAl6V4", Review of Investigations on Aeronautical Fatigue in the FRG, ICAF Conference

3. Lewis, R.E. et al, 1976, ASTM STP 601, p. 371 - 390

4. Zwicker, U., 1978, Z.f. Werkstofftechnik 9, p. 56 - 62

5. Schütz, W., 1980, "Forgings Including Landing Gears", AGARD AG 257.

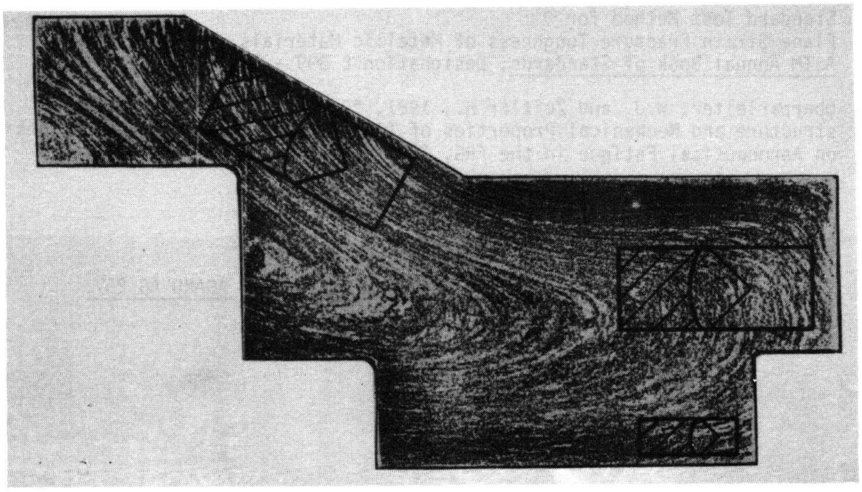

Figure 1 Die forged semiproduct (right part of a symmetric disc) V = 1 : 1

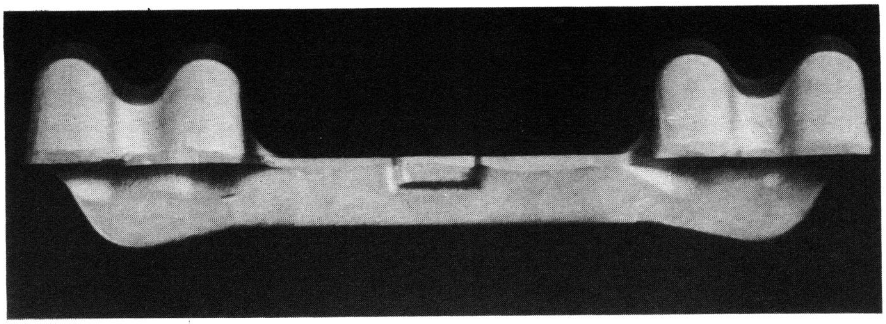

Figure 2 hand forging V = 1 : 20

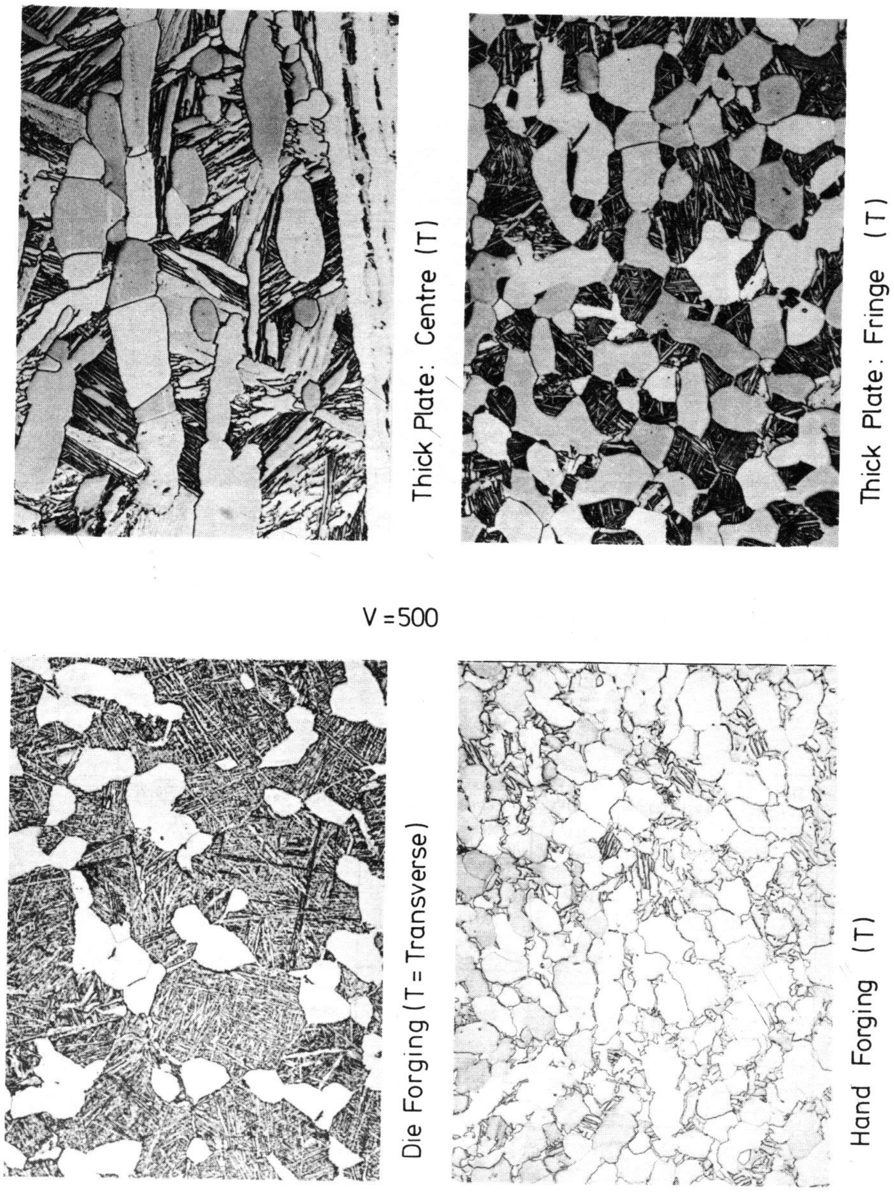

Figure 3 Comparison of microstructures of various semiproducts of TiAl6V4

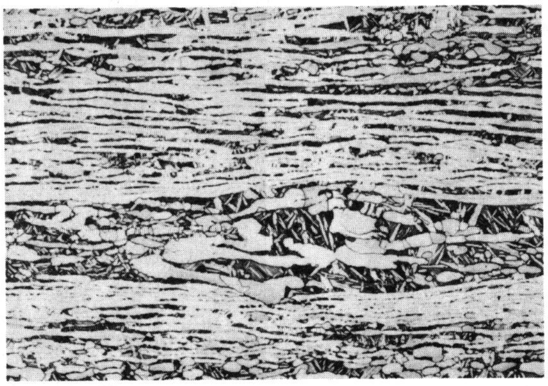

Figure 4 Large elongation of the primary alpha in the center of the plate (only in rolling direction) V = 1 : 100

SEMI FINISHED PRODUCT	ORIENTATION	FRACTURE TOUGHNESS CENTRE $\bar{K}_{IcC}$ /N/mm$^{3/2}$/	FRACTURE TOUGHNESS FRINGE $\bar{K}_{IcF}$ /N/mm$^{3/2}$/	$\frac{\bar{K}_{IcC}-\bar{K}_{IcF}}{K_{IcC}}$ %	YIELD STRENGTH CENTRE $\sigma_{0,2C}$ /N/mm^2/	YIELD STRENGTH FRINGE $\sigma_{0,2F}$ /N/mm^2/	$\frac{\bar{\sigma}_{0,2C}-\bar{\sigma}_{0,2F}}{\bar{\sigma}_{0,2C}}$ %
THICK PLATE	L - T	1742	1625	7	890	964	8
	T - L	1966	1609	22	-	-	-
	S - T	3002	1954	54	877	950	8
HAND FORGING PART	-	2401	2044	18	898	925	3
DIE FORGING	-	1891	1728	9	957		-

Figure 5 Comparison of fracture toughness and yield strength for different microstructure

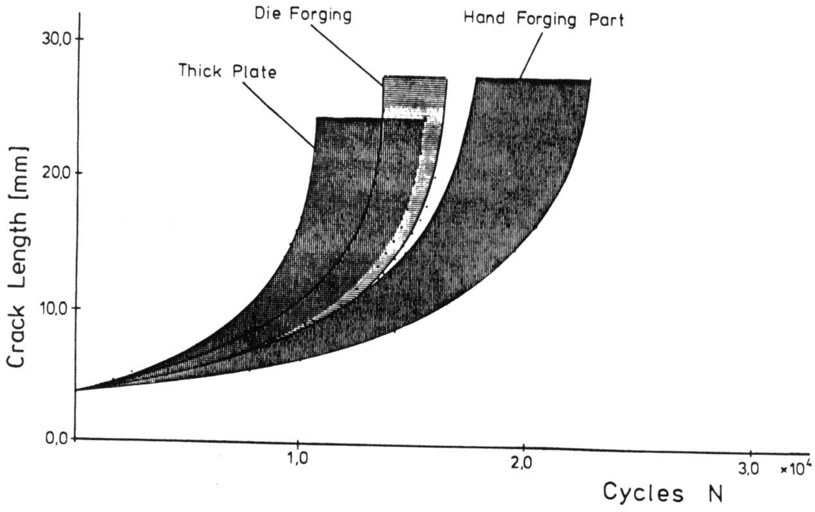

Figure 6 Fatigue crack growth behaviour of different semiproducts of TiAl6V4