Structural Changes of TiAl-Based Alloys during Mechanical Alloying

Adriana Bernatiková, Pavel Novák
University of Chemistry and Technology Prague, Department of Metals and Corrosion Engineering, Technická 5, 166 28 Prague 6, Czech Republic, E-mail: bernatia@vscht.cz

Titanium aluminides represent a class of materials with unique mechanical and physical properties. This is reason why they are often used in aerospace or automotive industries. These materials form lamellar or nearly lamellar TiAl and Ti_3Al phases. There are few methods how to synthesize Ti-Al based alloys, but they are often very difficult and expensive. In present work, a mechanical alloying which is probably best choice for synthesizing of Ti-Al intermetallic phases was used. Further, the most promising conditions of mechanical alloying allowing to create intermetallic phases were determined. It was shown, that by mechanical alloying allows to synthesize desired alloys with grains sizes of several tens of nanometres.

Keywords: titanium aluminides, structural changes, mechanical alloying.

1 Introduction

Development of physical metallurgy led to intensive evolution of intermetalics. In the first decade of 20^{th} century, phase stability as well as mechanical and physical properties of intermetalics were studied. Firstly, exceptional hardness was found. Unfortunately, intermetalics are also very fragile, which was the reason for initial scepticism. Due to this shortage, intermetalics were not used as structural materials in past except the amalgams. On the other hand, their high hardness and thermal stability up to high temperatures were still promising which lead to further continuous research [1]. These materials have also unique properties such as high modulus, with specific modulus being 50 % higher than that of any commonly used alloy, as well as 50 % higher density-adjusted stiffness. All these properties classify TiAl alloys to a group of promising materials for engineering technology and for structural design [2]. Nowadays, Ti-Al based alloys are described as lightweight materials with huge potential in aerospace and automotive industries. These materials can form a few type of phases where the most significant are γ (TiAl) and α_2 (Ti_3Al). They can be divided into two groups: single phase (γ) alloys and two-phase ($\gamma+\alpha_2$) alloys. Single phase alloys have poor ductility and fracture toughness, although they perform better than two-phase alloys in hostile environments [3]. Two-phase alloys may form lamellar or nearly lamellar structure Fig. 1 [4]. Furthermore, fully lamellar TiAl alloys exhibit superior fracture toughness and creep resistance.

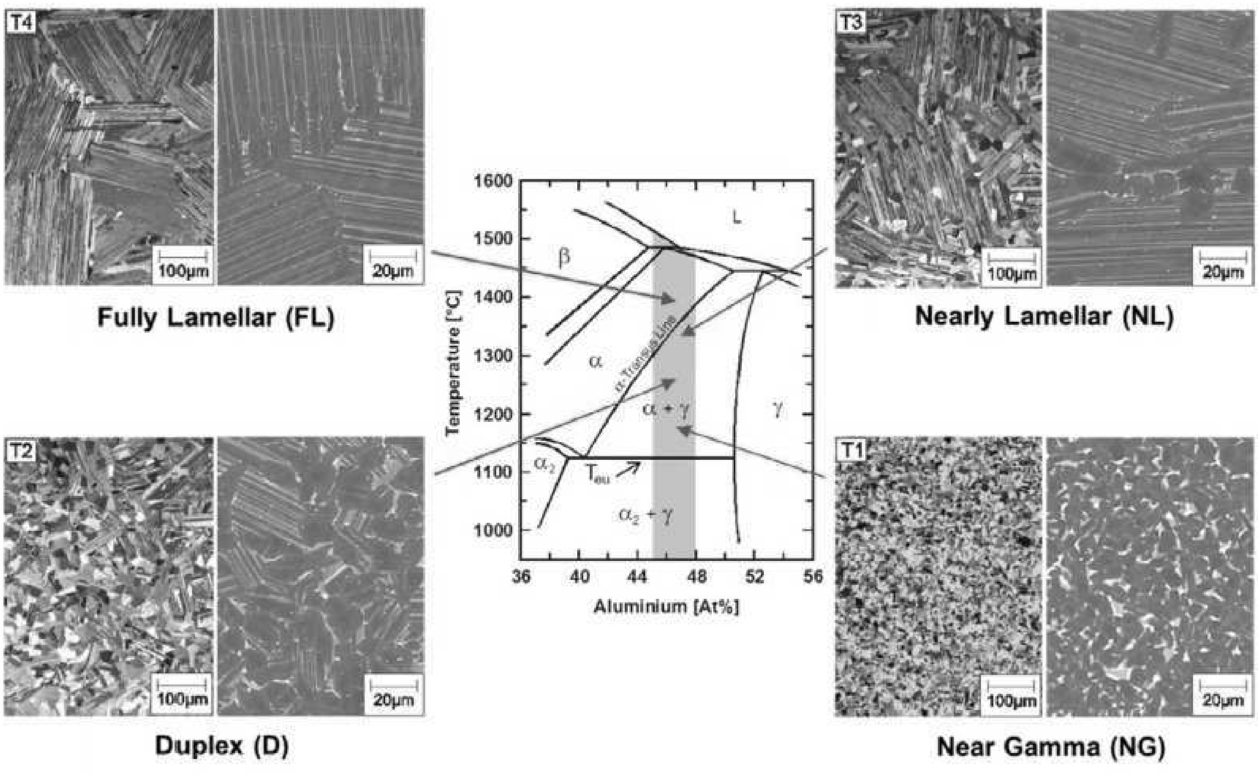


Fig. 1 *Structural changes of microstructure depending on the temperature [4]*

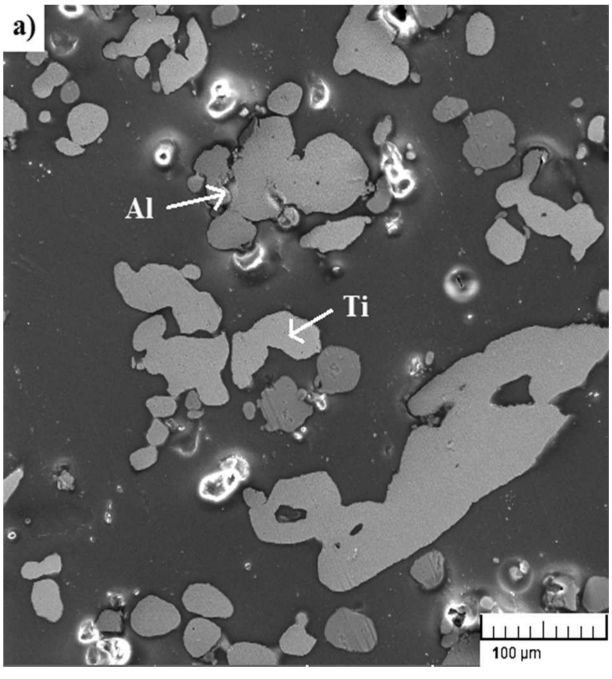
The mechanical properties of two-phase lamellar TiAl alloys depend on the lamellar orientation relative to the testing axis [5]. The mechanical alloying (MA) is one of the method for producing homogenous Ti-Al intermetalics. The high energy alloying process is carried out in milling vessel filled with a mixture made of balls and of processed powders. There are several types of mills such as shaker mill, planetary ball mill, attritor mill and others [6-8].

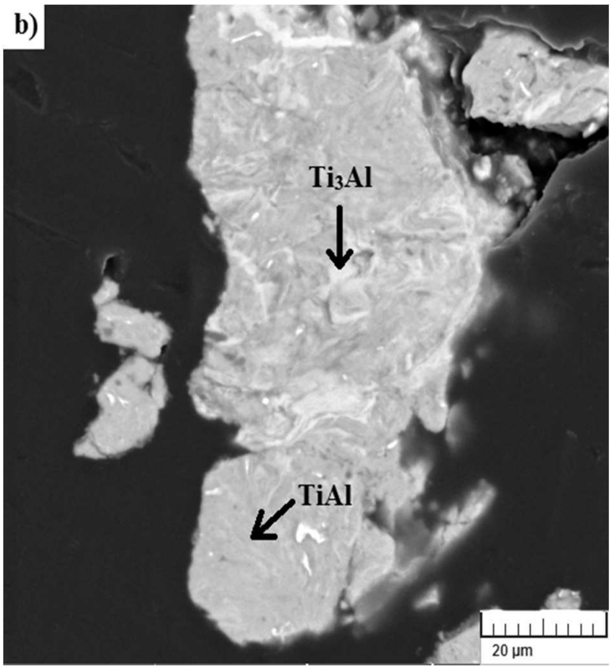
2 Experimental procedure

Aim of the work was to describe the microstructure developement of TiAl38 (wt. %) during the mechanical alloying process. For this, a mixture of Ti and Al was alloyed in planetary ball mill (Retsch PM 100) with a rotational speed of 400 rpm which was held constant throughout the entire process. Various milling times (0.5, 1, 2, 3, 4, 6, 8 h) were used. Sample weight was in all cases 5 g, which corresponded to ball-to-powder ratio of 64:1. To prevent oxidation of prepared alloy, milling was carried out under argon atmosphere. In all cases, the microstructural studies were carried out by scanning electron microscopy (SEM, Tescan Vega 3-LMU) and by transmission electron microscopy (TEM, Jeol JEM 2200FS).

3 Result and discussion

As is shown in Fig. 2, the microstructure of the powder particles changed during the MA. The as-mixed powder (Fig. 2a) shows presence of easily recognizable particles of titanium and aluminium. After 1 h of MA (Fig. 2b), lamellar zones of Ti_3Al were formed while the matrix was composed of TiAl. The 8 h of MA (Fig. 2c) lead to homogenous microstructure composed of TiAl. Present light points corresponds to particles of iron, which presence may be explained by intensive abrasion of the vessel walls which influence increases as the time of MA prolongs.





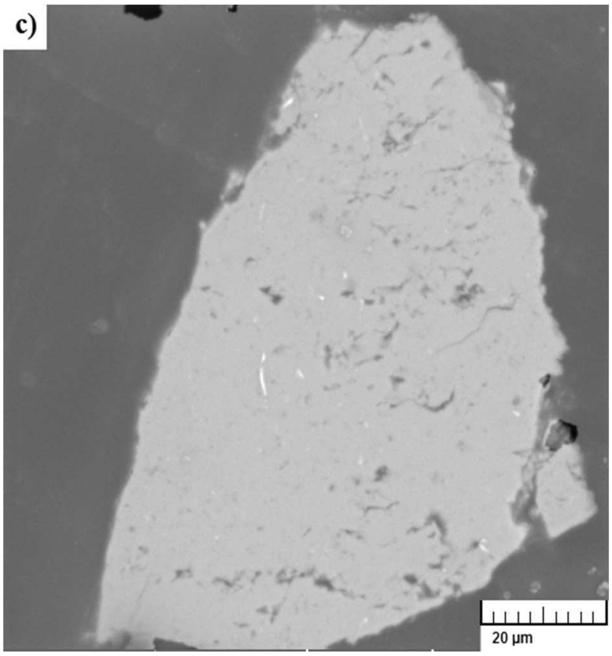


Fig. 2 *The SEM micrographs of the particles:* ***a)*** *before milling,* ***b)*** *1 h of MA,* ***c)*** *8 h of MA*

The 4 h MA powder was also investigated by TEM. It was discovered that the present grains have diameter a few tens of nanometer (Fig. 3). More importantly, the micrographs revealed presence of lattice defects mainly corresponding to disslocations and to stacking faults which manifested themselves as parallel lines in the interior of present grains. Presence of such kind of structural defects fully corresponds to the chosen processing technology.

Whereas the phase composition of during mechanical alloying changes it was interesting to find out if it will also affect the microhardness. As is seen from Tab. 1 during first 3 hours of MA, hardness increases which corresponded to formation of hard phases as well to the deformation strengthening. After 4 h of MA, hardness decreases and increases again at 6 h of MA. Present hardness decrease can be explained by significant microstructural refinement to a grain sizes of several tens of nanometres which may be crucial to the hardness decrease considering the inverse Hall-Petch relationship. Higher duration of MA lead to microstructural coarsening which positively influenced the microhardness reaching the second best result of 649 HV 0.05. After 6 h of MA a low softening caused by partial amorphisation of the material was observed.

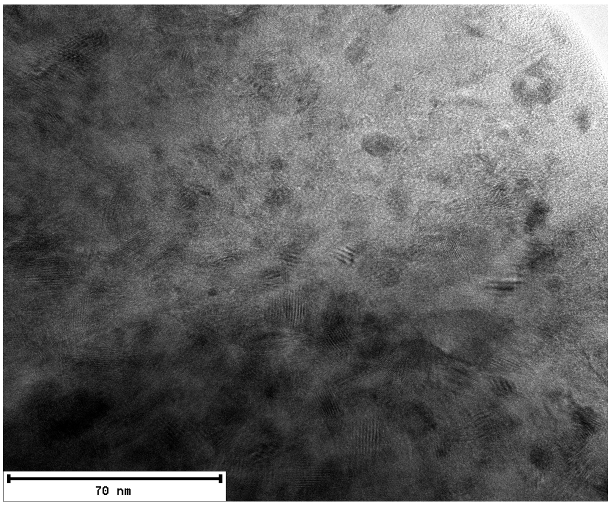


***Fig. 3** The TEM micrograph of powder prepared by 4h MA*

***Tab. 1** Changes in HV 0.05 during mechanical alloying*

Time of MA [h]	HV 0.05
0.5	482 ± 63.7
1	539 ± 41.0
2	547 ± 70.2
3	686 ± 71.7
4	245 ± 60.9
6	649 ± 69.9
8	535 ± 90.4

4 Conclusions

Aim of this work was to examine microstructural changes during the MA process. It was discovered that after 1 h of MA a partially lamellar $TiAl/Ti_3Al$ structure was formed. Further increase of the MA duration led to a significant microstructural refinement reaching their maximum at 4 h of MA which corresponded to presence of grains with dimensions of several tens of nanometres. Presence of such small grains caused steep decrease in hardness which can be attributed to the inverse Hall-Petch relationship.

Acknowledgements

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