Structure Analysis of Lanthanum containing Titanium alloys using hard X-ray

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Machining is a common manufacturing operation, especially, if complex geometries have to be produced. Due to the combination of low density and high strength, titanium alloys like Ti6Al4V are widely used in mechanical engineering. Machining of titanium alloys however, involves high production costs because of their poor machinability [1, 2]. Generally, three different kinds of chips can be formed during machining: continuous chips, segmented chips, or completely separated segments. From the technological point of view, the completely separated segments are desired. In machining of titanium and titanium alloys, segmented chips are formed in a wide range of cutting speeds and cutting depths. The segments are separated in the shear zone by a so called shear band.

The addition of lanthanum (minimum of 0.9%) to different titanium alloys results in improved machinability due to chips breaking into small fragments [3, 4]. Two different mechanisms may lead to the creation of these completely separated segments: 1. Due to the relatively high local temperature and local deformation in the chips (more than 800°C and 800% [5], respectively), the pure lanthanum particles soften essentially and might even melt ($T_m,La = 918°C$). The strength of the shear zone is therefore reduced and the chips separate in the primary shear zone. 2. Oxygen dissolved in titanium might create lanthanum oxide (La$_2$O$_3$) which causes strong embrittlement [6]. Due to the embrittlement of the alloy, chips might break during the extreme deformation of the material in the shear zone. It is also possible that both effects contribute to the improved machinability. Regardless of the mechanisms of these short chips formation they have three beneficial effects: 1. The cutting force decreases by about 20%. 2. The fact that the chips are much shorter than usually results in limited contact between tool and chips, which leads to a decrease of the rake face temperature and hence the tool wear is reduced. 3. Automated machining processes can be eased as the removal of long chips is technically awkward, especially in drilling processes.

In order to understand the role of lanthanum in the chip formation process, a set of specimens containing different amount of lanthanum has been prepared. As basic experimental material commercially pure titanium as well as the commercially available alloy Ti6Al4V ELI/LFN was used. Alloys with 0.9 – 2.8% of lanthanum were produced by plasma arc melting. Because of almost no solubility of lanthanum in titanium at room temperature, discrete lanthanum-rich particles developed in the martensitic alpha$'$ matrix. The particles can be found in almost unchanged form also in the structure after deformation and ageing. They are of globular shape with an average particle size of about 3µm and they are distributed rather homogeneously, however, mainly on the grain boundaries. From the engineering point of view and to introduce the material into industrial applications it was very important to analyze these particles. The literature reviews [6, 7] as well as the experimental methods used before the HASYLAB experiment was carried out implied to lanthanum oxide. However, all these analyses were performed on the surface, where lanthanum oxide can form by oxidation due to air contact. If this would be the case also in bulk, the lanthanum-alloyed titanium alloys would have only very limited application because the lanthanum oxide causes strong embrittlement. However, if the particles consisted of metallic lanthanum these alloys would be suitable for many applications, especially in medical engineering, automotive industry etc. In order to determine the structure of the particles, experiments using hard X-ray have been performed on BW5 at HASYLAB. Different titanium alloys containing various amounts of La (0.0 – 2.8 wt %) subjected to various heat treatments (as cast, deformed, deformed and aged) were measured on BW5 (77keV, PSD, exposure time 1 – 60 seconds) in 4 days. The data sets were then treated by Fit2D and FullProf software. In any of the La containing samples no lanthanum oxide has been found [8, 9]. All results refer to metallic bcc lanthanum and the presence of any other phase that was not reliably determined. However, lanthanum oxide has been excluded (see Fig. 1). The unknown phase is probably one of many ternary intermetallic compounds which lanthanum may create with the other alloying elements or impurities. Nevertheless, the important conclusion
for industrial applications is the presence of metallic lanthanum und the absence of lanthanum oxides in any of the alloys investigated. As can be further seen from the results, the particles of metallic lanthanum develop during casting and do not change by any thermal or thermo-mechanical treatment, which was found also by metallographic analysis. The integral intensity of the strongest lanthanum reflections increases with increasing lanthanum content as expected (see Fig. 2). Because of relatively low volume fraction of lanthanum in the alloys, only a qualitative comparison can be made; for precise quantitative analysis the lanthanum reflections are too weak. The results of HASYLAB experiment will significantly help to introduce the new alloys into industry. Exclusion of lanthanum oxide in the bulk material will open new possibilities for industrial applications, where the embrittlement is unacceptable, but the cost reduction is very welcomed.

Figure 1: Diffraction spectra of CP-Titanium Grade 2 containing different amounts of lanthanum (0%, 0.9%, 1.5%, 2.8%). No diffraction peaks referring to the different lanthanum oxides have been found, whereas metallic lanthanum can be easily detected.

Figure 2: The integral intensities of lanthanum reflections increase with increasing lanthanum content.

References