Advanced Titanium Alloys containing Micrometer-size Particles

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In the early 1950ies, since the introduction of CP-titanium and titanium alloys like CP-titanium Grade 2 (α), Ti 6Al 2Sn 4Zr 2Mo (near-α), Ti 6Al 4V (α+β), Ti 5Al 5V 3Mo 0.5Fe and Ti 15V 3Al 3Cr 3Sn (both metastable β) these materials have become backbone materials for the aerospace, energy and chemical industry. The self-diffusion rate in β-titanium is of two orders higher than in α-titanium. Hence, significant grain growth occurs during thermo-mechanical processing in the β-field so that the final deformation step is applied in the (α+β)-phase region if possible. As in metastable β-alloys the deformation obviously can only occur in the single-phase β-region, the deformation temperature is kept as low as possible and the semi-finished bars are water quenched after the final deformation step to minimise grain growth. Nevertheless, during the production of fine-grained metastable-β-, near-β- or β-alloys special care has to be taken in the production chain, especially during heat treatments above β-transus. The machinability of all titanium alloys is generally very poor [1].

In the current study, the machinability and the grain growth of the titanium alloys mentioned above exposed to heat treatments in the single-phase β-region have been studied. Afterwards, 0.9 wt.-% of two different rare earth metal elements (REM), namely lanthanum (La) and erbium (Er) have been added to distribute micrometre-size particles in the titanium matrix with different melting points. The machinability and the grain size stability were investigated and have been compared to the standard alloys. For alloy production commercially available alloys and 0.9% (all values given in wt.-%) of lanthanum (purity 99.9%) and 0.9% of erbium (purity 99.9%) have been used. All alloys including remelting of the reference alloys were fabricated by plasma arc melting of the initial materials in a laboratory furnace, followed by casting the material into bars of diameter 13 mm and height 80 mm. All alloys were subjected to fast cooling due to the use of a water cooled copper mould. Afterwards, the bars have been solution treated at approx. 50°C above the related β-transus temperature for 30 minutes followed by air cooling (solution treated state). Machining experiments have been carried out on a standard lathe. Grain size stability was investigated in heat treatments (additional to the solution treatment) 50°C, 100°C and 200°C above β-transus temperature for one, two, four or eight hours. Afterwards the grain size has been measured by quantitative image analyses and normalised to the initial grain size of the alloys after the solution treatment to calculate the relative grain growth [2].

The microstructure of all modified alloys consisted of a titanium matrix and equiaxed particles with a diameter between 2 µm and 10 µm. The grain size in the solution treated state was similar in all cases between 50 µm and 150 µm. To introduce the modified alloys into technical applications, it is necessary to show that the particles do not consist of rare-earth metal oxides. Surface analysing methods cannot be applied as rare earth metals oxidise once exposed to normal air. Therefore, samples of the standard as well as of all lanthanum and selected erbium containing alloys have been investigated in axial direction by means of synchrotron radiation (HASYLAB, beam line BW5), E = 85.94 keV, λ = 0.014427 nm, exposure time 10 seconds to 30 seconds, beam size 0.25 mm², in transmission (Debye-Scherrer set-up) using an image plate MAR 345 to obtain information from the bulk material [3].

The particles in the rare earth metal element containing alloys were located on the grain boundaries in CP-titanium, Ti 6Al 4V and Ti 5Al 5V 3Mo 0.5Fe and consisted of pure lanthanum and pure erbium respectively. In case tin (Sn) was present in the alloys (Ti 6Al 2Sn 4Zr 2Mo and Ti 15V 3Al 3Cr 3Sn), intermetallic compounds formed, namely La₅Sn₃ as shown in figure 1, and probably an Er₅Sn₃ intermetallic phase which has not been identified so far. If intermetallic phases were present, the particles were comparably larger and more homogeneously distributed in the matrix material.
During turning of all standard alloys long chips formed as expected. In case pure metallic lanthanum was present in the alloys, short chips formed, whereas La₅Sn₃ and ErₓSnᵧ intermetallic phases or pure erbium particles did not lead to improved machinability. This observation can be explained as follows: During segmented chip formation (true for all investigated titanium alloys) the temperature in the shear bands reaches or exceeds 1000°C. Metallic lanthanum particles (melting temperature Tₘ,La = 918°C) which are present in the zone of localised deformation will drastically soften or even melt once the segment starts to form. The adhesion between the segments will then be reduced so that the chips fall apart either directly once the shear band forms or due to vibrations during further progress of the tool after the segment is completely developed. This explanation is promoted by strongly elongated lanthanum particles being found on some of the shear planes and the fact that most of the chips of the lanthanum containing alloys were separated in the primary shear zones. Consequently, the addition of erbium cannot lead to short chips as the melting point of erbium is about 1522°C and thus much higher than the temperatures reached during the shear band formation. The La₅Sn₃ and ErₓSnᵧ intermetallic compounds with melting points above 1350°C do not improve the machinability as well [4].

In general, severe grain growth (up to 400%) occurred in all the standard alloys, the grain size was increasing with temperature and time as expected. The absolute grain growth was more pronounced in CP-titanium and the metastable β-alloys compared to the near-α- and (α+β)-type alloys. A grain stabilising effect was observed for all particle containing alloys as the growth was limited to about 20%. Due to their preferred location on the grain boundaries, pure metallic particles were slightly more effective then particles of intermetallic compounds which were more homogeneously distributed.

In conclusion, it can be stated that advanced titanium alloys can be produced by the distribution of second-phase particles in the micrometre scale. The solubility of these particles in titanium must be low or negligible. Rare earth metal elements fulfil these requirements. Benefiting effects could then be improved machinability and enhanced grain stability at elevated temperatures.

References