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ADVANCED TITANIUM MATERIALS FOR AEROSPACE APPLICATIONS – CURRENT STATUS AND OUTLOOK

High temperature resistant Ti- and TiAl-alloys are needed in aircraft and engines to reduce weight. The traditional construction materials in areas of elevated temperatures of more than 350°C are Ni-alloys like IN 625 and IN718. Unfortunately the density of Ni-alloys is more than twice of Ti and TiAl-alloys. The wrought Ti-alloys cannot be introduced with temperatures of more than ~450°C. The application for higher temperatures is restricted by low resistance against oxidation and hydrogen pick-up and due to sharp fall of hot strength properties. The TiAl-material retains its high hot strength level and its oxidation resistance to temperatures of more than 800°C. The very favourable service properties have some negative implications on the forming process however. At room temperature the material reacts very brittle. The elongation to fracture is less than 2%. Cold forming is not possible at all. Sufficient plasticity is generated only at forming temperatures of more than 980°C. The forming stress remains nevertheless high. Over 980°C the plasticity properties show a considerable amount of strain. It is possible to blow-form or to hot-form typical sheet metal part geometries. Forming of parts is done now at temperatures of up to 1150°C, the gas pressure can be as much as 50 bars. Considering the design and production of forming dies and the control of the press work a considerable amount of experience has been generated. The hot press installation works repeatable and reliable. The actual shortage of TiAl sheet metal will be overcome in next future. The sample geometries show very clearly the potential of TiAl sheet metal articles for a new approach targeting on weight reduction with help of new metal alloys.

superplastic forming, diffusion bonding, microstructure, workpiece, prematerial, homogenization, recrystallization, globularization

Introduction

TiAl materials applications might have a significant increase if the sheet metal product would be cheaper and the forming and joining processes would prove good respectability [1 – 5]. Cost of TiAl today is mainly driven by high temperature rolling. Forming and diffusion bonding are not very much exploited.

Thermomechanical treatment of $\gamma + \alpha_2$ alloys for production of prematerial for sheet rolling

Rod ingots of the Ti-44.2Al-3(Nb,Cr,B) and 45.2Al-3.5(Nb,Cr,B) alloys produced by induction scull technique were available. The ingots were HIPed and homogenized, followed by furnace cooling. The hot working procedure included primary quasi-isothermal (canned) forging in the $(\alpha + \gamma)$ phase field, an off-line, intermediate furnace globularization annealing slightly below the eutectoid temperature and additional isothermal forging in the $(\alpha_2 + \gamma)$ phase field. This method was successfully utilized for ingot workpieces of ∅ 70 × 120 mm, which were cut and machined from the HIPed and homogenized ingots. These workpieces were canned, preheated and forged at a nominal strain rate of about 5×10^{-2} s^{-1} using low-carbon steel as a can material and preheated die tools. The additional forging step was carried out in the same forging direction under isothermal conditions at a strain rate of $10^{-3} – 10^{-2}$ s^{-1} using a glass lubricant. Sound pancakes of ∅ 200 × 15 mm were successfully manufactured by the described technique (fig. 1). Partially recrystallized and globularized microstructures were produced throughout the pancakes of both alloys (fig. 2). The typical γ grain size was 2 – 4 μm and the coarsest grains did not exceed 10 μm. Globularized α_2 particles were less than 1 μm in diameter. In the Ti-44.2Al-3(Nb, Cr, B) alloy, lamellae

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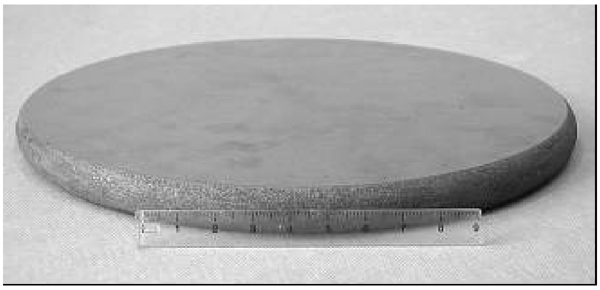

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Fig. 1. Ingot breakdown technique for the Ti-45.2Al-3.5 (Nb,Cr,B) and Ti-44.2Al-3 (Nb,Cr,B) alloys: a – workpiece after HIP and homogenization heat treatment, b – final workpiece after two-step forging

remnants occupied higher volume fraction than that in the case of the Ti-45.2Al-3.5(Nb,Cr,B) alloy.

Thus, two-step hot working with the last step below the eutectiod temperature was found to be an effective processing method for ingot breakdown of the alloys.

This led to a significant decrease in both the transition temperature (by about 300°C lower than the eutectoid temperature) and high temperature tensile strength. The latter is important for providing the minimum condition of can-preform flow stress mismatch. Reasoning from this, the wrought processed Ti-45.2Al-3.5 (Nb,Cr,B) and Ti-44.2Al-3 (Nb,Cr,B) alloys were used as prematerial for development of sheet rolling process below the eutectoid temperature.

Sheet rolling, structure and mechanical properties of sheet material

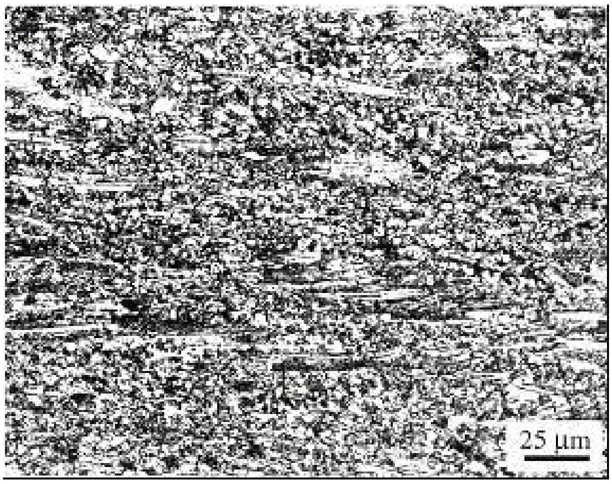

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Fig. 2. Fine-grained microstructures in (a) the Ti-45.2Al-3.5(Nb,Cr,B) and (b) Ti-44.2Al-3(Nb,Cr,B) alloys after two-step hot working. The forging direction is vertical

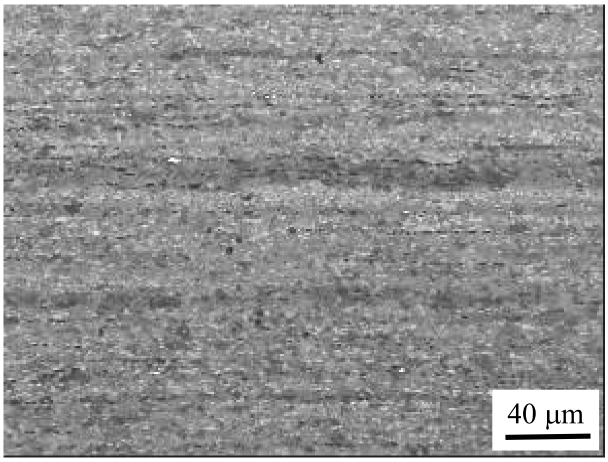
Rectangular performs for sheet rolling were cut out of the pancakes of the Ti-45.2Al-3.5 (Nb,Cr,B) and Ti-44.2Al-3 (Nb,Cr,B) alloys. Standard stainless steel was used as a can material. The pack was soaked in a furnace at a temperature lower than the eutectoid temperature and then hot rolled with intermediate reheat between each pass. Reductions per pass and rolling speeds produced effective strain rates of the order of 10^{-1} s^{-1}. Sheets on a laboratory scale have successfully been fabricated by the described technique (fig. 3).

Fig. 3. Semi-finished sheet products rolled below the eutectoid temperature

Fig. 4 presents the microstructures of the Ti-45.2Al-3.5 (Nb,Cr,B) and Ti-44.2Al-3 (Nb,Cr,B) alloys rolled to a reduction of 4:1. Due to sheet rolling the lamellae remnants were completely transformed into a globular microstructure. Particularly, a quite homogeneous microstructure was obtained in the sheet of the Ti-44.2Al-3 (Nb,Cr,B) alloy that might be ascribed to the fact that this alloy was to β-solidifying alloys. The Ti-45.2Al-3.5 (Nb,Cr,B) alloy appears to be near β-solidifying, i.e. a small amount of liquid during solidification solidified through peritectic reactions that led to the formation of some bands. Thus, the dark bands distinguished in Figure 4a most probably corresponded to interdendritic regions with higher aluminum content, which were inherited from the ingot structure of the alloy. The typical γ grain size was 2 – 3 and 3 – 5 μm in the Ti-45.2Al-3.5 (Nb,Cr,B) and Ti-44.2Al-3 (Nb,Cr,B) alloys respectively. Particles of the α_2 phase were found to be mainly globular ($d_{\alpha 2}$ < 1.5 μm) and elongated ($d_{\alpha 2}$ < 1.5 × 5 μm) in the former and latter alloys respectively (fig. 4).

Diffusion Bonding of γ-TiAl sheet materials

To exploit γ-TiAl sheet materials in structural applications, reliable joining techniques providing joints with mechanical properties similar to the base material should be developed. In this regard, diffusion bonding seems to be one of the most challenging joining techniques for γ-TiAl sheet based components [3]. Diffusion bonding experiments have shown that excellent joints with mechanical properties similar to the base material can be realized. Due to using much lower rolling temperatures (lower than the eutectoid one) the microstructure of the sheet materials produced by IMSP was significantly finer and more homogeneous than that of a previous producer. Thus, the aim of the present work is to establish diffusion bonding parameters of γ-TiAl sheet samples having different microstructures and to show the difference between joints quality of the sheet materials rolled above and lower the eutectoid temperature.



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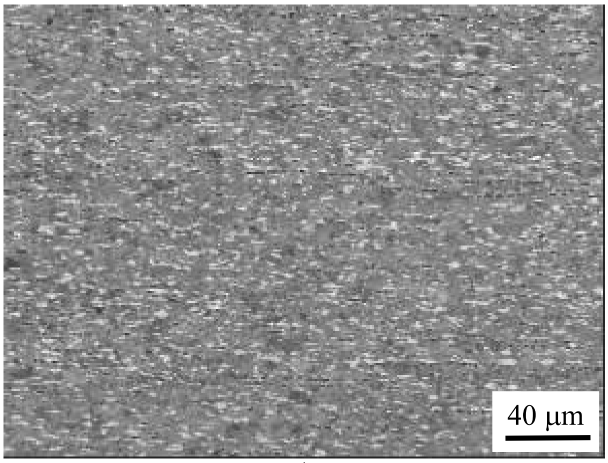

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Fig. 4. SEM micrographs (BSE images) of the sheet material of (a) the Ti-45.2Al-3.5 (Nb,Cr,B) and (b) Ti-44.2Al-3 (Nb,Cr,B) alloys rolled to a 4:1 reduction showing transversal plane of the sheets; the rolling direction is horizontal

Experimental Procedure

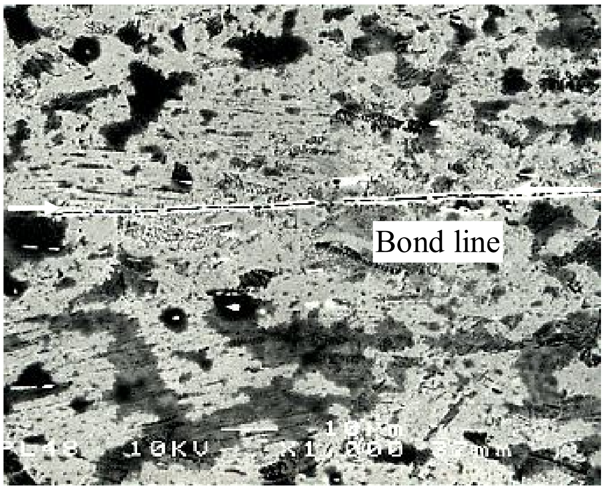
Diffusion bonding experiments were carried out using special equipment. The samples are settled by polished surfaces to one another and sealed inside a metallic container. The container is placed between load-bearing plates. The assembled equipment is connected by pipes with the automated control system and placed in a furnace.

During heating of the equipment the container is held under vacuum. With a pressure $P = 0\ldots6$ MPa diffusion bonding of the samples is provided. Two types of samples were used: 1-st type – cut from sheet material obtained from a western European source and 2-nd type – cut from sheet material obtained by IMSP. The diffusion bonding experiments were performed on 1mm thick samples, bonding temperatures were 950 and 1000°C, bonding time was 2 hours and pressure values were in the range of 6.6-88 MPa. The pressure led to a strain of the samples, which was $\varepsilon = 10\ldots60$ %. After finishing the bonding procedure the equipment was cooled and the samples were extracted.

Results

Metallographic examination of the bonded zones revealed the formation of diffusion bonding in all the samples. The joint quality was better in the case of the 2-nd type samples as compared with the 1-st type samples. For instance, the relative porosity in the area of the bonded zone was measured $V_p = 20.8\%$ in the 1-st type samples against $V_p = 3.6$ % in the 2-nd type samples after bonding at $T = 950°C$, $P = 11$ MPa, ($\tau = 2h$), a strain of the bonded samples was $\varepsilon \approx 13$ %. An increase in the bonding temperature up to $T = 1000°C$ using the same pressure resulted in a significant decrease in relative porosity in the area of the bonded zone, $V_p = 2$ and 1% was obtained in the 1-st type and the 2-nd type samples respectively. With increasing the bonding pressures the joint quality was improved. For example, using 44 and 88 MPa at $T = 950°C$ sound joints free of micro pores and invisible by SEM were obtained. A strain of the bonded samples in this case was $\varepsilon \approx 20$ and 60% respectively. The same result was obtained at $T = 1000°C$ but using lower bonding pressures.

Figs. 5 and 6 present typical bonding zones of the 1-st and 2-nd type samples obtained after diffusion bonding at $T = 950$ and 1000°C using the bonding pressure of 11MPa. It is seen that the joint quality is appreciably better in the case of the 2-nd type samples against the 1-st type samples. Using $T = 1000°C$ and the bond-



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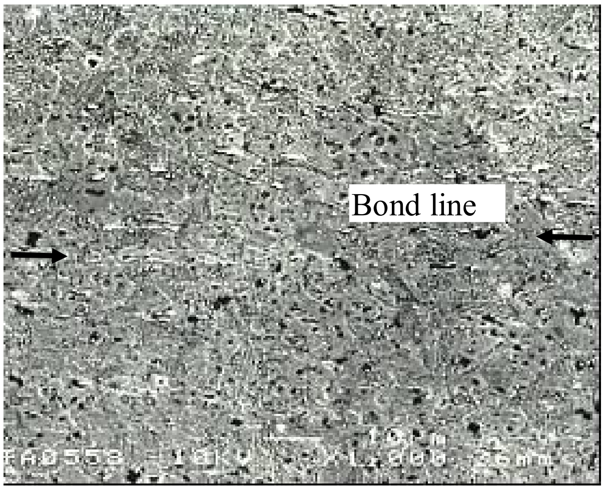

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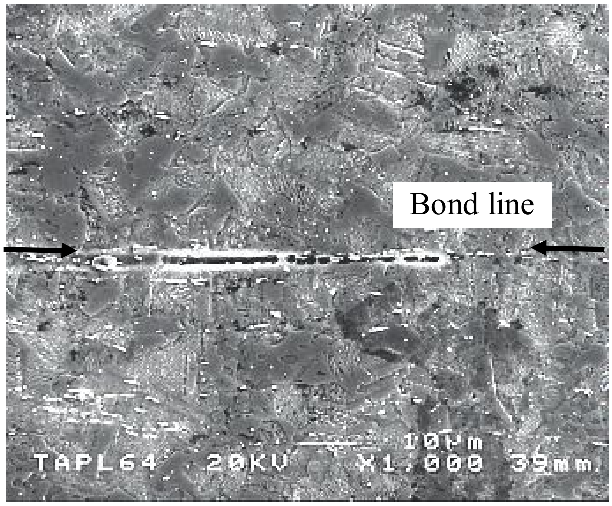
Fig. 5. Typical SEM images of bonding zones of the (a) 1-st and (b) 2-nd type samples (T = 950°C, P = 11 MPa, ε = 13%). $V_p = 20.8$ and 3.6% were measured in the area of the bonding zone in the first and the second

ing pressure of 11 MPa a sound joint, free of micro voids, was attained in the samples of the 2-nd type. In the case of the 1-st type samples the joint quality was



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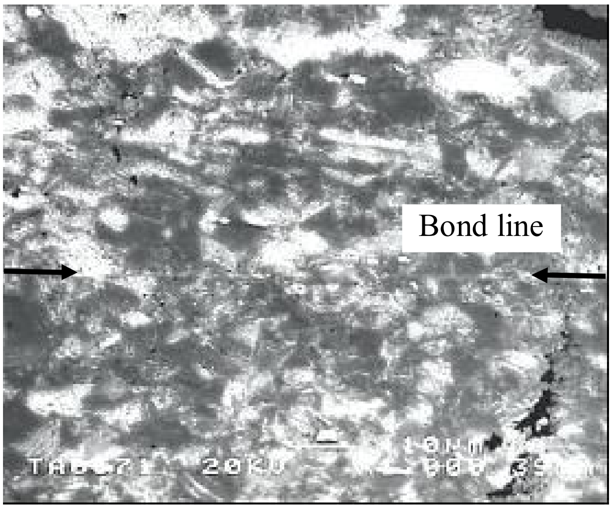

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Fig. 6. Typical SEM images of bonding zones of the (a) 1-st and (b) 2-nd type samples (T = 1000°C, P = 11 MPa, ε = 17%). V_p = 2 and 1% were measured in the area of the bonding zone in the first and the second case respectively

somewhat worse (fig. 5).

The bonding temperature of 1000°C and relatively low bonding pressures (P = 10…15 MPa) comparable with those used for conventional titanium alloys were found to be suitable to produce sound joints in the sheet material of the 2-nd type.

Forming

Forming of sheet metal parts of TiAl has to be made at high temperatures above 980 C. Hot forming and SPF parts have been produced (fig. 7 and 8). The press and die concept is working reliable.

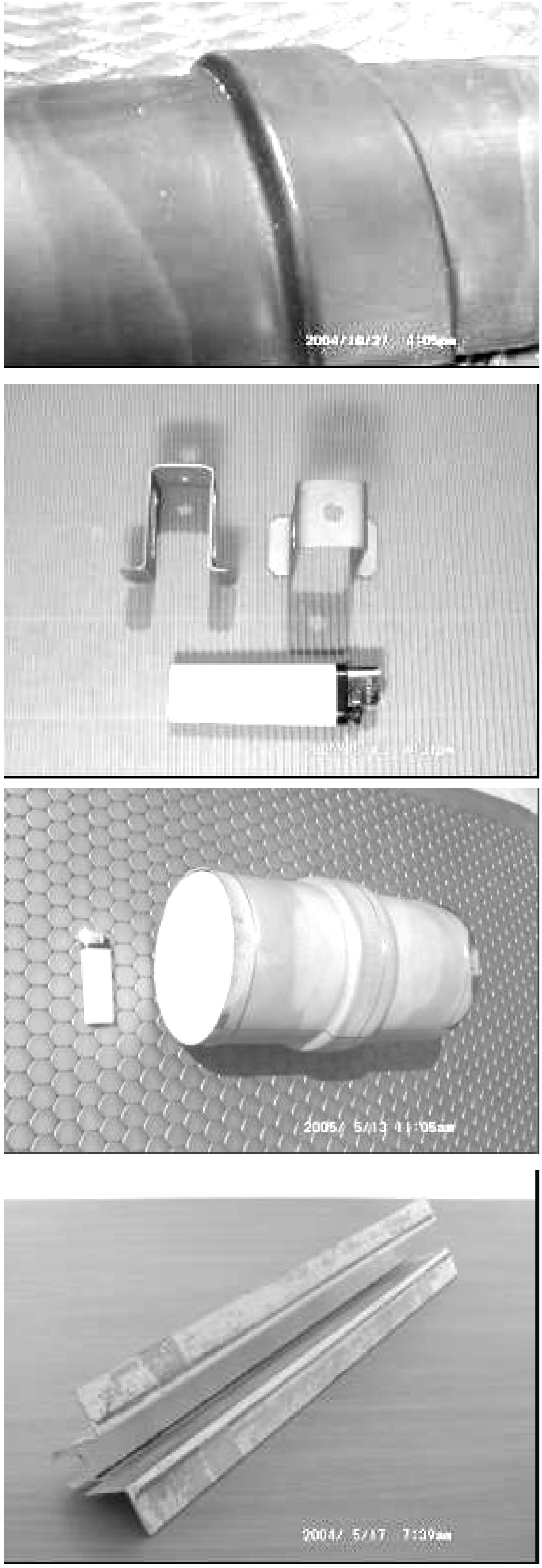

Fig. 7. Hot-formed parts

Summary

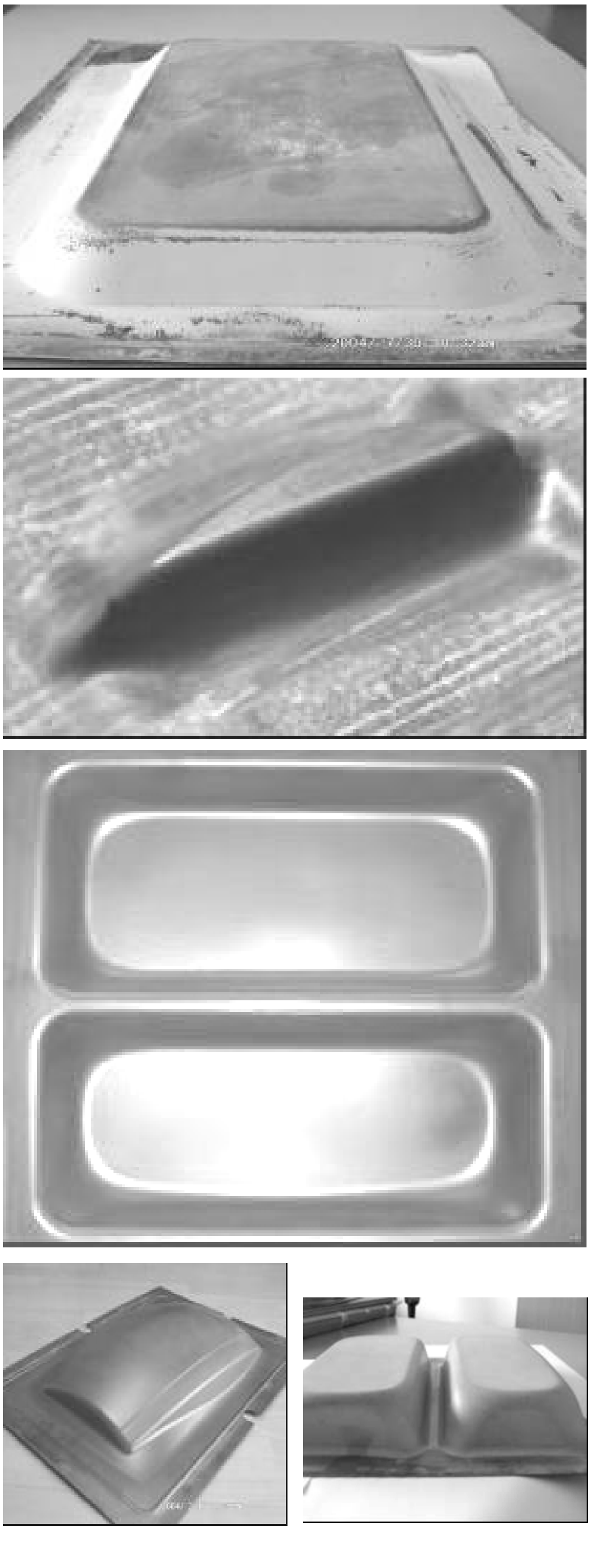

Fig. 8. SPF parts

Both the materials science investigations to find a new processing route to reduce production cost of TiAl sheet, the basic investigations to compare Diffusion Bonding performance of "conventional" with micro-grain material and the forming test proved successfully.

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