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Introductory Chapter: Novel Aspects of Titanium Alloys' Applications

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1. Introduction

Titanium is characterized by unique physical and chemical properties determining its specific applications. Since it was discovered in 1791 by William Gregor, its production was considered difficult and unprofitable for almost 150 years. In 1940, William J. Kroll developed commercially attractive production method based on the reduction of TiCl_4 using Na or Mg. Kroll process, in substantially unchanged form, is still the dominant process for titanium production. Titanium sponge is remelted (e.g., in vacuum arc process—VAR) to the form of commercial pure (CP) titanium or titanium alloys. Ingots are usually primarily processed by homogenization annealing or plastic working in the β -phase field. Products can be manufactured by casting and plastic working processes [1–5].

Titanium alloys—comparing with other structural materials—are characterized by high relative strength in the wide temperature range and very good corrosion resistance in many chemically aggressive environments. Such properties create many possibilities of improvements of technological processes, tooling and products in various industry branches. The main application areas of titanium alloys include transportation (mainly aerospace industry), chemical, food, machine building, papermaking, electrotechnics, electronic, fuel-energetic, metallurgical industries, and also geology and medicine [6]. Mechanical properties of titanium alloys are developed in plastic working and heat treatment processes, causing intentional microstructure evolution. It should be pointed that obtaining finished products having desired microstructure and properties is difficult due to some of the properties of titanium alloys, such as: high chemical affinity to oxygen, low thermal conductivity, high heat capacity and significant dependence of plastic flow resistance on strain rate. Quite often, hot-worked titanium products are characterized by various deformation conditions leading to formation of zones having various phase composition and dispersion and therefore various mechanical properties [7].

The main types of microstructure in two-phase titanium alloys are lamellar—consisting of colonies of α -phase lamellae within β -phase grains of several hundred microns in diameter (formed after slow cooling when deformation or heat treatment takes place at a temperature above the β -transus)—and equiaxed—consisting of globular α -phase dispersed in β -phase matrix (formed after deformation in the two-phase $\alpha + \beta$ field). Alloys having lamellar microstructure are characterized by relatively low tensile ductility, moderate fatigue properties and good creep and fatigue crack growth resistance, whereas in case of equiaxed microstructure, materials have a better balance of strength and ductility at room temperature and fatigue properties [8].

2. Perspective titanium alloys

Due to the high chemical affinity of titanium to atmospheric gases, the application of conventional titanium alloys at elevated temperature is limited. Single-phase α alloys can be used up to 600°C. Much higher heat resistance is achieved in intermetallic TiAl(γ)-based alloys. They exhibit superior specific strength-temperature properties, comparing to classical titanium alloys, steels, and nickel-based superalloys, in the temperature range from 500 to 900°C. Nowadays, TiAl-based alloys are considered as a high-potential material for aircraft engines. The main problems related to their applications are low ductility and the difficulty in processing to form a component. Over the last 30 years, three generations of gamma aluminide titanium alloys have been developed and the basic concept of the fourth generation has been described [9].

Another important feature of titanium alloys is the low value of Young's modulus (E)—from about 100 (for β -phase alloys) to 125 GPa (for α -phase alloys). Low-Young's modulus titanium alloys are considered as valuable biomaterials used for bone implants. It allows to prevent stress shielding, which usually leads to bone resorption and poor bone remodeling, when metal implants are used. The new generation of β -type titanium alloys composed of nontoxic and allergy-free elements, the so-called TNTZ alloys (e.g., Ti–29Nb–13Ta–4.6Zr), is characterized by Young's modulus lower than 90 GPa [10, 11]. TNTZ alloys can exhibit the E value lower than 20 GPa—they are called “gum metals.” It was found that the most important role in terms of obtaining the outstanding mechanical properties and the unique deformation behavior plays the oxygen content (stabilizes the bcc crystal structure by controlling the martensitic transformation temperature) [12].

Some of the β -type titanium alloys seem to have potential for even broader range of application due to shape memory effect. Shape memory alloys (SMA), especially Ni-Ti alloys (Nitinols), in recent years, have been mainly applied for biomedical implants and devices. However, due to the risk of Ni allergy and hypersensitivity, their long-term use is limited. The β -type Ti-based SMA have been extensively studied as promising candidates for Ni-free biomedical shape memory alloys [13].

3. Advanced material technologies

Novel aspects of material applications are also related to modern manufacturing and processing technologies. It is worth to note about the grain refinement, which causes high strength increase in metallic materials. Severe plastic deformation (SPD) methods allow to achieve high mechanical properties in conventional titanium alloys. Pure nanocrystalline titanium is characterized by the strength level very close to solution-strengthened titanium alloys (e.g., Ti–6Al–4V) [14]. Ultrafine-grained titanium alloys exhibit high superplastic deformability. Superplastic forming combining with diffusion bonding (SPF/DB) is a well-established method used in aerospace industry for the production of complex-shaped sheet elements made of titanium alloys [15].

Other developing processing areas are: surface engineering, joining methods (e.g., friction stir welding—FSW), and machining [3, 4]. Highly promising are especially additive manufacturing (AM) methods. In contrast to conventional processes (casting, plastic working, or expensive machining), the AM allows to produce near-net shape structural parts—minimizing finishing techniques cost (machining) and achieving mechanical properties at least at the level of cast and wrought products. AM of titanium alloys has been used quite quickly to many applications in aerospace and medical industry. Titanium and its alloys are considered as ideal materials for the additive manufacturing industry [16].

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