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# A study of the properties and development in technology for obtaining multi-component systems of particle reinforced aluminum and titanium alloys

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Abstract: The article analyzes the groundwork on the influence of alloying contaminants on the structure and mechanical properties of aluminum alloys. Aluminum has become widely used in various parts of machine-building due to its physical properties. However, the main task of modern material science is to increase the strength of aluminum alloys. Therefore, today there is the development of materials and alloys based on aluminum with alloying constituents (copper, silicon, magnesium, zinc, mangan), which are administered in aluminum mainly to increase its strength. Especially attractive are properties of aluminum-doped by transition metals, in particular scandium, zirconium, iron, etc. Finally, conclusions are drawn in order to develop a material based on aluminum with increased hardness, durability, and crack resistance.

Keywords: aluminum alloys, multicomponent systems, iron, particle reinforced phase



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## Introduction

The development of technology leads to an increase in the consumption of various structural materials, in which the strengthening is realized due to the formation of various intermetallic phases during sintering or crystallization. Composite materials have a special place in this aspect, in particular multicomponent, two- and

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three-component systems (Gumen et al., 2019; Gumen et al., 2021). In modern machine-building, aluminum alloys have become widespread due to their low density (2.5-2.8 g/cm$^3$), high specific strength, high resistance against atmospheric corrosion, relatively low cost, and ease of obtaining and processing. Therefore, today's development of materials and alloys based on aluminum is relevant.

## 1. Al-Fe alloys

The structure of alloys based on aluminum is gained mainly from α-solid solutions and intermetallic phases at room temperature. Alloying additions (copper, silicon, magnesium, zinc, mangan) are introduced in aluminum mainly to increase its strength. In industry, aluminum alloys based on the following systems: Al-Cu, Al-Si, Al-Mn, Al-Mg, Al-Cu-Mg (Kaufman & Rooy, 2004; Sverdlin, 2003) are used. However, today, especially attractive are the properties of aluminum alloys doped by transition metals, in particular scandium, zirconium, iron, etc.

The main concomitant admixtures of aluminum are iron and silicon. Where they form triple compounds of these metals α-(Al-Fe-Si) and β-(Al-Fe-Si) in a plate or needle form. The composition of the α-phase is described by the formula $Fe_2SiAl_8$, and β-phases – $4FeSiAl_5$. In casting, the following phases: $FeAl_3$, $Fe_3SiAl_{12}$, $Fe_2Si_2Al_9$ may be present in pure aluminum (Fig. 1).

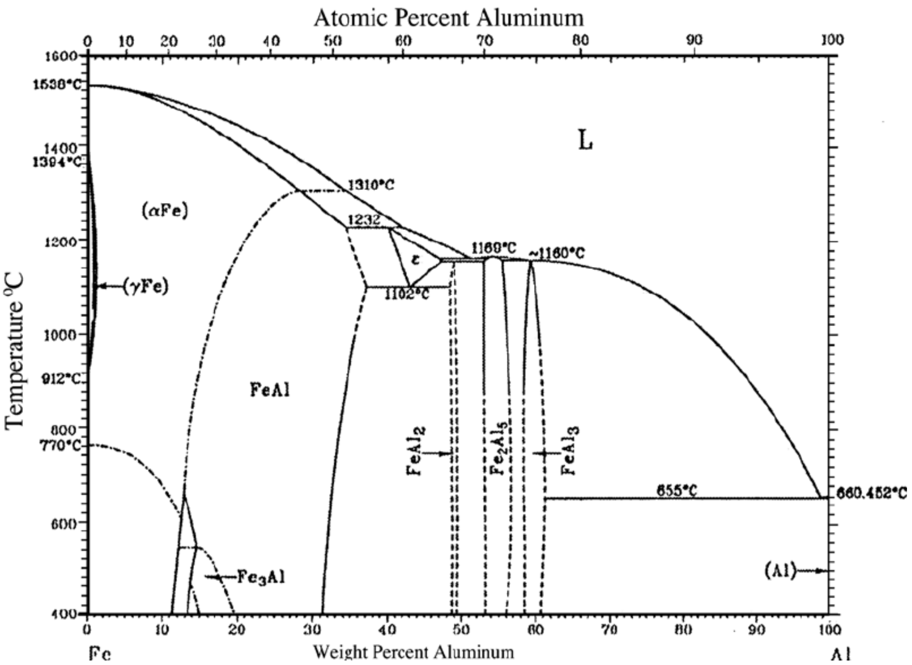


**Fig. 1.** Phase diagram Fe-Al (Kaufman & Rooy, 2004)

However, according to ASTM, the continuum of iron in aluminum greater than 0.4% by weight makes metal unsuitable for use, resulting in the need for additional refining of the material. A well-developed system of brittle intermetallics is formed in the structure of the material during crystallization. As a result, aluminum becomes more brittle.

An option for solving this problem may be the use of powder metallurgy, where the powder should be used as the starting material, intermetallic compounds should be used as a particle reinforced phase. That is why it is urgent to develop the theoretical and technological aspects of derivatization particle reinforced alloys based on aluminum with high iron content.

The structure of the Al-Fe alloy casting comprises an existing plate phase of $Al_3Fe$, which induces the emergence and propagation of microcracks, and therefore reduces the mechanical strength of the material. On the other hand, with an increase in iron content in the range of 0.07-1.09% by weight, there is an improvement in the heat resistance of the material, which promotes the use of an aluminum alloy with iron in electrical engineering and machine building.

Some authors (Korotkikh et al., 2020) indicate an increase in the ability to weld the Al-Fe alloy with an increase in the number of intermetallic compounds. The high strength of Al-Fe alloys can be achieved as nanograined structures and a solid-state solution strength improvement.

The improvements in the physical properties of aluminum alloys in increasing the content of iron show the need to improve the method of obtaining an Al-Fe system and the study of mechanical characteristics of the material obtained.

Also, quaternary systems are concisely studied due to the complexity of structure formation and are described by quaternary phase diagrams. Those systems are difficult to manipulate and analyze. Unprecedented leaders in the materials used to create the most innovative alloys amid metals remain Ti, Al, and Fe and their borides, which are due to mechanical, structural, and technological properties.

The method of production of titanium alloy castings is adapted for the production of the iron content of 7% by weight and aluminum 1% by weight. The addition of alloying iron to straight titanium inspires the dilatation of the titanium β-phase zone due to a decrease in the temperature of polymorphic transformation, so an iron can be used as a stabilizing additive. However, the method of powder metallurgy allows a variation in the percentage of components, so it is advisable for the manufacture of this system.

## 2. Al-Fe-Ti alloys

Initially, Fe-Ti alloys are prepared by electron-beam melting, and then the triple alloys Fe-Ti-Al are made in an arc furnace using an argon atmosphere (Weiland et al., 1999). However, the indicated approach causes increased resource and energy--consumption, which significantly reduces the profitability and efficiency of technology. In addition, the introduction of B into the Fe-Ti-Al system will increase the hardness and increase the melting point of the material, and therefore promotes the improvement of wear resistance.

Some works (Lepakova et al., 2020) indicate that high-temperature synthesis of Ti-Al-B does not provide triple compounds, but $TiB_2$, TiB, and $AlTi_3$ compounds (Fig. 2).

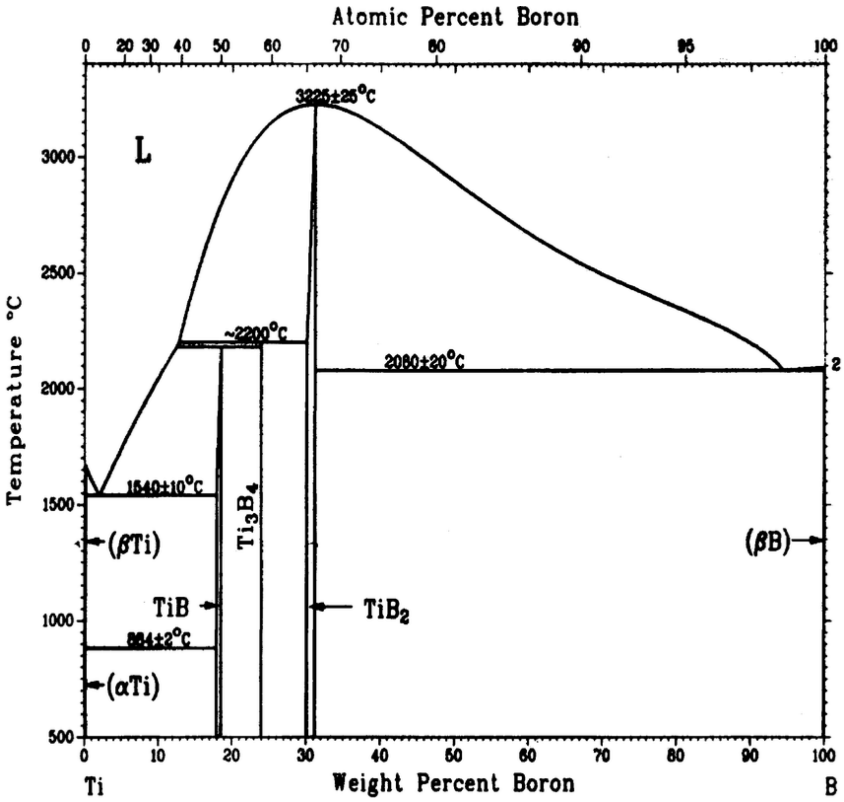


**Fig. 2.** Phase diagram Ti-B (Lepakova et al., 2020)

The coating of Ti-Si-B demonstrated almost 2.5 times higher wear resistance than $Ti_3SiC_2$ while collating the performance characteristics of the coating. As a result, the introduction of boron intensifies the processes of reinforcing titanium alloys, due to the formation of simple and complex borid phases (Korotkikh et al., 2020).

Some sources demonstrate the study of the structure and chemical composition of the Ti-Fe-Al-B system (Ibrahim et al., 2019). The balance of equilibrium is built in the quaternary system. The results are the basis for improving the technology for obtaining the Ti-Fe-Al-B system and studying the properties of the resulting material.

Previous studies of the Al-Ti-B system with the addition of Fe, Ni, CO have shown memory form in the study by the method of reverse scattering of electrons (Kocks et al., 2000; Lee et al., 2020). The increasing scope of multicomponent Ti-Fe-B systems will greatly expand the possibility of the application of the developed material.

## Conclusion

Aluminum has become widely used in various parts of machine-building due to its physical properties. However, the main task of modern material science is to increase the strength of aluminum alloys. Therefore, today there is the development of materials and alloys based on aluminum with alloying constituent (copper, silicon, magnesium, zinc, mangan), which are administered in aluminum mainly to increase its strength. Especially attractive are the properties of alloys of aluminum-doped by transition metals, in particular scandium, zirconium, iron, etc.

Summing up, the study of the properties and development of technology for obtaining multi-component systems of Ti-Fe-Al-B can be seen as the main vector of development of future material science. And the application of the results is not limited, as the control of the content of the components offers opportunities for new technological parameters and physical properties of the Ti-Fe-Al-B system.

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