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Metallurgy

Production of Layered Composite Materials Based on Adhesively Less Compatible Pairs of Metals (Iron-Aluminum, Titanium-Aluminum) by the Liquid Phase Method

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(Presented by Academy Member Tamaz Shilakadze)

The paper discusses the process of forming composite plates based on less compatible pairs of metals (aluminum-steel, aluminum-titanium) using the “non- ingot rolling” method. In order to increase the reliability of the resulting material, an original method is used to establish an additional mechanical connection between the layers, the so-called riveted connection, which involves the use of a profiled steel or titanium sheet as the middle layer. The choice of less adhesively compatible pairs depends on the following circumstances. The difference in the strength and mass ratios of high-alloy steel and aluminum alloys allows, depending on the purpose of the composite material, to produce material of the same weight and increased strength or the same strength, but less weight. The same applies to titanium-aluminum. Taking into account the conditions of further operation of the resulting layered material, a technique has been developed for the optimal number and diameter of holes in steel or titanium sheets used as the middle layer. *© 2024 Bull. Georg. Natl. Acad. Sci.*

crystallizer front, composite material, steel, aluminum, packet transfer, “non- ingot rolling”

Composite materials are made from one type of material, for example, aluminum + aluminum, steel + stainless steel, as well as from different materials: steel + copper, steel + aluminum, titanium + aluminum, etc. There are adhesively highly compatible and less compatible pairs [1-3]. The last group includes pairs steel-aluminum and titanium-aluminum, which is our area of interest.

This choice is due to the following circumstances. If the adhesion problem is solved, these metal pairs make it possible to create layered materials with a much larger range of applications. Due to the large difference in the ratios of strength and specific gravity of steel and aluminum ($\sigma in/\sigma shaft \approx 3.3$, $\gamma st./\gamma al. \approx 2.7$), it makes possible to obtain composite materials, taking into account their purpose, the same weight with increased strength, or vice versa, the same strength but with less weight. The same can be said in the case of a titanium-aluminum pair (titanium is inferior in strength to high-alloy steel, but is much lighter than steel.

In the production of composite materials, low adhesion in less compatible pairs is due to the formation in the transition zone between the layers of intermetallic compounds (FeAl, FeAl2, FeAl3, Fe2Al5, TiAl, TiAl2, TiAl3, Ti2Al5), which are characterized by high fragility and, under conditions of impulsive impacts, are the center of destruction of the layered material [4].

The process of formation of intermetallic compounds begins at 400-450°C and develops with increasing intensity as the temperature rises. This problem arises when producing layered materials using liquid-phase methods (which refers to the non- ingot rolling" method), but when producing layered composite materials using the "non- ingot rolling" method, molding and rolling are completed in just 2-4 seconds and immediately after the workpiece leaves the crystallizer, it passes through a water cooling zone, which practically eliminates heating of the steel or titanium sheet to a temperature of 400-450^{0}C. However, to solve this problem at the Institute of Metallurgy and Materials Science named after. F. Tavadze developed a rather original method for establishing an additional mechanical connection between the layers. A perforated sheet is used as the middle layer (see Fig. 1).

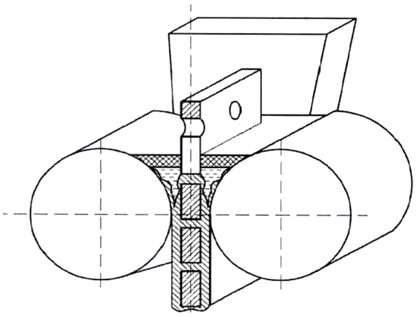

Fig. 1. Using perforated sheet as the middle layer in the composite.

During the casting process, bare metal flows through the holes and, once solidified and deformed, acts as a rivet. The dimensions and number of holes are determined taking into account the expected loads [5-11]. When using a riveted connection, the main condition is that the rivet material is not stronger than the material of the sheets being joined. Thus, this requirement is fully met for both steel-aluminum and titanium-aluminum layered composite materials.

In the case of using a rivet connection, it would be fair to assume both dynamic and impulsive loading. There is only one force acting in the transverse direction – the transverse force Q; 1. Forces are evenly distributed over the cross section of the material; 2. In the case when several sheets are connected together, the resulting forces in them are distributed evenly.

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The condition for shear strength for riveted joints is as follows:

$$\tau_{\text{cat}} = \frac{Q}{F_{cat}} \le \left|\tau_{\text{cat}}\right|,$$

where Q is the shear force under load and is equal to

$$Q = \frac{P}{Z_i},$$

where P is total load; Z – quantity of rivets; i – number of sheets minus –1; $F = \frac{\pi d^2}{4}$ – cross-sectional area of one rive; [τ_{cat}] – the maximum permissible force for shearing the rivet material, which is determined by the formula

$$\sigma_{cat} = (0.25 - 0.35)\sigma_{fluid},$$

where $\sigma_{fluidity}$ is the yield strength of the rivet material.

The strength condition of the rivet on the cut will take the following form:

$$\sigma_{cat.} = \frac{4Q}{\pi d^2 Z_i} \le (0.25 \div 0.35)\sigma_{fluid}.$$

In case of multiple rivets:

$$\sigma_{cat.} = \frac{4Q}{n\pi d^2 Z_i} \le (0.25 \div 0.35)\sigma_{fluid}.$$

Cutting when riveting, the strength condition (rivet) is as follows:

$$Q = \frac{P}{zi}.$$

As an example, consider a specific case where a layered material will be used in the defense sector, in particular in the form of armor [9-12].

Kinetic energy of a bullet upon impact is

$$W_{kin.} = \frac{mv^2}{2}.$$

When a bullet hits armor, the kinetic energy of the bullet is $W_{kin.} = \frac{mv^2}{2}$, where m is the mass of lead; v – the speed of the bullet. It creates force – $\frac{mv^2}{2} = Fs$; F – armor resistance forces; S is the thickness, therefore $F = \frac{mv^2}{2S}$.

Total load $F = P$. In turn, $Q = \frac{P}{zi}$ and we get $\tau_3 = \frac{mv^2}{2Szi} \le (0.25 \div 0.35)_{fluid}$.

In the theoretical calculation, we used the characteristics of D16 duralumin, rather than armored aluminum, where the tensile strength – σ kg/m^2 is 48.5; yield strength – $\sigma_{0.2}$ kg/mm^2 – 34.5; relative elongation-%-16; Strength H_B-70.

Also, when entering the kinetic energy of a bullet, we used data from the CBD sniper rifle, since it has the highest kinetic energy among all other light weapons: weapon type CBD rifle – bullet material steel, caliber – 7.62 mm, bullet area – 0.45 mm^2, weight – 9.6 g, bullet speed – 830 m/s, kinetic energy – 3306.7, sheet thickness – 2.5÷5.8 mm. All this will create an additional reserve when using composite armor material.After entering the numerical values, we received that the number of holes per 1 m^2 should be at least twenty-four, if the diameter of the holes does not exceed 4 mm, which is less than the caliber of any light firearm, and not exceed 0.03% of the total area of the armor material, which quite acceptable.

From the resulting composite plates, samples were made for structural and metallographic examination of a sample of the transition zone between steel and aluminum alloy. The structure study was carried out using a Neofot-32 microscope.

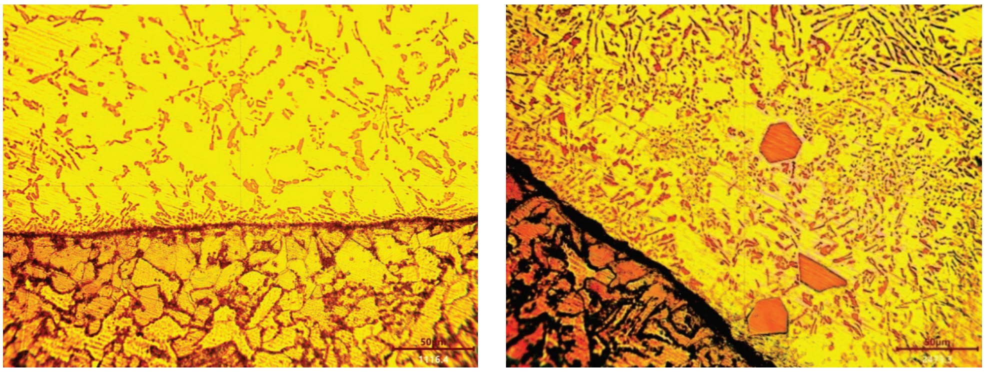
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Fig. 2. Transition zone between steel and aluminum, X400.

Figure (2 a) shows the transition zone between aluminum and steel. The section is poisoned with 4% nitric acid. Magnification X400. As can be seen in Fig. 2 (a) and (b), there is no delamination between the layers of composite. Structure b. Nitride inclusions are visible on the matrix.

The samples mentioned above were examined on a scanning electron spectral microscope TM 3030 PLIUS "HITACHI".

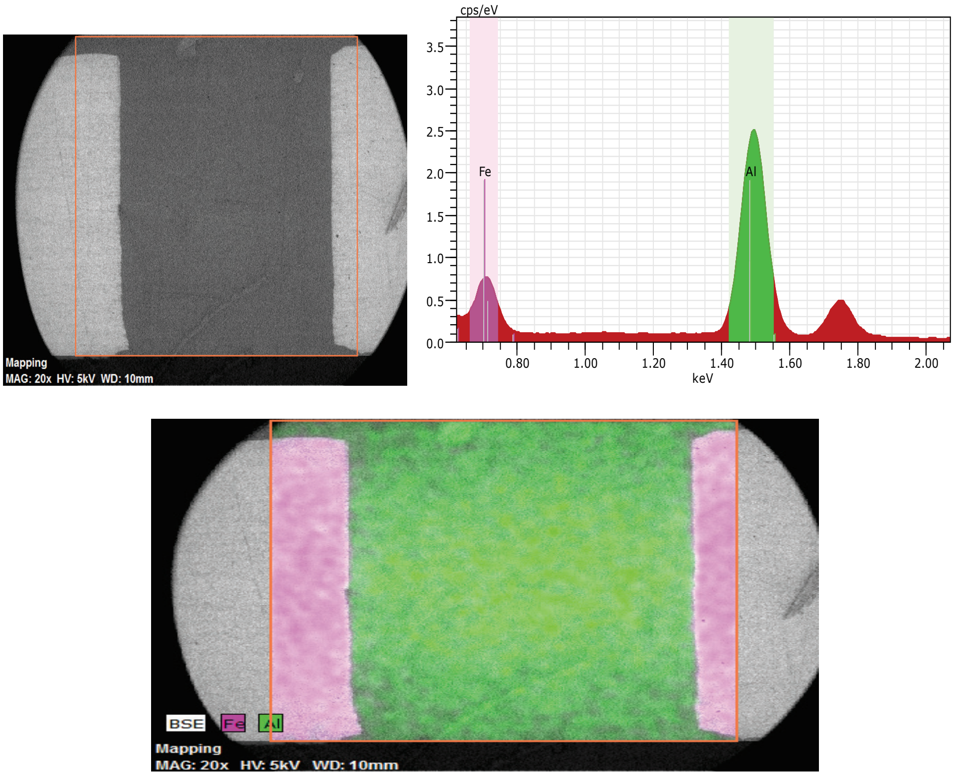

Fig. 3. The border between steel and aluminum. Magnification X20.

Figure 3 shows a composite sample of steel and aluminum cast using the "non-ingot rolling" method.

Rivets were used to fill the metal well. The photo shows that the process is paid off. Composite ingots were cast. There is a clearly defined transition zone on both sides. The 10 mm thick steel holds well on both sides. No delamination is observed between the composite layers.

As can be seen from the Figures, although the thickness of the outer layer (10 mm) when casting a layered composite is the same as when casting a 10 mm thick sheet using a method without ingot rolling, the casting speed (and, accordingly productivity) is lower, which is quite logical, the cooling intensity of the casting on the side of the steel sheet is significantly less than that of a crystallizer equipped with water cooling. However, when casting a layered composite, the overall productivity of the process increases by 25-30%.

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მეტალურგია

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ნაშრომში განხილულია „უსხმულო გლინვის“ მეთოდით ნაკლებად თავსებადი ლითონური წყვილების ბაზაზე (ალუმინი-ფოლადი, ალუმინი-ტიტანი) კომპოზიციური (ფენოვანი) ფილების ჩამოსხმის პროცესი. მიღებული მასალის საიმედოობის გაზრდის მიზნით, ფენებს შორის გამოყენებულია დამატებითი მექანიკური კავშირის დამყარების ორგინალური ხერხი, ეგრეთ წოდებული, მოქლონური კავშირი, რაც შუა ფენად პროფილირებული ფოლადის ან ტიტანის ფურცლის გამოყენებას გულისხმობს. ადჰეზიურად ნაკლებად თავსებადი წყვილების არჩევანი განპირობებულია შემდეგი გარემოებით. კომპოზიციური მასალის დანიშნულებიდან გამომდინარე, მაღალლეგირებული ფოლადისა და ალუმინის შენადნობების სიმტკიცის ზღვრებსა და კუთრი წონების ფარდობათა სხვაობა საშუალებას იძლევა, დამზადდეს მასალა იმავე წონისა და გაზრდილი სიმტკიცის ან იმავე სიმტკიცის, მაგრამ ნაკლები წონის. იგივე ითქმის ტიტან-ალუმინის შემთხვევაშიც. მიღებული ფენოვანი მასალის შემდგომი ექსპ-

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