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The Synthesis of Two- and Multilayer FGMs

Guram Varshalomidze, George Oniashvili, Zurab Aslamazashvili,
Garegin Zakharov

F. Tavadze Institute of Metallurgy and Materials Science, Tbilisi

(Presented by Academy Member R. Adamia)

ABSTRACT. Two- and multilayer functionally graded materials (FGM) are produced via high-temperature self-propagated synthesis (SHS). Their 1 and 2 layers are produced using high-temperature thermo-mechanical treatment (HTTMT). One layer of the FGMs produced by SHS-compacting and tested with an original device is composed of one or two refractory compounds (borides, diborides, carbides), while the other plastic layer is composed of steels, metals or intermetallics. *© 2008 Bull. Georg. Natl. Acad. Sci.*

Key words: *graded materials, synthesis, layer, intermetallics, hardness.*

Several modern machines and mechanisms work in severe conditions characterized by pulse intensive impact that leads to decrease of mechanical properties or deviation of some performance parameters. Hard alloys with high physical and mechanical properties, make them very useful in several branches of engineering [1,2].

However, wider application of the material is limited by their brittleness and inability to withstand shock stresses [3]. This deficiency of hard alloys may be avoided by creation of graded materials with highly dispersed grains [4]. Due to the peculiarities of SHS-compacting, production of oversaturated solid solutions with non-equilibrium structure with fine grains (1-3μ) is feasible. Moreover, heat treatment may provide precipitation of more fine-grained phase in an amount sufficient to alter the mechanical properties of the final product.

In the present paper the results of development of two- and multilayer graded materials are discussed, which on the one hand, have properties intrinsic to hard alloys, and on the other hand, they possess a high impact strength as well.

During production of functionally graded materials (FGM) via SHS-compacting, common SHS equipment is used [5]. Impact tests were conducted using an original device (Fig. 1).

The device consists of 7m long and 250mm diameter pipe. The pipe with different loads falls free on the

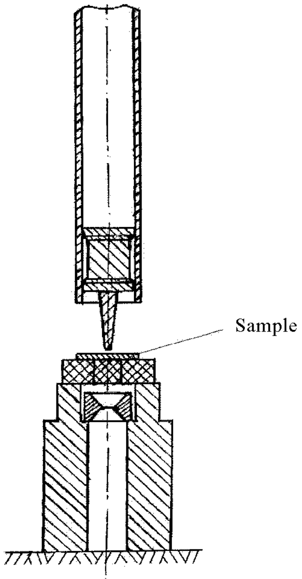


Fig. 1. The device for impact tests

Table 1

Refractory components	$TiB_{0,4}$, $TiB_{0,5}$, $TiB_{0,6}$, TiB_2 , $(Ti,Cr)C$, $Me_{23}C_6$, TiC
Intermetallics	TiAl, Ti_3Al, $TiAl_3$
Metals	Ni, Cr, Ti, Cu
Alloys	X20H80, X40H60, X17H2, X18H15, $Cr_{12}Fe_{36}Ti_{10}$

tested material from different heights. The tip of the falling pipe represents a sharp cap of different diameters, made from strengthened steel (see Fig. 1).

Three different FGMs are developed using the SHS-compacting which contain 1 or 2 HTTMT (high-temperature thermo-mechanical treatment) layers. At least one layer is an oversaturated solid solution. Additional heat treatment provides increase in strength of the FGM, and this results in the improvement of the material's shock resistance.

FGMs produced via SHS-compacting and tested with the above device are composed of one or two refractory compounds (borides, diborides, carbides) intermetallics, metals and their alloys. Possible components of the FGMs are shown in Table 1.

The first material consists of one layer with iron-based alloy, undergone HTTMT (thickness 1-1.5mm), and the second layer containing titanium-chromium carbide (3.5-4mm).

In Fig. 2 the alteration of microhardness of this FGM is schematically shown. The microstructure of layers I and II in the transition zone (a,b) is shown in Fig. 3.

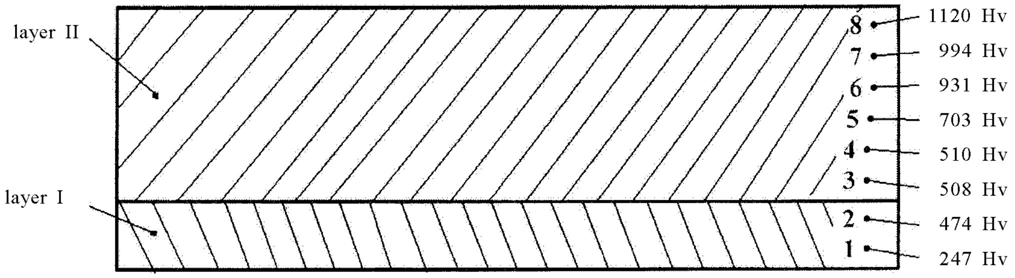
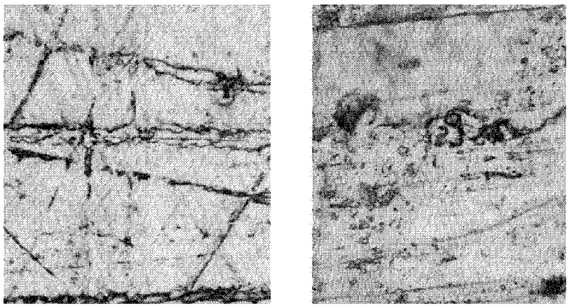


Fig. 2. Variation of microhardness in the sample of the first FGM



a) layer I b) layer II

Fig. 3. Microstructure of layers I and II in the transition zone (a, b).

The second material consists of three layers. Layer I – titanium boride (2–2.5m); layer II – titanium-based HTTMT alloy (up to 1mm); layer III – solid solution of titanium diboride and titanium carbide (3–3.5mm).

In Fig. 4 the alteration of microhardness of the second material along the height of the sample is shown.

The microstructure of the three layers of the second FGM is shown in Fig.5. The respective X-ray spectra of the layers in this material showed the following distribution of local compositions in the layers:

Layer I. (Ti – 88.39 weight %, B – 11.61 weight %), Layer II. (C – 6.77 weight %, Ti – 89.08 weight %, Cu – 2.15 weight %, B – 1.8 weight %), Layer III. (C – 13.55 weight %, Ti – 69.98 weight %, Cu – 4.47 weight %, B – 5.6 weight %).

The third material is composed of four layers (Fig.6.). Two of them are HTTMT-alloys (the first is an iron-based alloy, 1–1.2 mm, and the third is a titanium-based alloy, up to 1mm). The remaining two layers represent oversaturated solid solutions: the second layer – titanium-chromium carbide, 3.5–4 mm, and the fourth layer, solid solution of titanium diboride and titanium carbide, 4–4.5 mm).

The microstructure of the layers (a, b, c, d); Respective X-ray spectra diagrams (e, f, g, h), are presented in

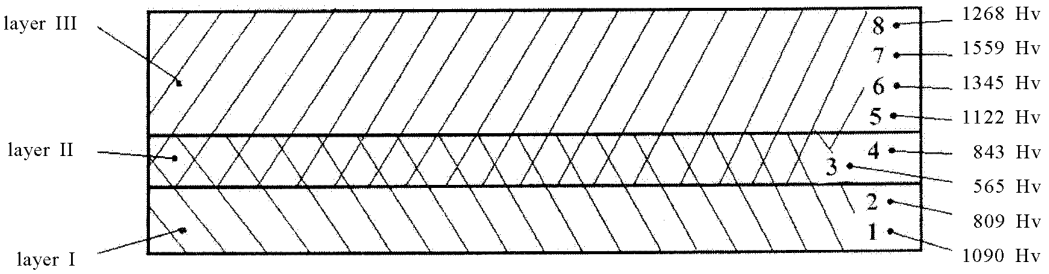


Fig. 4. Variation of microhardness of the second FGM.

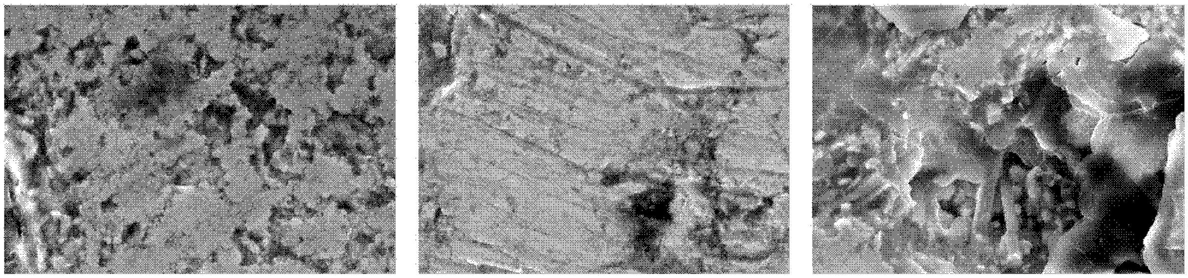

a) layer I b) layer II c) layer III

Fig. 5. Microstructure of the three layers of the second FGM (a, b, c).

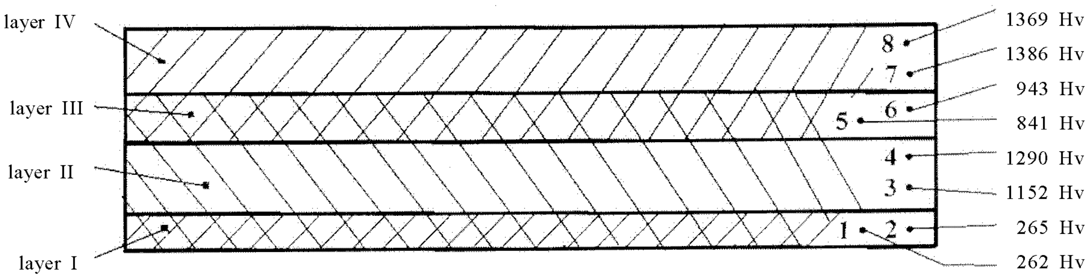


Fig. 6. Variation of microhardness of the fourth material along the height of the sample.

Fig.7. The measurements of the local compositions in the layers show the following distribution of the elements in weight %:

Layer I – (Fe – 67.0 weight %, Cr – 17.9 weight %, Ni – 14.7 weight %, C– 0.4 weight %).

Layer II – (B – 1.6 weight %, C – 14.6 weight %, Ti – 54.7 weight %, Cr – 6.9 weight %, Fe – 12.9 weight %, Ni – 4.8 weight %).

Layer III – (C – 7.9 weight %, Ti – 71.6 weight %, Cr – 4.6 weight %, Fe – 11.99 weight %, Ni – 2.3 weight %, Cu – 1.03 weight %, B – 1.02 weight %.

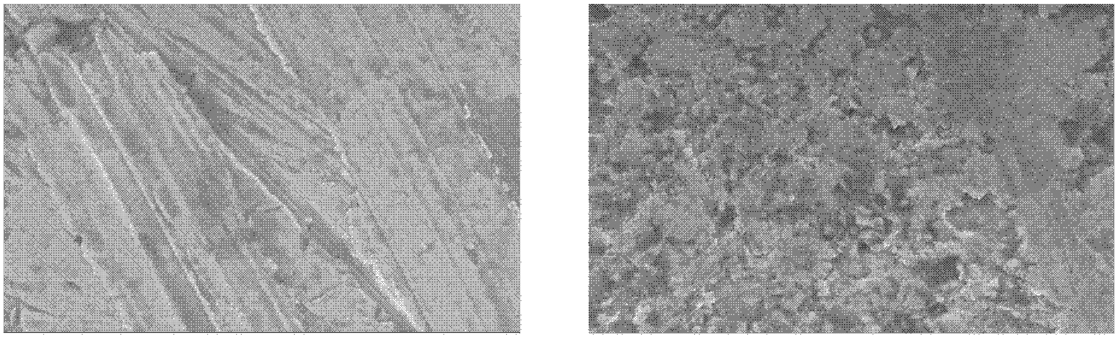
Layer IV - (C – 13.2 weight %, Ti – 68.58weight %, Ni – 1.11 weight %, Cu – 7.12 weight %, B – 5. 6 weight %).

It should be noted that, depending on the weight ratio of the preliminarily compressed layers, there is a possibility to govern the phase composition of the FGM and even its quality.

The energy transmitted to the sample during impact ranges from 130 to 3400 J, i.e. 5 to 74 J per 1mm^2. To reduce the rigidity of the impact auxiliary material is used, such as synthetic materials, so that their content does not exceed 10-15% of the total mass of the FGM.

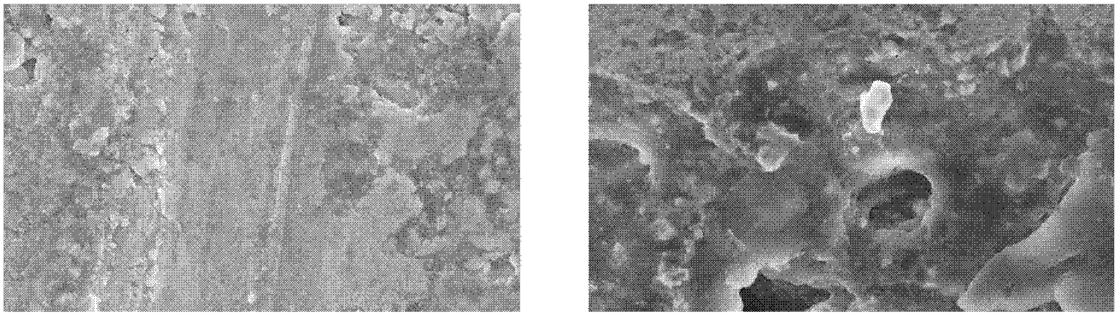
To simplify the comparison process between different FGMs with different density along the thickness of the samples, we introduce a “unit square weight” of the sample. In Fig. 8 impact energy versus the weight of material per unit square is shown for different FGMs.

As is obvious from Fig.8, this dependence is deviated from the linear, depending on the weight of the sample. The latter means that increase of sample’s thickness over some definite value does not appreciably lead



a) Layer I

b) Layer II



c) Layer III

d) Layer IV

Fig. 7. Microstructure of the layers in the third material (a, b, c, d);

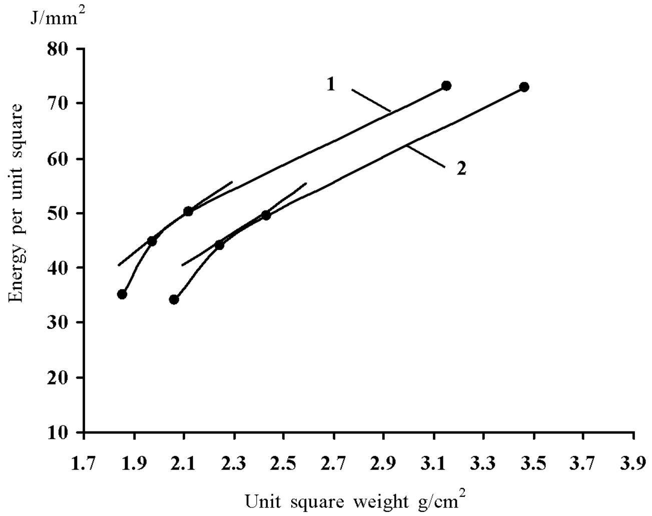


Fig. 8. 1 – FGM based on oversaturated titanium-chromium carbide; 2 – Titanium-based composite material.

to increase in shock resistance of the sample. Here it should be noted that use of high-strength steel instead of composites and FGMs leads to increase in the "unit square weight" by the factor of 1.7. Consequently structures made from FGMs are 1.7 times lighter than those made from special high-strength steel.

მასალათმცოდნეობა

ორ და მრავალფენიანი ფუნქციონალურ-გრადიენტული მასალების სინთეზი

გ. ვარშალომიძე, გ. ონიაშვილი, ზ. ასლამაზაშვილი, გ. ზახაროვი

ფერდინანდ თავაძის მეტალურგიისა და მასალათმცოდნეობის ინსტიტუტი, თბილისი

წინამდებარე ნაშრომში აღწერილია ორ და მრავალფენიანი ფუნქციონალურ-გრადიენტული მასალების (ფგმ) მიღების ტექნოლოგიის შემუშავების შედეგები. ფგმ-ს ერთი მხრივ ახასიათებს სალი შენადნობების თვისებები და მეორე მხრივ გააჩნია კარგი სიბლანტე. ფგმ-ის კომპაქტირებით მიღების პროცესში გამოყენებული იქნა თვითგავრცელებადი მაღალტემპერატურული სინთეზის (თმს) მარტივი დანადგარები, ხოლო გამოცდები დარტყმაზე ჩატარდა ორიგინალური დანადგარის გამოყენებით. თმს-ის კომპაქტირების მეთოდით შემუშავებულ იქნა სამი სხვადასხვა ფგმ. ისინი შედგებიან 1 ან 2 მაღალტემპერატურული თერმომექანიკური დამუშავებით მიღებული ფენებისაგან, რომელთა შორის ერთი მაინც წარმოადგენს გადაჯერებულ მყარ ხსნარს. დამატებითი თერმული დამუშავება განაპირობებს ფგმ-ის სიმტკიცის გაზრდას, რაც თავს იჩენს მიღებული მასალის დარტყმისადმი მედეგობის გაზრდაში. ფგმ, მიღებული თმს-ის კომპაქტირებით და შემდეგ გამოცდილი ზემოთ ნახსენები დანადგარით, შედგენილია ერთი ან ორი მხურვალმედეგი ნაერთისაგან (ბორიდები, დიბორიდები, კარბიდები), ინტერმეტალიდებისაგან, მეტალებისაგან და მათი შენადნობებისაგან.

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