Metallurgy

Investigation and Development of Modern Technologies for Gradient Throat Plates

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ABSTRACT. **The topical problem of research and development of modern technological processes for production of gradient materials, in particular, gradient throat plates is considered in the paper. The goal of the work is to produce a two-layer armor plate consisting of high quality plates (HRC 62, KCU 0.5; 48-50 HRC KCU 0.9) with special physical and chemical properties. Such armor plates can resist to ballistic effect or any other impact. Two kinds of technologies developed for production of the two-layered armor plates with the above-said properties are described in the paper: production of armor plates by means of ultrahigh impulse pressure and by pack rolling. To this end, a complete technological cycle of production was developed including the steel smelting, casting and treatment under pressure and thermally. The two-layer plates was produced by means of ultrahigh pressure (explosion) in a classical way: the angle of explosion - 2.6^0 - 3.5^0; the explosive – ammonite (6 ЖВ); the charge height - 35mm; detonation velocity 4.2 km/sec. The working surfaces were treated by inductive method in order to give them hardness reaching HRC 62 and HRC 48, respectively. The other way of production of the layered plates developed recently is the pack rolling. However, the pack rolling is also connected to some difficulties. In pack rolling a special metal powder is applied between the pretreated layers for better adhesion; then, the layers are packed and after heating up to 1150^0C are rolled according to the preliminary defined technology of pressing. As a result, a two-layer throat plate of HRC 62 and HRC 48 is obtained. One of the significant properties of the layer production is the adhesion strength. According to the recommendation 10885-85 of the State Standards the admissible adhesion strength should be above 147mgpa-15kgp/mm^2. The adhesion strength of the layers produced by the above described technology of pack rolling was 170mgpa (17kgp/mm^2); the adhesion strength of the layers produced by the above described technology of explosion also satisfied necessary requirements.** *© 2015 Bull. Georg. Natl. Acad. Sci.*

Key words: *pack rolling, adhesion strength, gradient materials.*

Modern advanced technology has a growing demand on special materials of high-quality such as gradient materials. Nowadays our country has no experience in production of gradient materials in particular gradient throat plates, which are highly necessary for us. Therefore, it is reasonable to solve

Table 1. Table of rolling

Pass	Height Hn mm	Width Bn mm	Length Ln	Pressing		mm ΔBn	Deform. site Ln mm	Contact area mm^2
				mm	%			
I cast	52	86	200	15	29	4	45.8	3941
II	37	90	268.6	9.0	25	3	35.5	3195
III	28	93	343.5	6	22	3	29.0	2695
IV	22	93.8	433.5	4,0	19	0.8	23.7	2220
V	18	94	528.7	4.0	18	0.2	21.5	2487
Maximum deformation: P = 50.2 t=500kn								
Division into two L = 264 and the secondary heating up to 1180C^0								
VI	13	94	365.5	5.0	28	0	20.5	1926
VII	10	94	475.0	3.0	23	0	16.7	1573
VIII	8.0	94	594.0	2.0	20	0	15.9	1492
IX	6.2	94	766.4	1.8	22	0	13.0	1218
	5.0	94	950.0	-----	----	0		
Maximum deformation P = 21.9 t= 2190 kn								

Table 2. The dynamics of the temperature drop

Pass №	$t_1{}^0C$	Delay, sec	$t_2{}^0C$	$t_1 - t_2$	Passing №№	$t_1{}^0C$	Delay, sec	$t_2{}^0C$	$t_1 - t_2$
I	1150	10	1060	90	V	1180	10	1080	100
II	1060	10	990	70	VI	1080	10	1000	80
III	990	10	930	60	VII	1000	10	970	30
IV	930	10	900	30	VIII	970	10	950	20
					IX	950	10	930	20

such a topical problem in time.

There are two kinds of gradient throat plates: 1) Single-layer gradient plates with different physical and chemical properties of the surfaces; 2) Layered gradient plates consisting of the layers with different physical and chemical properties

According to the references [1-7], in double-layer throat plates one of the layers should provide surface hardness HRC 62 and the impact strength of 0.5 mj/m^2 in a quenched and slightly pulled position, and the other layer should provide surface hardness of HRC 48-50 and impact strength of 0.5 mj/m^2 KCU 0.9mj/m^2.

Such plates can resist to the ballistic or any other impact. In order to develop the technology of gradient plates including the double-layer throat plates the Institute of Metallurgy carried out research [8] including the present one in two main directions:

1. Production of the double-layer plates by means of the ultrahigh pressure - explosion
2. Production of the double-layer plates by means of pack rolling.

The low-carbon content low-alloy steel of the chrome-nickel molibdenium type was selected as the basic material for the layer of high hardness. Complete technological cycle of production was developed including steel smelting, casting, and pressure and thermal treatment.

An induction furnace of 10-kg with high-frequency current and basic lining was selected for steel smelting. The technically pure "armco" iron was used as the burden material.

In order to increase its strength and the engine capacity the Laboratory mill "duo-200" was modernized and reconstructed for steel rolling. A special computer system was assembled for automatic control and record of thermal, electric and strength parameters.

With account of the overall dimension and mechanical properties of the casts a new technology of rolling was developed and the distribution of pressing from the cast of 52mm thickness to the plate of

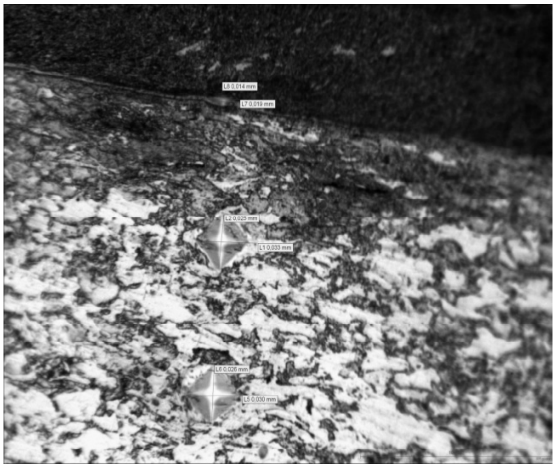

Fig. 1. The twin armour steel + steel 3.

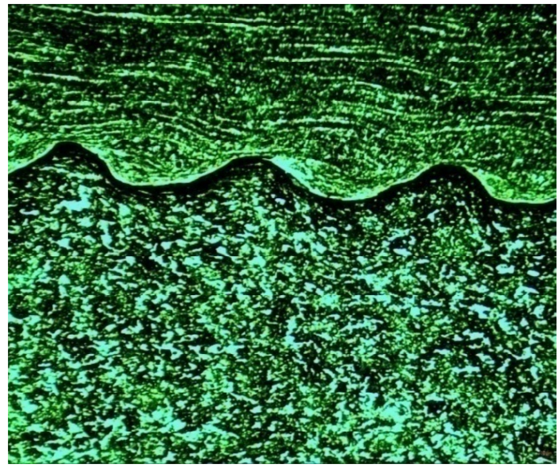

Fig. 2. The twin armour steel + aluminium.

5mm through nine passes was calculated; The power parameters, high-speed parameters, the steel heating range and the dynamics of the temperature loss were defined (Tables 1, 2).

The overall dimensions of the cast were: height H=52mm, width B=86mm, length=200mm. The diameter of the rolling mills Ø=280mm; rotation number N=20 rev/min; temperature of rolling 1150^{0}C.

Along the power parameters the dynamics of the temperature drop was defined according to the distribution of pressing.

By means of the technology described above the plates of the following geometrical sizes $H \times B \times LB \cong 5 \times 94 \times 3320$ mm^3 and HRC 48 ÷55 were obtained, on the basis of which the bimetal throat plates with the planned mechanical properties will be produced.

Generally, in production of bimetals (including the layered armor) apart from a high service ability one of the main difficulties is the process of cladding and adhesion of the basic metal layers.

As it was mentioned above, one of the ways of production of the layered plates is the technology of ultrahigh pressure (explosion) [6,7].

Selection of optimal pairs for layered plates is related to certain difficulties. The process becomes more complicated by the fact that according to the literature data, the thickness of the layer of high hardness is about 20 – 60% of general hardness. The problem should be solved by establishing certain criteria for the abovesaid sought values or by means of empirical method.

The explosion process was going on within the classical scheme: the explosion angle was 2.6^0 - 3.5^0; the explosive substance was amonite (6 ЖВ); the charge height was 35mm and the velocity - 4.2km/sec.

Taking into account the coefficients of the metal thermal expansion the proportion of the overall dimensions of twin plates was computed: the plate length of the thrown plate L was 7-12% greater and the breadth B and thickness were 5% less compared to the same dimensions of the stationary plates (steel 3). Such a ratio of the overall dimensions of plates avoids necessity of flattening the samples deformed as a result of explosion. The induction hardening method was used to give appropriate hardness to the working surfaces. As a result, their hardness increased up to HRC 62 and HRC 48, respectively.

The adhession microhardness in that twin plates measured with the load of 100 g on the device ПМТ-3 was within 510-520HV. The adhesion line was sinusoidal. Near the adhession line the microstructure of the armor layer was textured and the texture was very fine-granular and wavy. Near the adhession line the microstructure was martensitic and the microhardness reached 540 HV. The microstructure of steel 3 was fine-granular with slight texture.

Experimental adhesion of steel and aluminum was a success.

Table 3. The types of steel for pack rolling of gradient. Layer plates [10]

Steel trademark Face/back	Alloying system Face/back	HRC Face/back	Strength mpa Face/back	Technology
H-11 HP-4-0.3(USA)	40X5M2Φ/ 30XH9K5M1Φ	58/48	2400/ 1900	Pack rolling with metal powder in the middle
H-11 D6AC(USA)	40X5M2Φ/ 45XHM1Φ	60/ 52	2450/ 1950	Pack rolling with metal powder in the middle
D11/ SDPX-27 (USA)	45XHM2Φ/ 30XH3M2Φ	59/ 53	2400/ 2000	Pack rolling with metal powder in the middle
MARS/DD (France)	50CXM1.25ΦO.45/ 35X2H4M	59/ 45	2100/ 1450	Pack rolling with metal powder in the middle
VZ-43/.PZ (Italy)	65XB2Φ/ 26Γ2C2M	58....64/ 48....54	——	Pack rolling with metal powder in the middle
197352П (Czech)	60XB2Φ/ 26Γ2C2M	58/45	——	Adhession

The twin consists of the steel and aluminium leaves. After exploision the hardness of the steel alloy increased from 49HHRC to 59 HRC. The adhession microhardness measured with the load of 100g was 390.69 HHV in three places. After explosion the steel microstructure near the adhession line was fine-granular – martensitic.

The structural analysis of the layered plates showed that the microhardness of the transitional layer in most of the samples is greater than the microhardness of the layers. The adhension strength of the plates is within the allowable limits (see below).

Recently, priority is given to the pack rolling pocess in production of the layer plates. We chose the hot rolling of packs because according to references [8-10] adhesion of black metals by means of cold pack rolling is impossible.

The pack rolling is also connected with some difficulties, but main difficulty in the process of forming the pack into a monolith is the difference between the coefficients of expansion. In practice, in most cases rolling is necessary for adhession of the materials with significantly different physical and chemical properties, i.e. for the materials with different thermal coefficients of linear expansion that is often followed by tearing up the layers or bending the rolled stock. Experimentally, it was established that in hot rollng the adhession of metal layers occurs on the expense of difusson of the alloying elements, but very often in that process the adhession strength of layers cannot satisfy the requirements [9,10]. In pack rolling the process of adhession can be seriously improved by means of a special metal powder, which is applied between the pretreated layers. The powder layer applied between the plates basically changes the picture. According to recent references [9,10], really good rersults are obtained in case of hot rolling of the three-layer pack, where between the two metal layers there is a middle layer of metal powder (Table 1). However, the information about the content and molar weight of the powder applied is limited. For theoretical estimation of the optimal content of molar parts the following powders are suggested as the middle powder layer [9]: Ni-Si alloy 55-65%, (with Si 30-50%), nickel powder 20-25%, tungsten, vanadium and titanium carbide -10 -25%. In the process of hot deformation of the particles with the size of 15-40 mkm (950-1100^{0}C) the liquid Ni-Si fraction fills all the gaps of the transtional layers. At the increase of pressure and temperature the diffusion process of Ni and Si in adjacent layers intensifies. As for the metal carbide, in the process of deformation its hard particles implant in the steel layers increasing

Table 4. The parameters of the hot deformation of (with middle powder layer) steel stock [9]

Experiment №	Degree of shrinkage, %	Rolling temperature C^0	The middle layer
1	0.10	950	85
2	0.10	1250	115
3	0.12	950	155
4	0.20	1050	210
5	0.30	1050	240
6	0.40	1050	260
7	0.50	1050	280
8	0.60	1100	280
9	0.65	1250	260

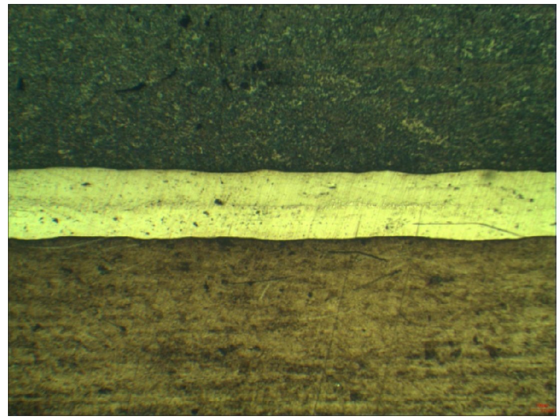

Fig. 3. The sample obtained by pack rolling. In the middle – the middle layer of powder, on the top – the armour steel layer, below – the layer of steel 3.

the shear strength of the connecting layer. Apart from that, the hard particles implant in the layers destroy the oxide layer and stimulate the difussion process. Thus, in such a case the basic cohesive parameter is the middle powder layer. In addition, the degree of adhession significantly depends on the pressure treatment parameters (Table 4).

By the use of the above-mentioned technology a regular lot of armor plates were smelt and cast for pack rolling. Overall dimensions of the cast were as follows: height H_0= 52mm; breadth B_0= 86mm; length Ze L_0= 200mm. By means of the mentioned technology the casts were reduced to the condition of plate stocks of 5mm thickness.

Primary goal of the first experimental rolling was to use the above mentioned technology for reliable adhession of layers (armor steel + steel 3). The following preparatory operations were carried out:

• Powder content was selected as follows: Ni-Si alloy 50% (Si 30%), nickel powder 25%; tungsten carbide – 20% the particles of 30 mkm.

• The metal powder of such a composition was produced in the amount of 260 gr.

• Two pack samples were produced for rolling consisting of the above mentioned steel layers. The ratio of the coefficients of thermal expansion was 1. The same was the ratio of thickness of the layers.

• The contact surfaces of the plates were mechanically treated until shining

• The overall dimensions of plates were selected with acount of the sizes of the adhesion shelves as specified in [9].

According to the existing technologies [9, 10] it is recommended to apply hot powder to one of the pack plates by the air-arc method. In our case for simplification of the process the assembled pack sample (with middle layer) was loaded by pressing with 80-100 ton (21.55 kg/mm^2) in order to provide the preliminary invasion of solid particles of tungsten carbide into the steel plates. The whole adhesion of the total contour of the pack occured in such a loaded condition. Both packs were placed in sylite furnace heated up to 1150^{0}C (the temperature of rolling and melting of Ni-Si) holding there for an hour. The first sample was rolled in one pass with 49.7% pressing. The second one was rolled in two passes with 49 + 6.6 = 55.6% pressing and without middle heating.

As it was mentioned, the strength of the layers adhesion is one of the important properties of the layered products. According to the reccommendation 10885-85 of the State Standards the admissible strength of the layers adhession should be above 147H/mm^2 - 15kgZ/mm^2. As a result of the above mentioned technology of pack rolling, the adhession strength of the layers was 180mgpa (18kgp/mm^2) that means that the main goal of the experiment was achieved.

The hardness -200 mgpa (20kgp/mm^2) of the above considered layers obtained by explosion also satisfies the necessary requirements.

Finally, it can be concluded that development of the technology of explosion and rolling for production of the special layered plates (including gradient armor plates) with gradient structures is sucessful.

მეტალურგია

გრადიენტული სტრუქტურის დამცავი ფილების მიღების თანამედროვე ტექნოლოგიათა კვლევა და დამუშავება

ა. თუთბერიძე*, თ. ნამიჩეიშვილი*, ზ. მელაშვილი*, კ. პაპავა*, დ. მაჭარაძე*

* *ფერდინანდ თავაძის მეტალურგიისა და მასალათმცოდნეობის ინსტიტუტი, თბილისი*

(წარმოდგენილია აკადემიის წევრის გ. თავაძის მიერ)

ნაშრომში განხილულია აქტუალური პრობლემის, გრადიენტული დამცავი ფილების წარმოების თანამედროვე ტექნოლოგიური პროცესების კვლევა-დამუშავება. სამუშაოს მიზანი არის შეიქმნას მკვეთრად განსხვავებული ფიზიკურ-მექანიკური თვისებების (HRC 62, KCU 0,5; 48-50 HRC KCU 0,9), მაღალი ხარისხის ურთიერთშეჭიდულობის მქონე ფილებისაგან შედგენილი ორფენოვანი ჯავშანფილა. ამ თვისების ჯავშანფილები უძლებს როგორც ბალისტიკურ, ისე სხვა სახის ძალოვან ზემოქმედებას. ნაშრომში შემოთავაზებულია ზემოაღნიშნული თვისებების მქონე ორფენოვანი გრადიენტული ფილების მიღების ორი/დამუშავებული ტექნოლოგია: ჯავშანფილების მიღება ზემაღალი იმპულსური წნევებითა და პაკეტური გლინვის გზით. ამ მიზნით შემუშავდა დამცავი ფილების მიღების სრული ტექნოლოგიური ციკლი, რომელიც მოიცავს აღნიშნული ფოლადის გამოდნობას, ჩამოსხმას, წნევით და თერმულ დამუშავებას. ფენოვან ფილათა ზემაღალი იმპულსური წნევებით (აფეთქებით) მიღების ტექნოლოგია განხორციელდა კლასიკური სქემით: აფეთქების კუთხე 2,6-3,5^0; ფეთქებადი ნივთიერება ამონიტი 6ЖВ; მუხტის სიმაღლე 35მმ; დეტონაციის სიჩქარე 4,2კმ/წმ. მუშა ზედაპირებისათვის შესაბამისი სისალის მისანიჭებლად მათ ჩაუტარდათ ზედაპირული წრთობა ინდუქციური მეთოდით. შედეგად ზედაპირების სისალემ მიაღწია შესაბამისად HRC 62 და HRC 48. ბოლო პერიოდში ფენოვანი ფილების მიღების პრიორიტეტულ გზად პაკეტური გლინვის პროცესი ჩამოყალიბდა. მაგრამ პაკეტურ გლინვასაც გარკვეული სირთულეები ახლავს. პაკეტური გლინვისას ფენათა შედუღების პროცესს მნიშვნელოვნად აუმჯობესებს სპეციალური შედგენილობის ლითონური ფხვნილი, რომელიც დეფორმაციამდე გარკვეული წესით თავსდება წინასწარ დამუშავებულ შესადუღებელ ფენებს შორის. იკვრება ფენების პაკეტი, 1150^{0}C ტემპერატურამდე გახურების შემდეგ იგლინება მოჭიმვათა წინასწარ დადგენილი ტექნოლოგიით. შედეგად მიღებულ იქნა HRC 62 და HRC 48. სიმტკიცის მქონე ორფენოვანი დამცავი ფილა. ფენოვანი პროდუქციის ერთ-ერთ მნიშვნელოვან მახასიათებელს ფენათა შეერთების სიმტკიცე წარმოადგენს. სასტ 10885-85-ის რეკომენდაციით ფენათა შეერთების მისაღები სიმტკიცე უნდა აღემატებოდეს 147 მგპ - 15 კგძ/მმ^2. პაკეტური გლინვის ზემოაღნიშნული

ტექნოლოგიით ფენათა შეერთების (ადგეზიის) მიღებულმა სიმტკიცემ შეადგინა 170 მგპა (17 კგძ/მმ^2), წაყენებულ მოთხოვნებს აკმაყოფილებს აგრეთვე ზემოგანხილული, აფეთქებით მიღებული ფენათა შეერთების სიმტკიცე — 200 მგპა (20 კგძ/მმ^2), რითაც მიღწეულ იქნა ექსპერიმენტის ძირითადი მიზანი.

REFERENCES

1. Patent of the Russian Federation 2139357, МПК C21D 9/42, 1999.
2. Patent of the Russian Federation 2185459, МПК C22C 38/44, 2002.
3. *Zlobin B*. (2000) Doctoral Thesis. Novosibirsk (in Russian).
4. *Deribas A.A*. (1980) Fizika uprochneniia i svarki vzryvom. 222 s. Nauka (in Russian).
5. *Vitman R.V.* (1973) Obrabotka materialov vzryvom (in Russian).
6. *Chekhurina K.E, Golovanenko S.A. et al.* (1973) Bimetallicheskie soedineniia. M. (in Russian).
7. *Namicheishvili T., Tutberidze A., Tavadze G.,. Oniashvili G., Melashvili Z., Aslamazishvili Z., Zakharov G.* (2011) "Sovremennye tekhnologii i metody neorganicheskogo materialovedeniia". Materialy dokladov. Tbilisi. 250 – 254 (in Russian).
8. *Dreev A.V., Kobelev A.G.* (1985) Russian patent of invention RU2422283. Sozdanie sposoba izgotovleniia sloistogo materiala v vide polos ili listov iz korrozionno-stoikoi stali, obespechivaiushchego povyshenie prochnosti soedinitelnogo sloia na srez.
9. *Voatrikov V.P., Chernikov V.N.* Russian patent (19)R(11)2234385. Sposob izgotovleniia prokatkoi stalnogo sloistogo materiala.

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