Coimbra,2015

Recent advancements of ISMAN in SHS and in explosion/combustion-assisted materials processing

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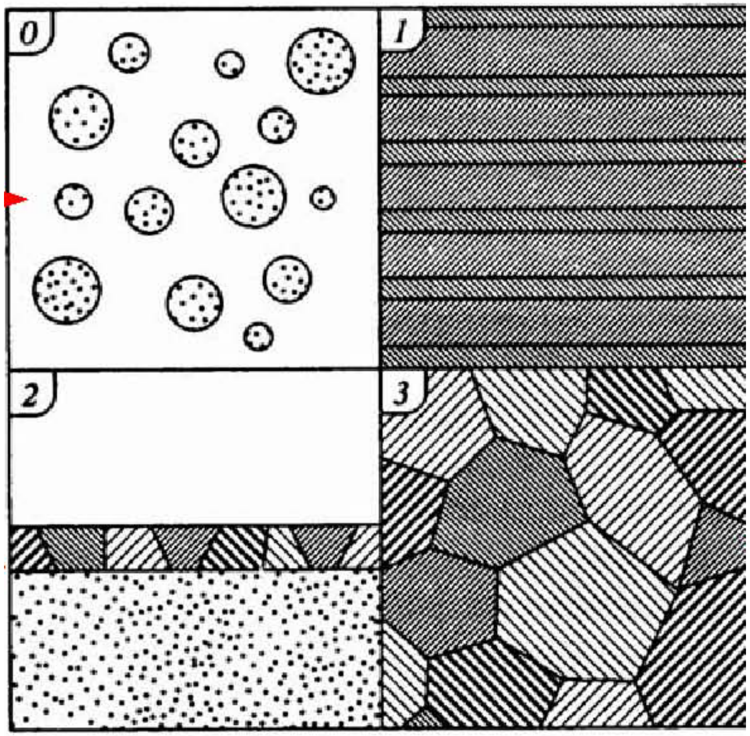
Classification of nanomaterials

1. **Powders.**

2. **Layers and coatings.**

3. **Composite materials.**

4. **Bulk materials.**



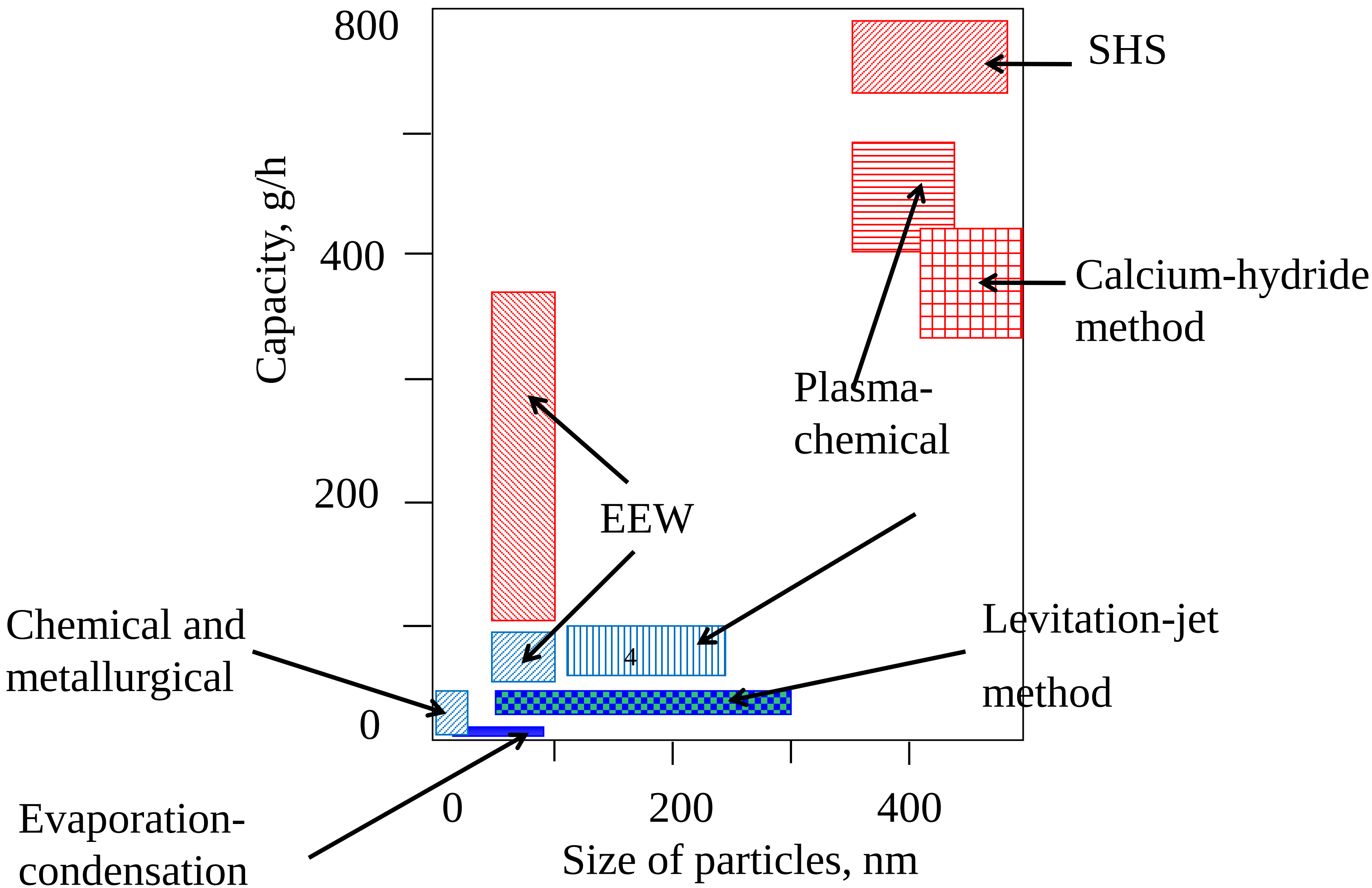
Powder metallurgy = synthesis of powders + consolidation of powders.
By powder metallurgy methods we can produce all kinds of nanomaterials.

R.W. Siegel, Proc. Of the NATO SAI, 1993,v.233, p.509

METHODS FOR PROCESSING OF BULK NANOSTRUCTURED MATERIALS

Methods	Technologies	Materials
Powder metallurgy	Consolidation of nanopowders: Pressing and sintering, Pressure sintering	Metals and alloys, ceramic, metal-ceramic, composites, polymers
Crystallization from amorphous state	Crystallization of amorphous alloys, Consolidation of amorphous powders with further crystallization	Metallic materials able to bulk amorphisation.
Severe plastic deformation	Equal channel angular pressing, Torsion under high pressure, Multiple all-round forging.	Metallic materials
Nanostructurisation by precision heat treatment and thermomechanical treatment	Heat treatment. Thermomechanical treatment	Metallic materials

The ratio between the average particle size and performance of methods



Alymov M.I. Composites and Nanostructures, 2012, v.3.

Methods for the nanopowders consolidation

Uniaxial pressing: static, dynamic, vibration

Isostatic pressing

Extrusion

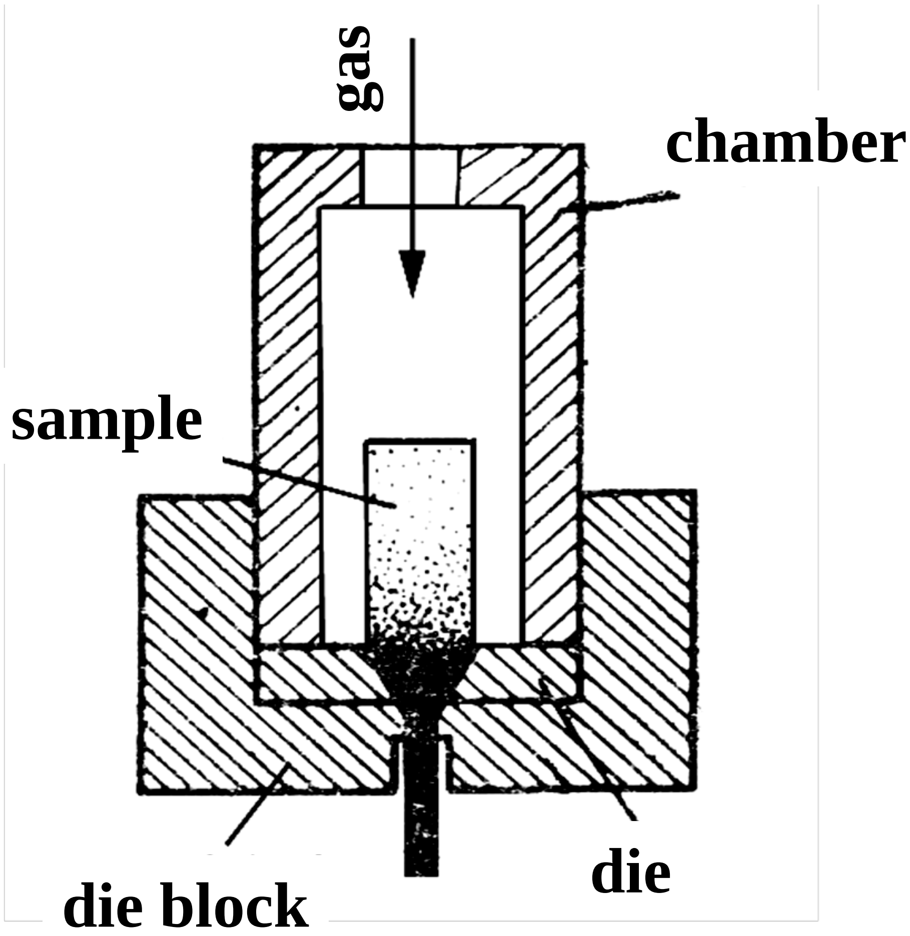
Sintering under pressure

Spark plasma sintering

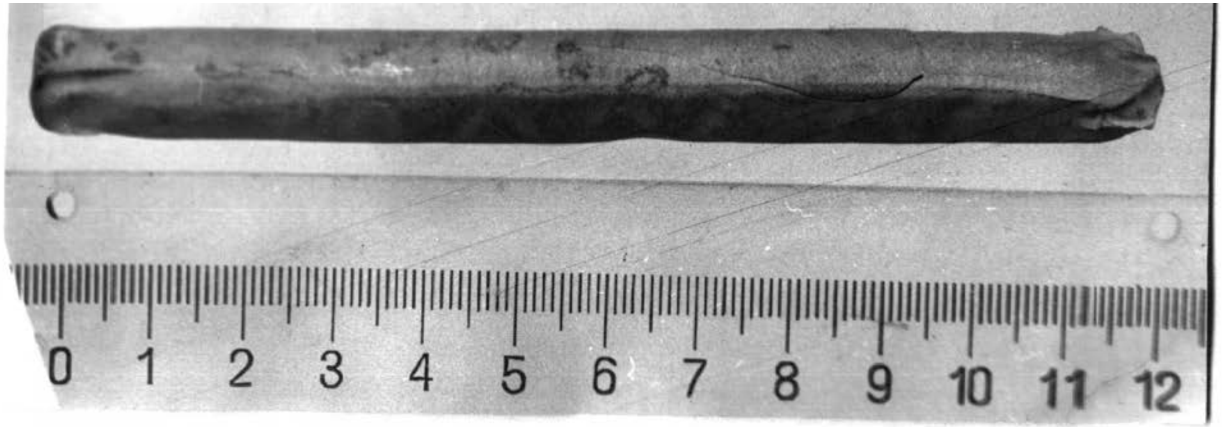
Sock wave pressing

Severe plastic deformation

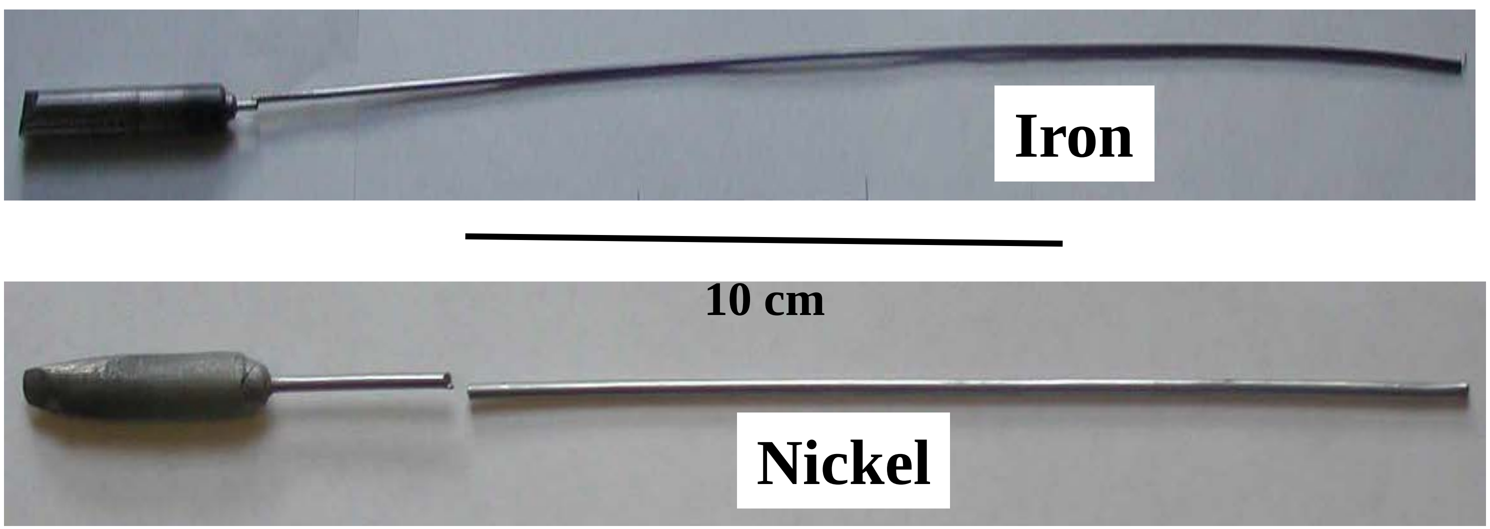
Gas extrusion method



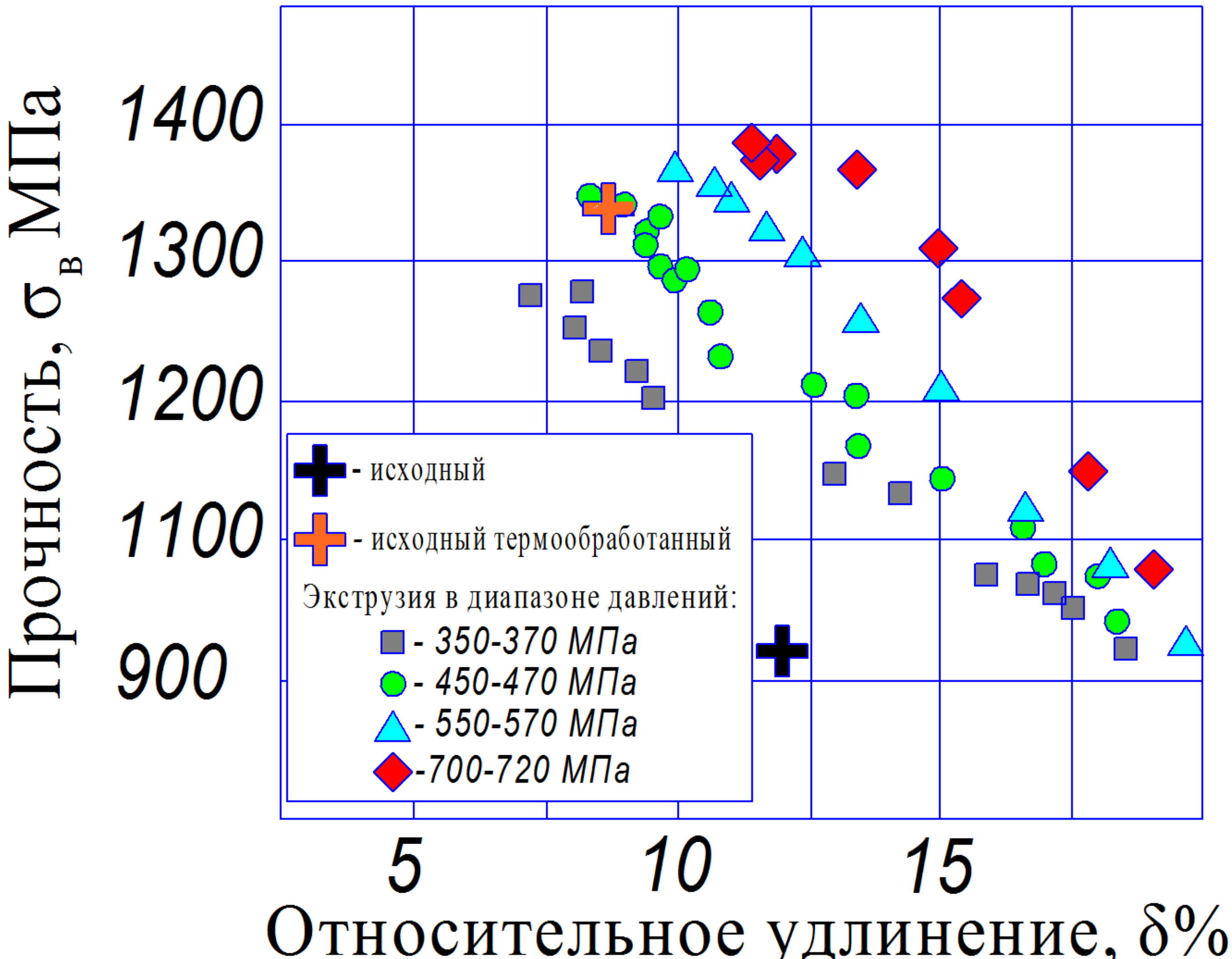
Nickel nanopowder green compact after hydrostatic pressing



Compacts of iron and nickel nanopowder after extrusion

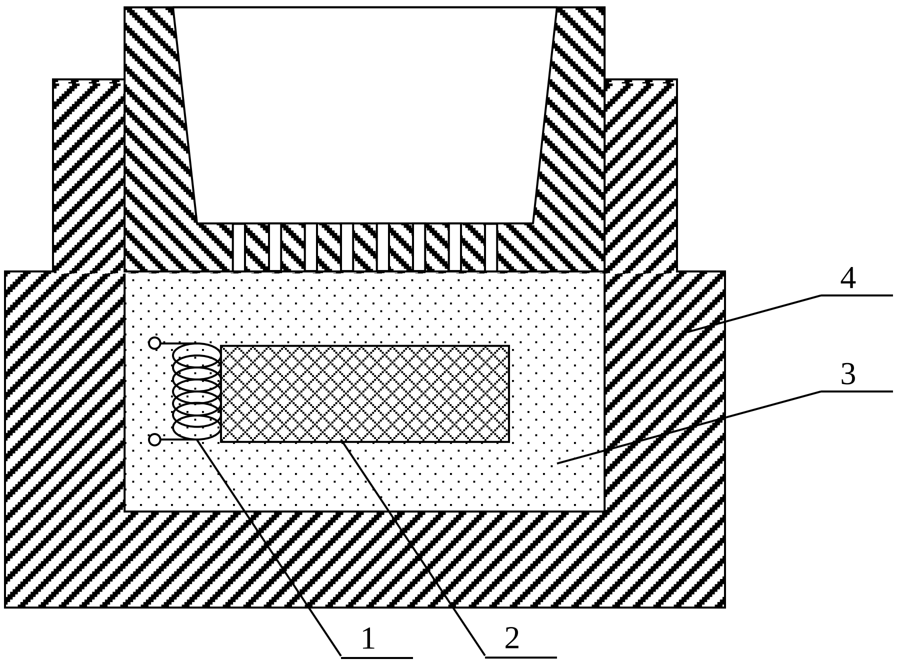


Mechanical properties of titanium alloy VT-14



Ваганов В.Е., Аборкин А.В., Алымов М.И., Бербенцев В.Д. Металлы, 2015. №5.

SHS pressure sintering



4 - mold.

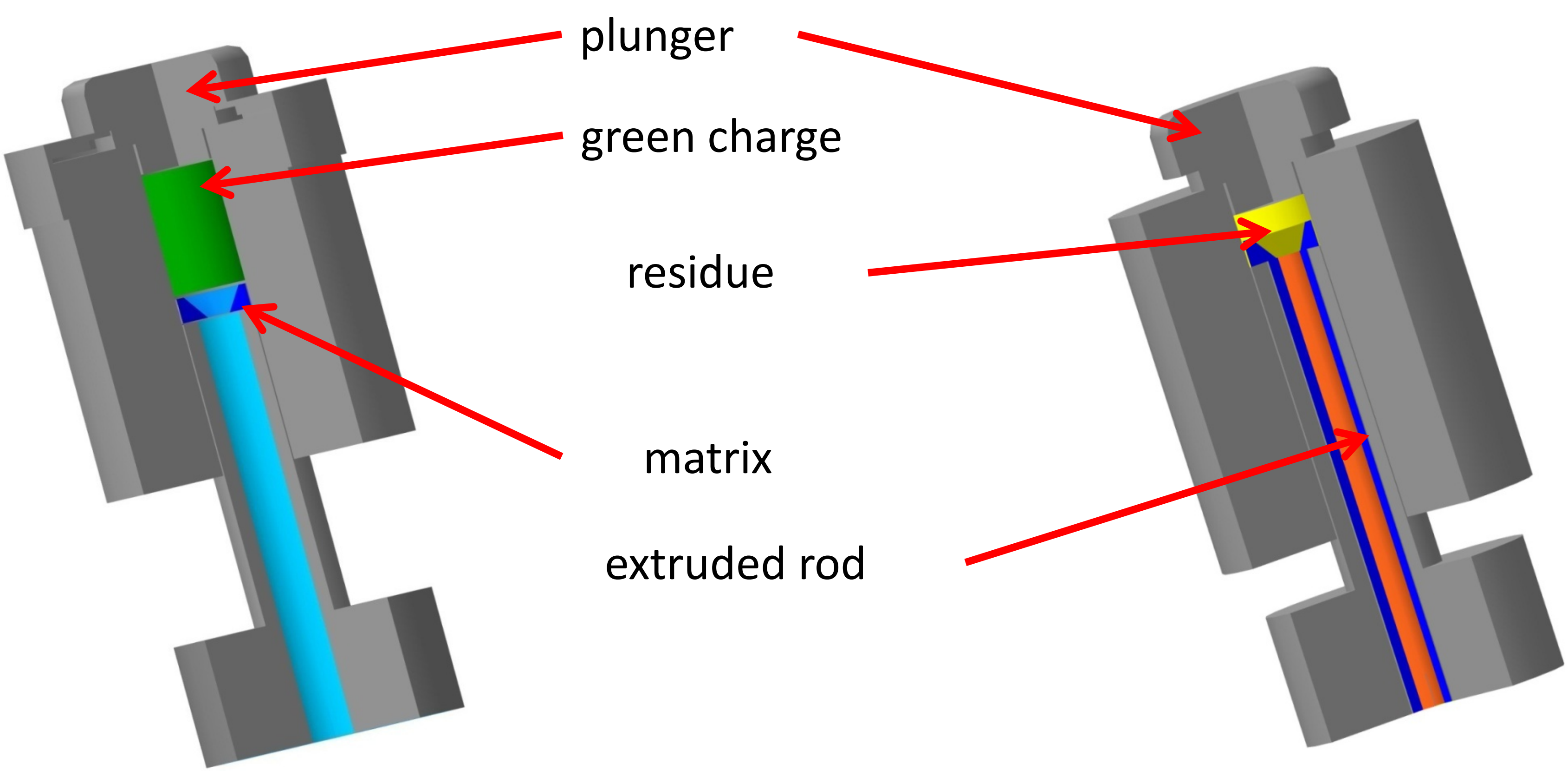
3 - insulating porous medium (sand);

1 - tungsten spiral initiating the SHS reaction

2 - tablet from powders of the initial reactants

Sherbakov V.A.

SHS extrusion



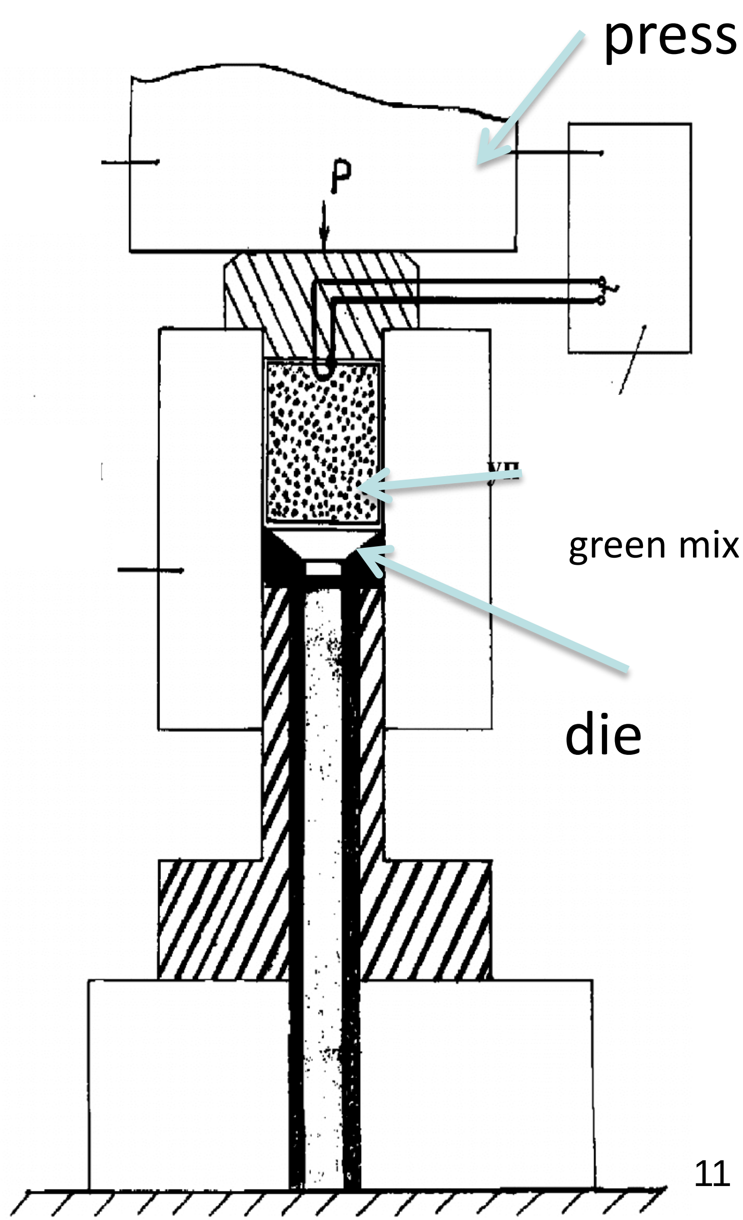
A. M. Stolin and P. M. Bazhin. SHS Extrusion: An Overview, International Journal of Self Propagating High-Temperature Synthesis, 2014, Vol. 23, No. 2, pp. 65–73.

Schematic of SHS extrusion

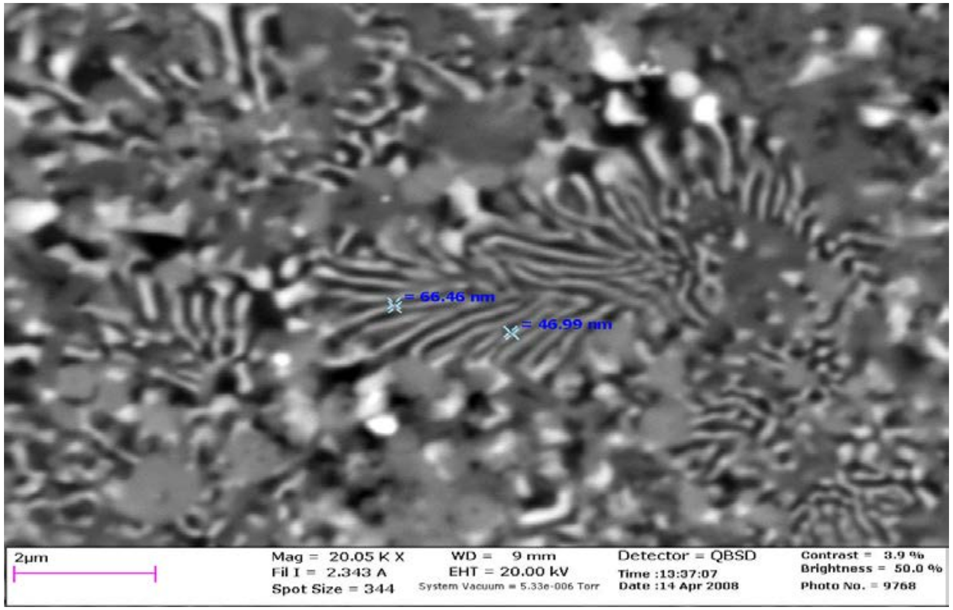
Advantages:

- No external heating
- Feasibility of ceramics fabrication
- Short processing time (10 s or so)
- Feasibility of regulating temperature and strain

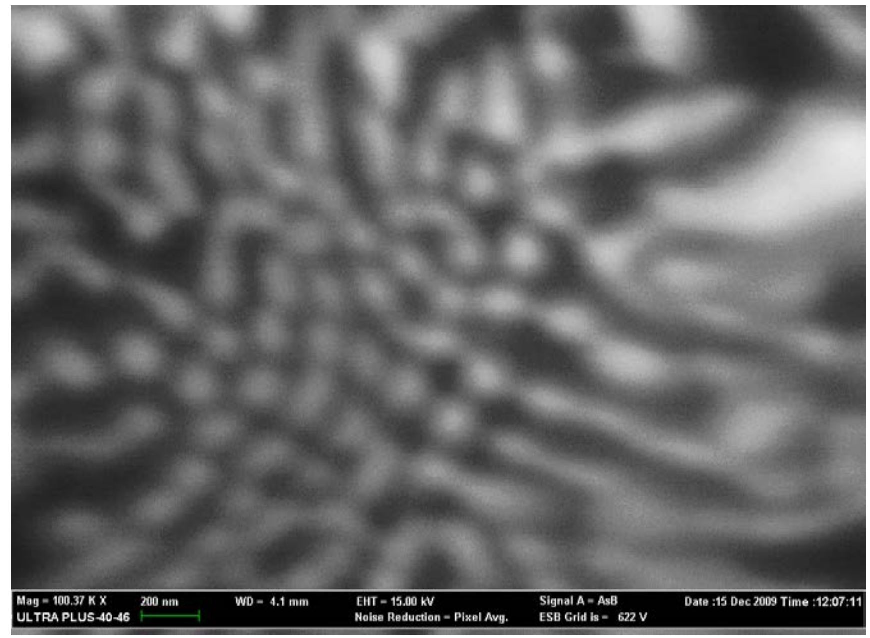
Bazhin P.M., Stolin A.M., Shcherbakov V.A., Zamyatkina E.V. Nanocomposite ceramic produced by SHS extrusion, Dokl. Chem. 2010. V.430. №2. P. 58. [Бажин П.М., Столин А.М., Щербаков В.А., Замяткина Е.В. Композитная нанокерамика, полученная методом СВС-экструзии, Доклады АН, Химическая технология. 2010. Т. 430. №5. С. 650].



Microstructure of ceramic material



Материал	Hv, kg/mm^2
High-speed steel (P18, P9, P6M5)	750-800
Commercial hard alloys (VK8, VK6, T15K6)	1200-1900
Special hard alloys (TT20K9, TT7K12)	1600-2300
Cutting ceramics (TiB_2-Al_2O_3, TiC-Al_2O_3)	1500-2200
CBC-produced electrode TiC-TiB_2-Al_2O_3-ZrO_2	1800-2100



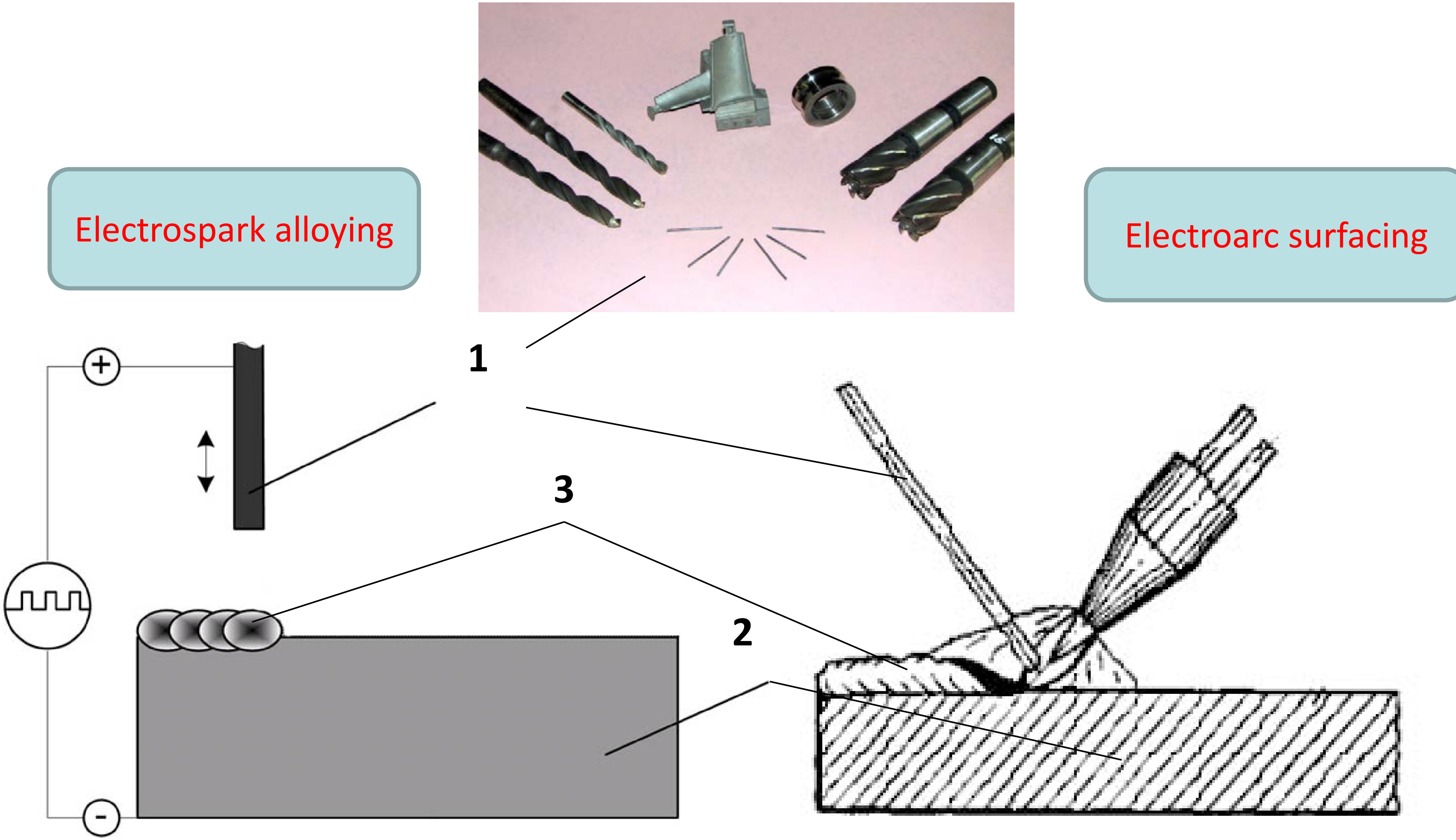
Fabrication of nanomaterials by SHS extrusion

1. Selection of proper green composition
2. Adjusting combustion temperature via synthesis conditions, compaction, and preforming
3. Specification of strain via die design, applied pressure, plunger velocity, and dwell time under pressure
4. Use of sub-micron and nano-sized reagents
5. Addition of nanopowders to green mixture
6. Dilution with end product

П.М. Бажин, А.М. Столин, М.И. Алымов. Nanostructured ceramics by combined use of combustion and SHS extrusion, *Российские Нанотехнологии* (in press).

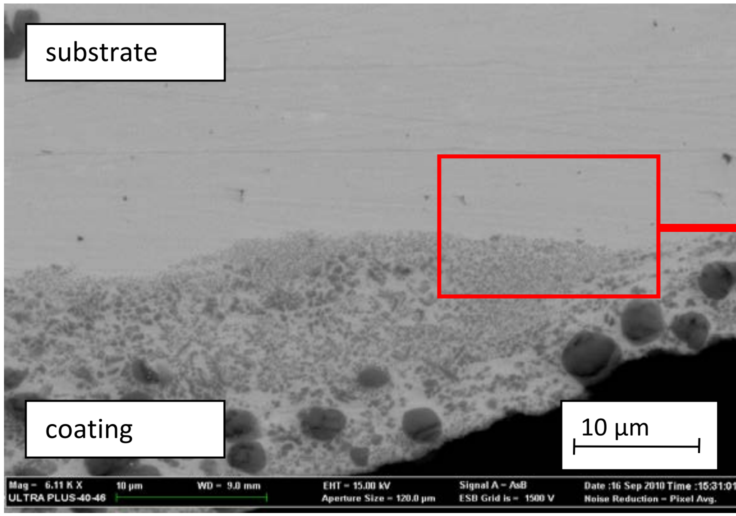
Pilot batch of items

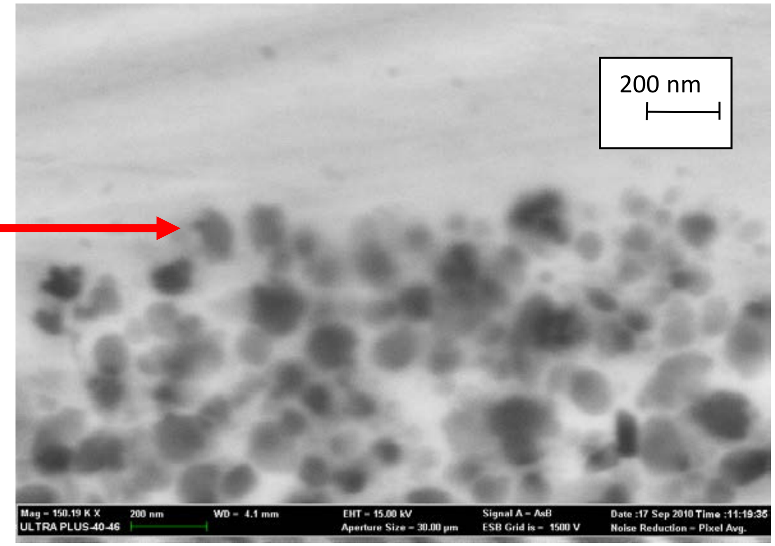
Protective ceramic coatings



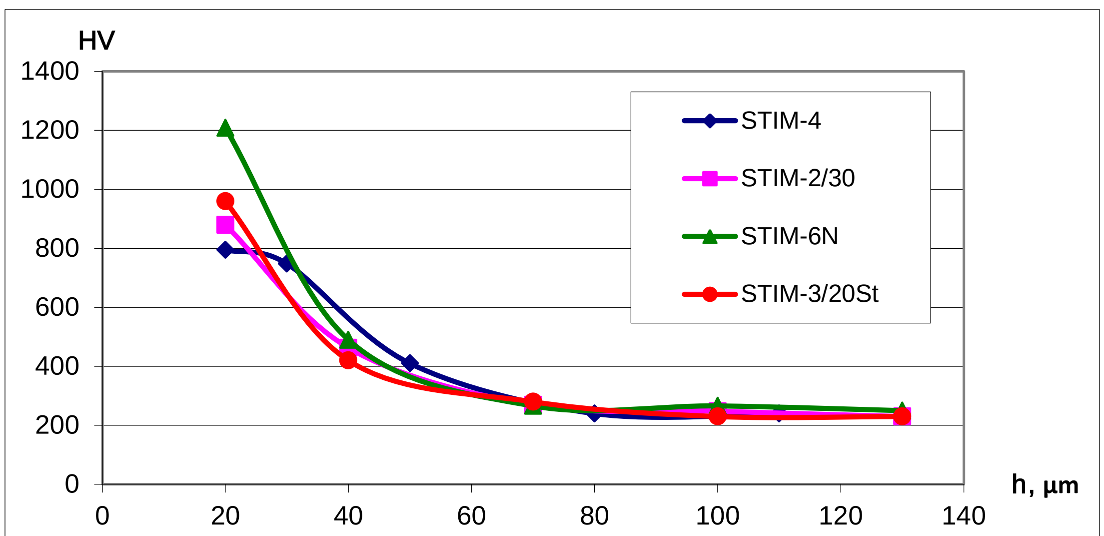
1, SHS electrode; 2, metal substrate; 3, protective coating

Protective coatings





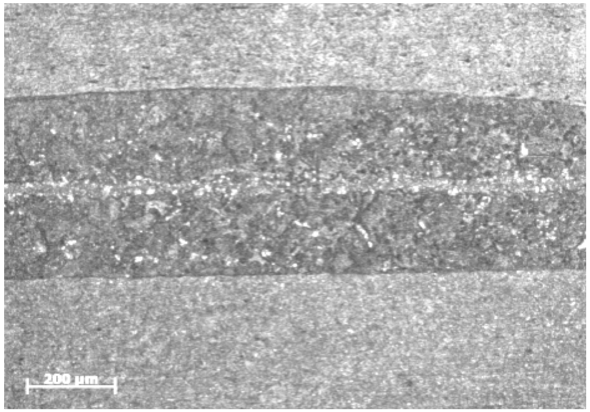
Microhardness of coatings



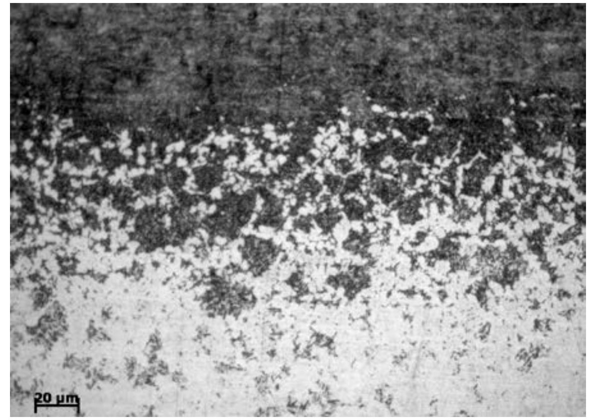
Effectiveness for bulk nanopowder materials

Materials	Effectiveness
Hard alloys	Increase of hardness by a factor of 5-7
High strength steels and alloys	Increase of strength by a factor of 1,5-2
Ceramic materials	Formability as for titanium alloys
Nanopowder materials with special properties	Mechanical, chemical, optical and other properties
Wear resistance coatings	Increase of resistance by a factor of 100

Wear-resistant bimetal
structural steel / wear-resistant steel



The intermediate layer after explosion welding and hot rolling



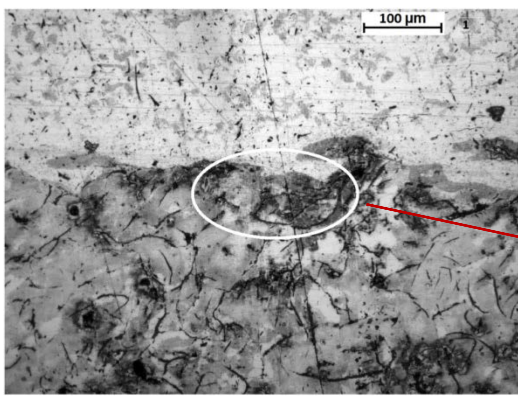
The transition area between the layers

The combined technology (explosion welding + hot pack rolling), for providing the production of bimetal with high strength properties and defect-free structure is developed.
Structural changes in the bimetal caused by an explosion during welding and hot rolling batch were studied. The diffusion of carbon in the intermediate layer of low carbon steel, resulting in an increase in its hardness was found.

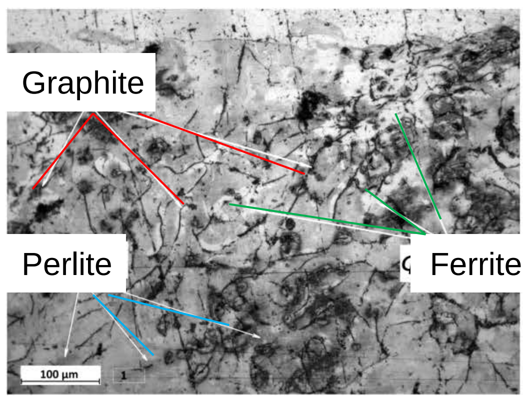
Pervukhina O. L.

Structural steel + cast iron

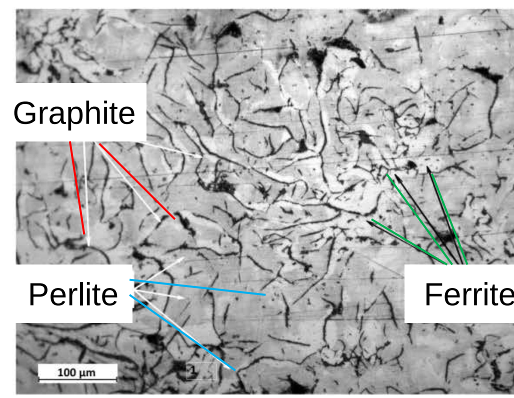
Bimetal structural steel / low-alloy cast iron was produced. Effect of various heat treatment regimes on the properties was examined. Structureless "white phase" is revealed at the border. heat treatment mode, in which the restructuring of the "white phase" in the structure of perlite + graphite has been installed. The chemical composition of the "white phase" corresponds to hypoeutectic cast iron.



interface



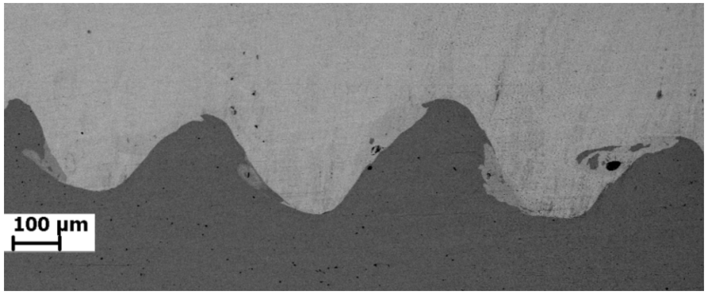
4 mm from the surface



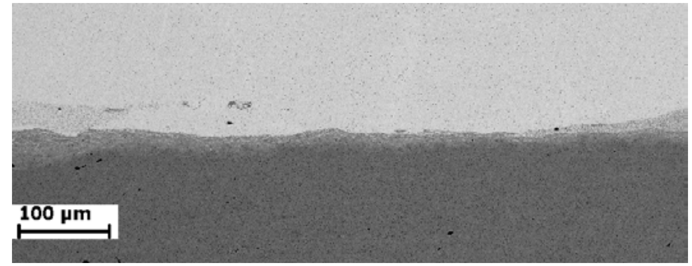
Cast Iron structure after heating to 700 - 730 ° C at 50 ° C / hr, soaking for 1 hour, and cooling with the furnace

Pervukhina O. L.

Brass + Invar



Joint area after
the explosion welding

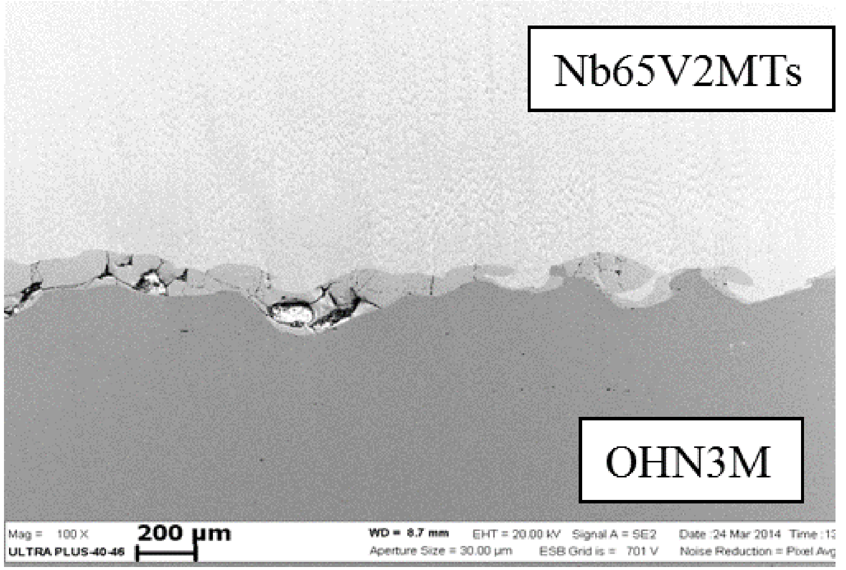


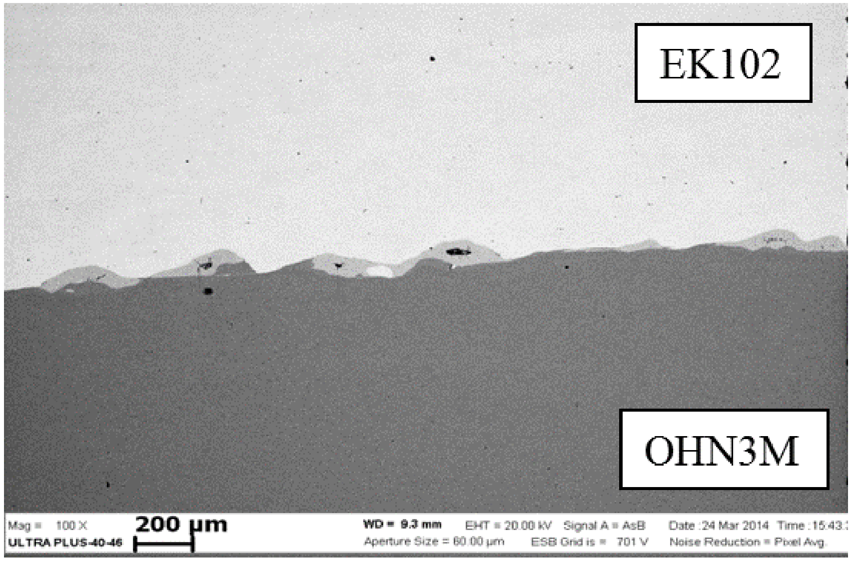
Joint area after hot and
cold rolling

The technology of thermostatic bimetals brass-Invar comprising explosion welding followed by hot and cold rolling. It is shown that the new process provides a satisfactory quality of the weld zone "without wave" structure and strength characteristics at brass strength. The optimal ratio of the original layers of brass thermostatic bimetals-Invar, which is 1.2 : 1 - 1.3 : 1.

Pervukhina O. L.

Explosive welding of cylindrical billets with a heat resistant layer. Tube length was 200 mm.





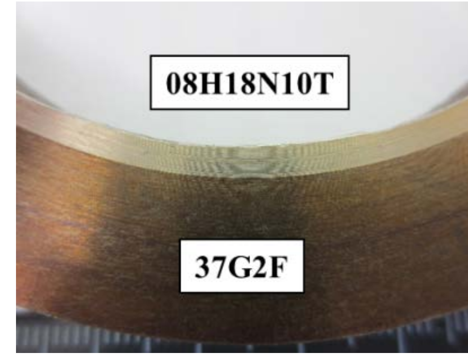
The work aims to study the features of the internal explosion cladding steel pipe superalloys niobium (Nb65V2MTs) and nickel-cobalt (EK102) basis.

The experiment used the scheme with simultaneous initiation of internal and external power.

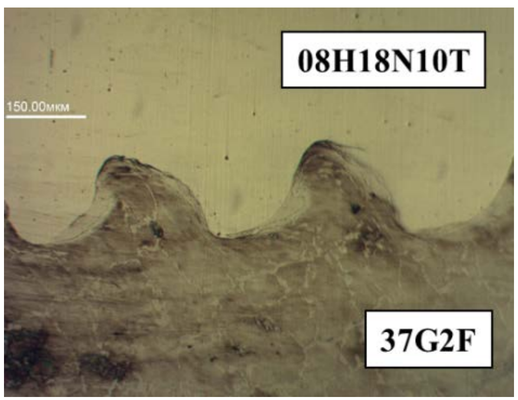
Saikov I. V.

Corrosion-resistance tubes by explosive welding

Two-layer tube with a length of 2,4 m



Circular sample



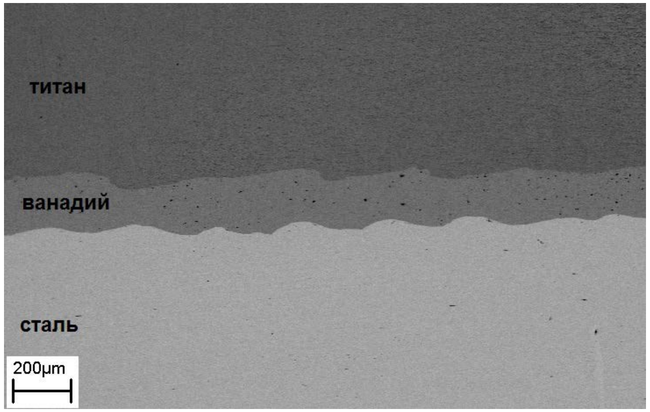
Mechanical properties of bimetallic tubes

№	$\sigma_в$, MPa	σ_Y , MPa	δ_5, %	Ψ, %	$\sigma_Y/\sigma_в$
1	909	813	17,5	56	0,89
2	910	819	15,5	55	0,90

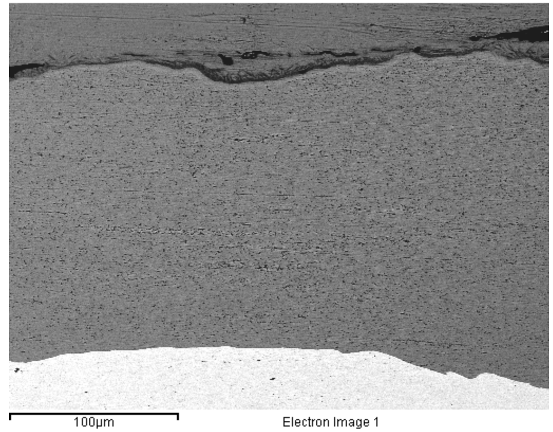
The aim of this work was to obtain by explosion welding of two-layer pipe billets for further cold rolling at the pump-compressor pipe. As a result of experiments were obtained test samples 1 and with a length of 2.4 meters.

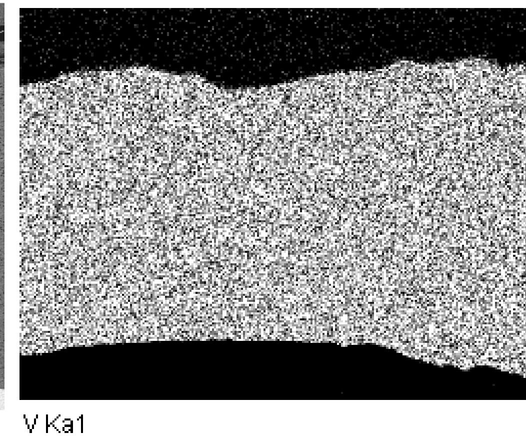
Saikov I. V.

TITANIUM/STEEL EXPLOSIVE WELDING: INFLUENCE OF VANADIUM INTERLAYER[1]

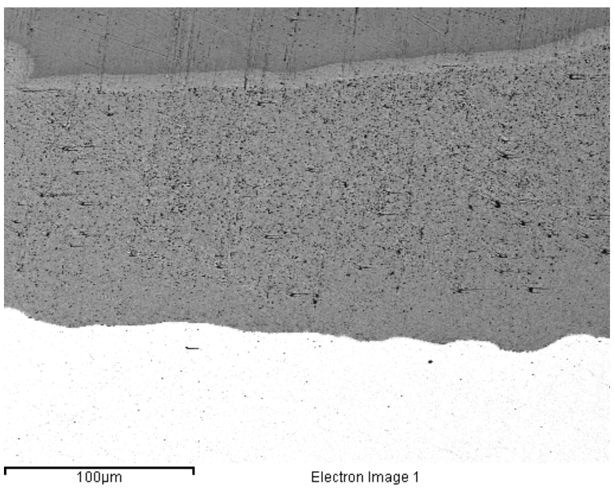


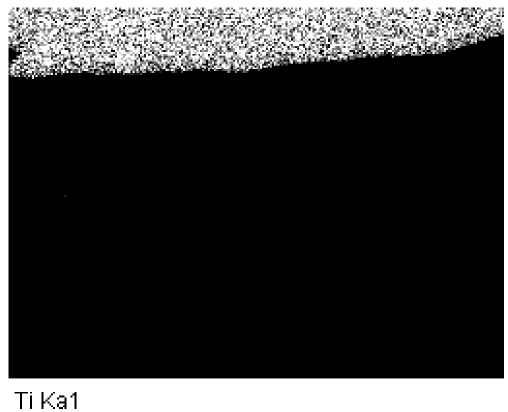
«Ti+V+steel» after explosive welding

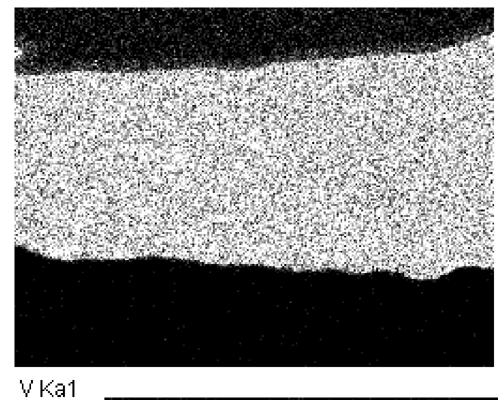


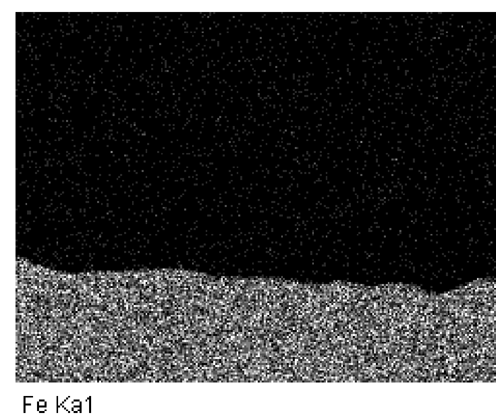


Heat treatment 700°C









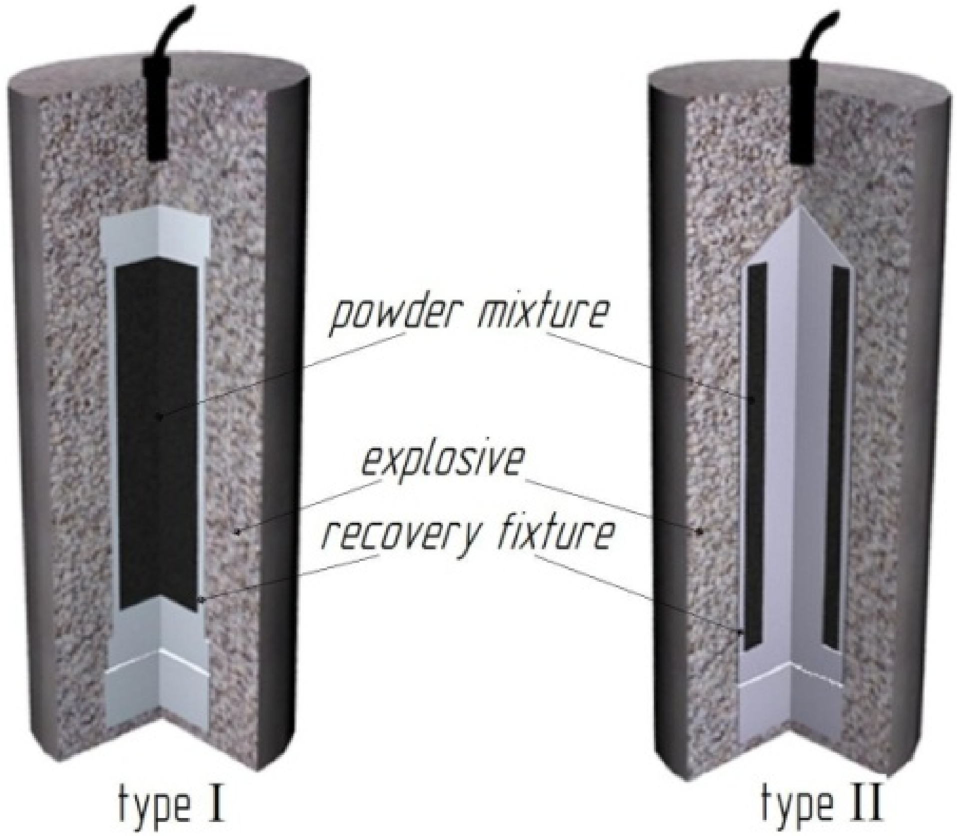
Heat treatment 800°C

Saikov I. V.

The clad metal titanium/vanadium/stainless steel was prepared by explosive welding and the weld seam was characterized (after heat treatment at 500–800°) by SEM/EDS. The V interlayer was used in order to suppress the formation of intermetallic. The presence of intermetallic was detected only after thermal treatment at 800°C for 1 h. The tensile strength of the joint was 545 MPa. So the use of V interlayer can be readily recommended for practical implementation.

Shock compaction and ignition of tungsten and teflon powder mixtures

Geometries of shock compaction



Shock compaction of tungsten / teflon powder mixtures

Three powder mixtures:
mix 1 - tungsten/Teflon,
mix 2 - tungsten/Teflon/Al,
mix 3 - tungsten/Teflon/(Al,Ti,B)
were subjected to shock compaction in the recovery fixtures with and without axial rod.

Type I recovery fixtures were loaded with compressed pellets. The tubular gap in Type II recovery fixtures was filled with bulk density powder mixtures.

Ammonite 6ZhV was used as explosive.

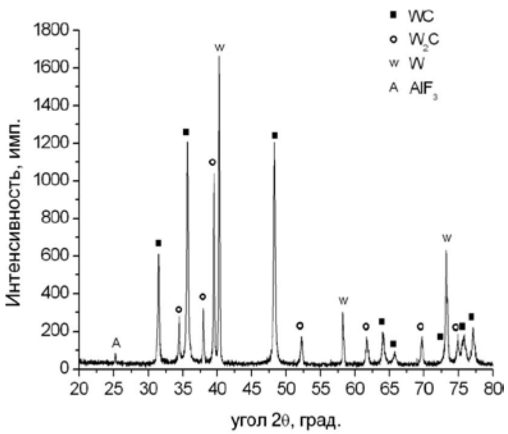
Saikov I. V.

Type I

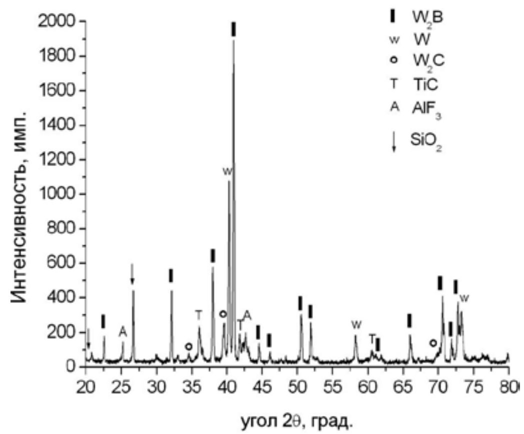
Saikov I.W.

Type II

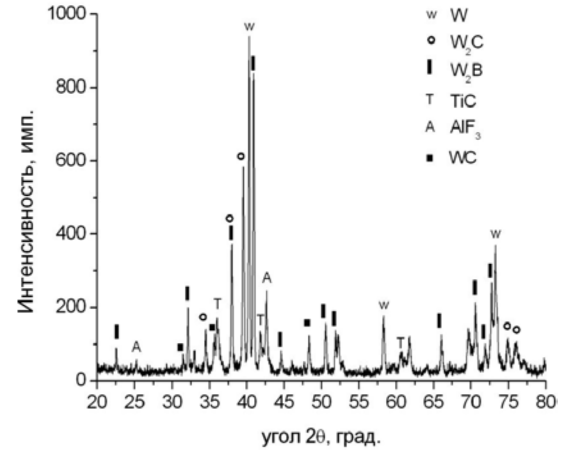
Saikov I. V.



Diffraction pattern of shocked mix 2 $W+C_2F_4+Al$ taken from the bottom of fixture I



Diffraction pattern of shocked mix 4 W-Al-B-Ti- Teflon taken from the fixture I



Diffraction pattern of shocked mix 5 W-Al-B-Ti-Teflon taken from the fixture II

Saikov I. V.

№	Powder mixture					Recovery fixture type	Result
	W	Teflon	Al	Ti	B		
1	+	+				I	no reaction
2	+	+	+			I	W, WC, W_2C, AlF_3
3	+	+	+			II	no reaction
4	+	+	+	+	+	I	W, W_2C, W_2B, WB, TiC
5	+	+	+	+	+	II	W, W_2C, W_2B, WB, TiC, WC

In type I fixtures with mix 1 and type II fixtures with mix 2, no formation of new phases was detected by XRD. Shock compaction of mix 2 in fixture I was found to yield WC, W_2C, and small admixture of AlF_3 at the fixture bottom.

Shock compaction of mix 3 in both fixtures resulted in explosive destruction of the fixtures. The XRD data for the remnants showed the presence of W_2C and W_2B.

Saikov I. V.

Ignition of tungsten-teflon mixtures

Composite materials obtained by the method of explosive compaction: structural, antifriction, heat-, sound insulation, coatings, high-energy nanocomposites.

The aim of the work is to study the effect of additives of aluminum on ignition of mixtures of tungsten and aluminum to obtain more high-density energy emitting composites.

Green mixtures containing 70% W, 25% Teflon, and 5%Al (by weight) were prepared with an intention that the combustion products would contain WC as the main product. Aluminum was added as an initiator.

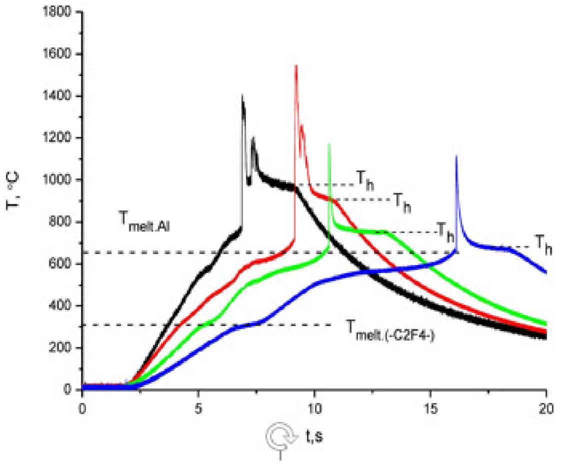
Combustion was carried out under 1 atm of Ar.

S.G. Vadchenko

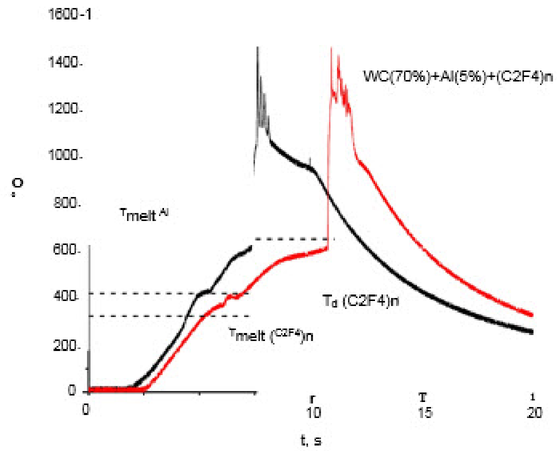
Calculated T_{ad} of combustion and products of the reaction

Green powder mixture	Tad, K	Products						
wt.%		WC	W2C	W	C	WF_4, WF_5	AlF3	C2F4, CF_2
W(70)+ Al(5)+(C_2F_4)n(25)	3050	68.6	-	10	—	9	14.4	—
W(75)+ (C,F4)n(25)	1635	57	—	—	—	32.4	—	10.4
WC(70)+ Al(5) +$(C_2$F4)n(25)	2840		64.1		7.2	12	15.5	—

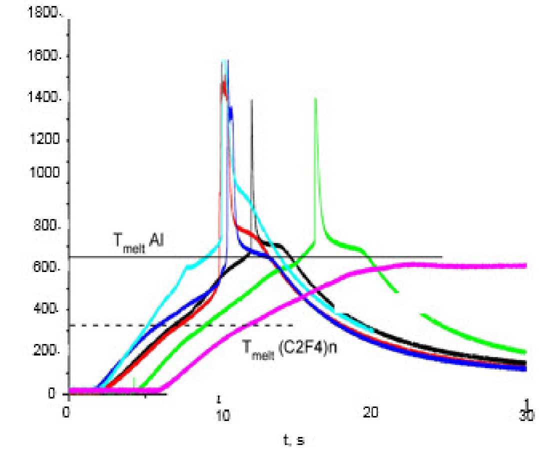
S.G. Vadchenko



Thermograms of ignition W+Al+Teflon at different heating temperatures T_h.



Thermograms of ignition WC+Al+Teflon at different heating temperatures T_h.



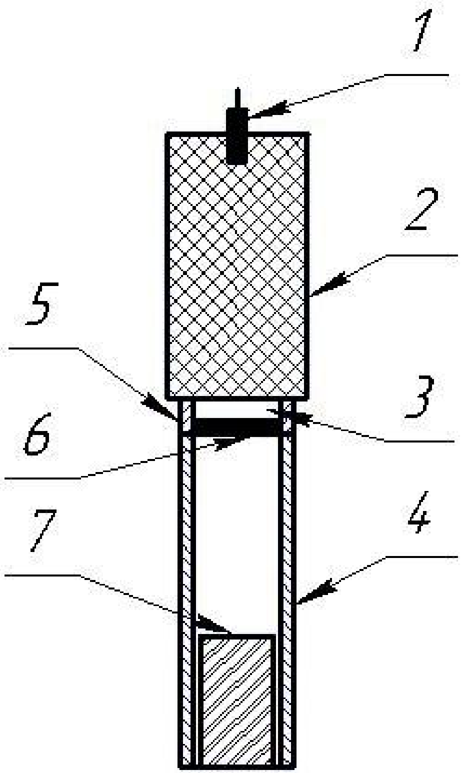
Thermograms of ignition Wnano+Al+Teflon at different heating temperatures T_h.

To initiate the reaction of tungsten with Teflon required small additions of aluminium. Reducing of the heating rate lead to the transition from the ignition mode to the thermal explosion mode

For the practical application the tungsten in the mixture may be replaced by tungsten carbide.

S.G. Vadchenko

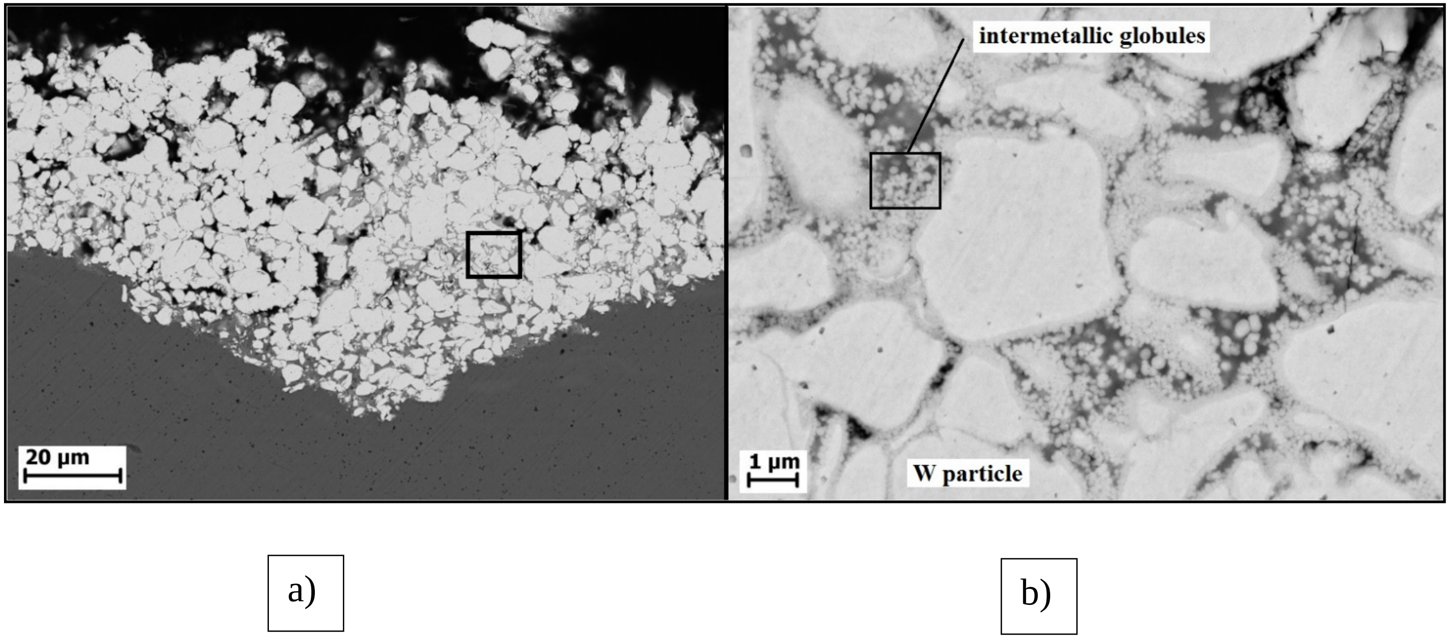
Impact of bombardment with high-speed tungsten particles on structure and properties of structural steel



Scheme of experiment.
1 - detonator,
2 - explosive,
3 - clearance,
4 - steel tube,
5 - ring,
6 - powder,
7 - sample.

Steel samples: diameter 20 mm, height 30 mm.
Tungsten particles size: 10–16 µm.

Petrov E. V.

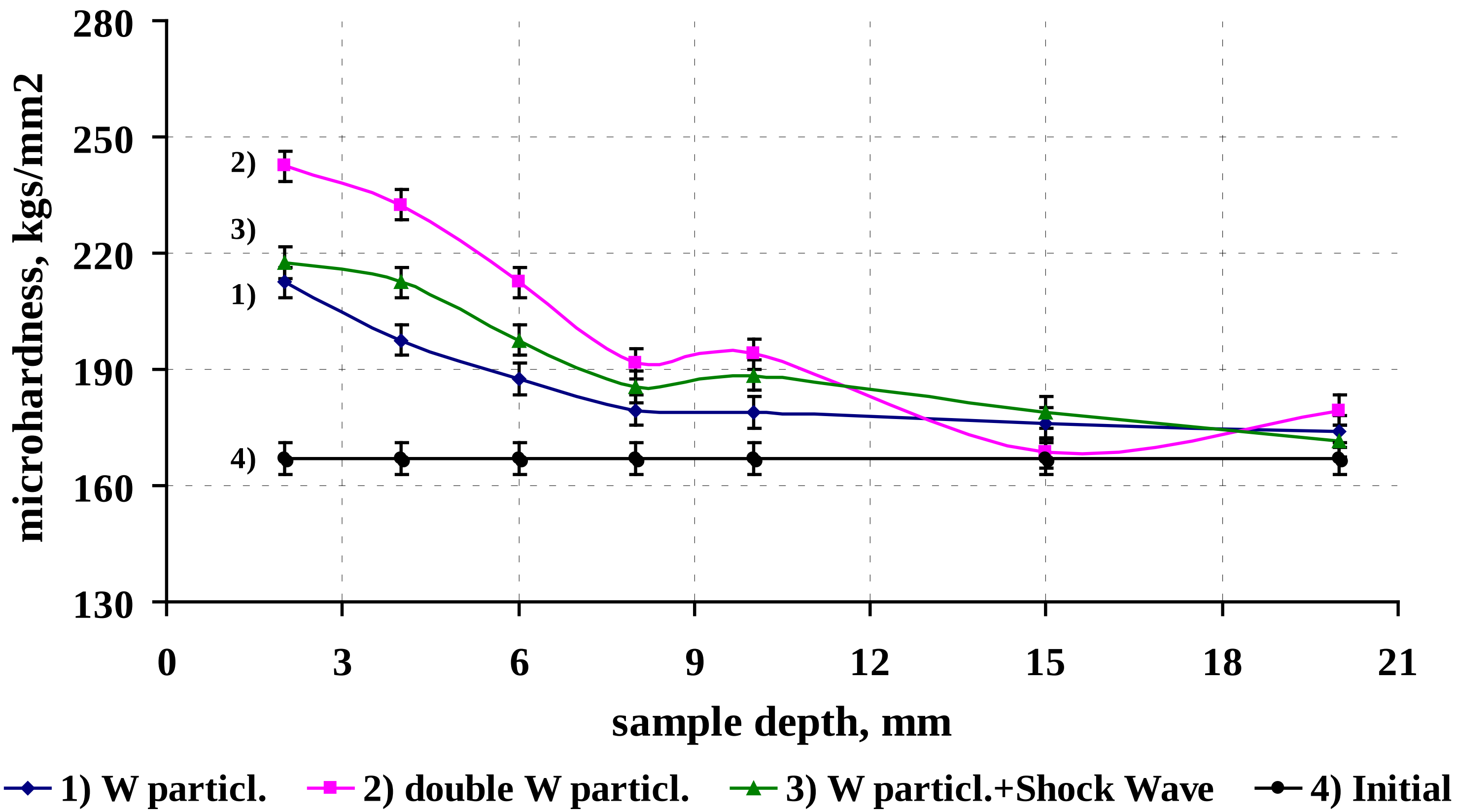


SEM image of (a) the W particles shock-embedded into a steel target and (b) small intermetallic globules surrounding the embedded W particles.

The formation of intermetallic globules with a mean size of about 200 nm is indicative of the occurrence of the W–Fe reactive diffusion yielding the seeds of the intermetallic phase.

Petrov E. V.

Microhardness distribution along the sample depth



The bombardment was found to improve the microhardness whose maximum gain of 45 and 39 % was reached at depths of 2 and 4 mm.

Petrov E. V.

ONCE MORE ON THE ROLE OF SHOCKED GAS IN EXPLOSIVE WELDING

M. I. Alymov, I. S. Gordopolova, and A. A. Deribas

Institute of Structural Macrokinetics and Materials Science, Russian Academy of Sciences, Chernogolovka, Moscow, 142432 Russia

As is known, explosive welding of some dissimilar metals (including titanium) gives poor results in the presence of air in the welding gap. For this reason, in some cases special measures should be taken in order to replace ... onation

V_c, m/s	Wave parameters	Air	He	H_2
1500	V, m/s	1800	2200	2500
	T, °C	1850	300	200
	P, MPa	4.0	0.6	0.4
2500	V, m/s	3000	3300	3500
	T, °C	4800	620	400
	P, MPa	10.0	1.25	0.8
3000	V, m/s	3600	3850	4000
	T, C	6800	860	520
	P, MPa	14.0	1.75	1.05
4000	V, m/s	4800	5050	5150
	T, C	11800	1450	850
	P, MPa	24.5	3.0	1.7
5000	V, m/s	6000	6150	6300
	T, C	18000	2150	1280
	P, MPa	38.0	4.5	2.6

U. Richter, J.F. Roth, Grundlagen und Anwendung des Sprengsplattierens, *Naturwiss.*, 1970, vol. 57, no. 10, pp. 487–493

Previously [6], we have demonstrated that the duration of contact between shock-compressed gas and metal surface is too short for any kind of heat-exchange processes. Since the mass of gas in the gap is much smaller than the mass of metal plates, the contribution of shock-compressed gas to the overheating of Ti plate can be safely neglected. Moreover, explosive welding in vacuum was found [7] to give the same results as that in air. Nevertheless, vivid discu... continuing in the literature.

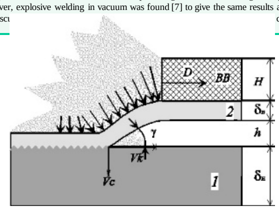


Fig. 1. scheme of welding in the blast.

6. M.I. Alymov, A.A. Deribas, I.S. Gordopolova, *Perspekt. Mater.*, 2013, no. 12, pp. 51–55.
7. A.A. Deribas, *Fizika uprocheniya i svarki vzryvom* (Physics of Explosive Strengthening and Welding), Novosibirsk: Nauka, 1980.

The question is: "what has a determining impact on the temperature in the area of impact: impact speed, the angle of impact, and as a result of plastic deformation or impact shock-compressed gas? How can you manage it?

This can be expected to hamper harmful overheating of clad plates and to avoid sharp temperature/pressure jumps in the gap [2]. High-quality joining between Ti and steel was achieved in the presence of He in the weld gap. Local bulging and rupture of metal observed in explosive welding of Ti [3, 4] was explained by ignition and combustion of gas-saturated Ti particles ejected into the gap due to the jet-formation effect. An attempt to check the above assumption was made in [5] by using the method of traps. However, in the experiments under Ar no trapped unburned Ti particles have been detected. This suggests that there is some other cause for overheating a Ti plate.

Previously [6], we have demonstrated that the duration of contact between shock-compressed gas and metal surface is too short for any kind of heat-exchange processes. Since the mass of gas in the gap is much smaller than the mass of metal plates, the contribution of shock-compressed gas to the overheating of Ti plate can be safely neglected. Moreover, explosive welding in vacuum was found [7] to give the same results as that in air. Nevertheless, vivid discussion on the decisive role of shocked gas in explosive welding is still continuing in the literature.

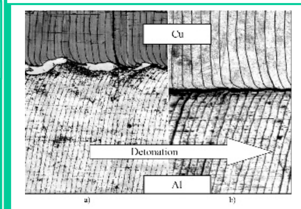


Fig. 3. Impact velocity contact on deformacionnuû picture in model cross-layered sampleswhen welding with aluminium copper explosion (Vc = 200 m/s a-Vk = 2600 m/s b-Vk = 2000 m/s.

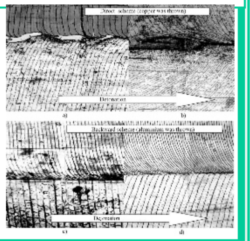
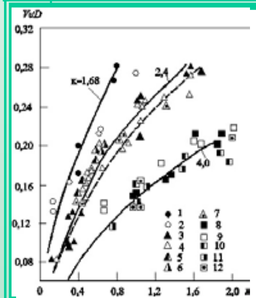


Fig. 4. the structure of the zone copper compounds with aluminum (cut on modeling lateral inserts welded specimens when Vk = 2600 m/s): (a), (c)-Vc = 200 m/s; (b), (d)-Vc = 350 m/s;

Kuzmin S.V., Lysak V.I., Rybin V.V., Peev A.P. Osobennosti plasticheskoi deformacii metalla ... svarki vzryvom raznorodnyh metallov. [Features a plastic deformation of the metal when welding zone cent explosion of dissimilar metals] Izvestia VolgGTU. 2010, т.5, №4, p. 4-12.



1-Nil-1 (ρ = 0.32g/cm3); 2-Nil-1 (ρ = 0.2 g/cm3); 3-Ammonite; 4-AC 50/50; 5-TC 15/85; 6-TC 12/88; 7-RDX; 8-G60; 9-G40; 10-G20; 11-TG 50/50; 12-G75

$$V_c = 1.2 \cdot D\frac{\sqrt{1+\frac{32}{27}r}-1}{\sqrt{1+\frac{32}{27}r}+1};$$

Baum F.A., Stanyukovich K.P., Shehter B.Ya, Phyzika vzryva[E xplosions Physics.]. Moscow, Phizmatgis. 1959, 800 p

$$V_c = \frac{r}{r+2} \cdot D\sqrt{2k/[(k^2-1)(k-1)]}$$

Gurney R.W. The initial velocities of fragments from bombs, Shells and grenades. B.R.L.Report, 1943, p. 405

. Fig. 2. Dependence of the velocity of detonation speed plates (V0/D) from mass CC to weight metaemoj plate (r) calculated using equation (1) by a factor of 1.2 (dashed line) and equation (2) (solid line) with different indicator isentropic product explosion k.

Moscow: Metallurgiya, 1978.

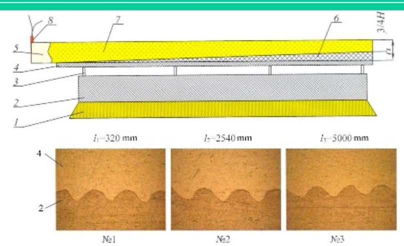


Fig. 5. Assembly scheme. Wedge-shaped element in the entire length of the welded sheets.
a) 1-Sandy basis; 2-metal plate; 3-welding clamps clearance height h; 4-leaf plating; 5-container for ES; 6-wedge-shaped element (foam, foam); 7-ES; 8-electric Exploder.
b) Macrostructure research zone metallographic Results connection.

Silchenko T.Sh., Kuzmin S.V., Lysak V.I., Dolgii Yu. G., Chuvichilov V.A., Yurasov V.V., Rybin V.B., Schastlivaya I.A., Vasilenko A.Yu. Sposob poluchenia krupnogabaritnyh bimetallicheskih listov svarki vzryvom. [Method of obtaining large-sized explosion welding of bimetallic plates](patent RU № 2417868, posted 10.05.2011)

Conclusions

The problems encountered in explosive welding of titanium should be associated not the temperature and other parameters of shocked gas but with specific properties of Ti metal;
such as the ability to adsorb and retain large amounts of gaseous hydrogen, oxygen, and nitrogen.
This circumstance must be taken into account in practical implementation of explosive welding.

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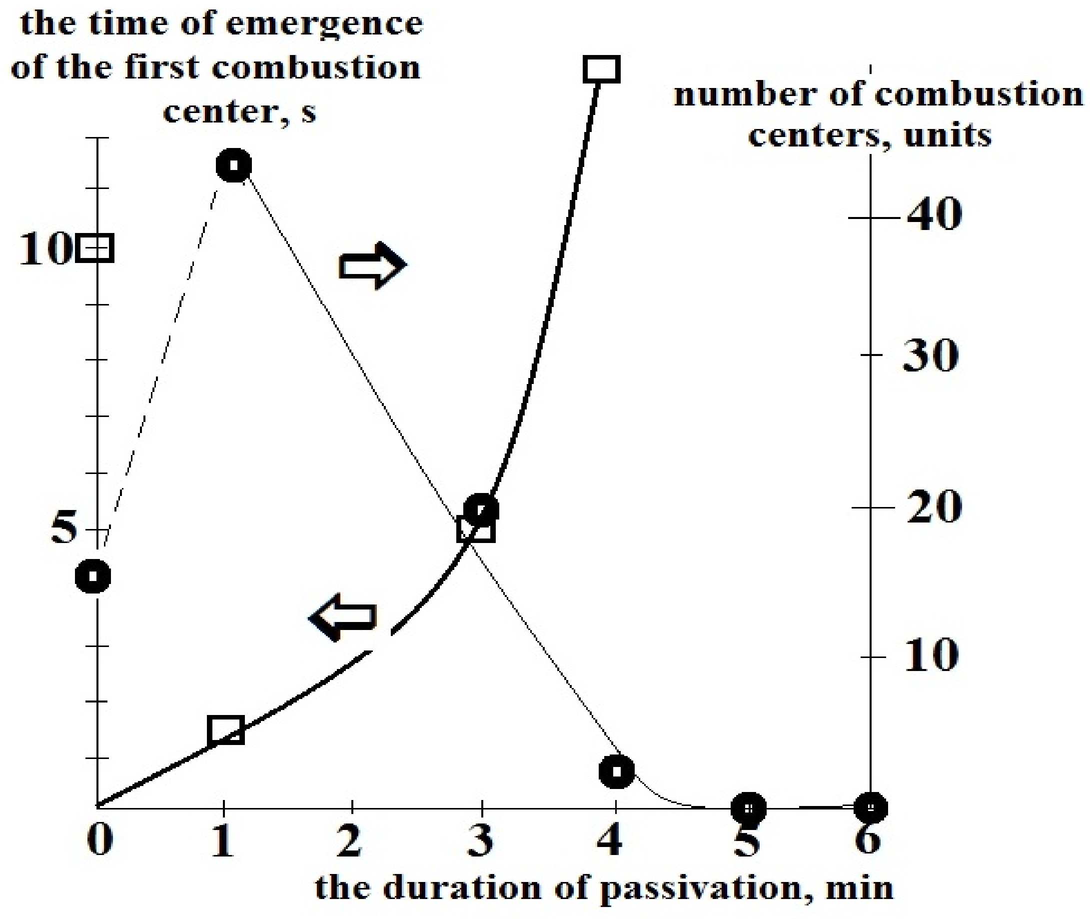
Ignition and combustion of iron nanopowders in air



Sepliarskii B.S.

The non-uniform quasi two-dimensional mode of combustion of iron nanopowders in the absence of external flows is revealed for the first time.

The method of estimation of the extent of passivation of Fe nanopowders with the use of a method of color high-speed filming is offered. It is experimentally established that both the dependencies of the period of a delay of ignition and quantity of the primary centers of combustion on the time of passivation can be used for estimation of the extent of passivation.

On the basis of the experimental data for the certain sample, the approximate equation for estimation of the minimum time of complete passivation for the sample of arbitrary thickness is offered.

By the method of X-ray phase analysis, it is established that 1 mm thick samples of iron nanopowder treated in a stream of 3% of air + Ar for the time interval more than 6 min contain only metallic iron. Therefore, the method of passivation suggested is rather effective.

Thank you

for your attention