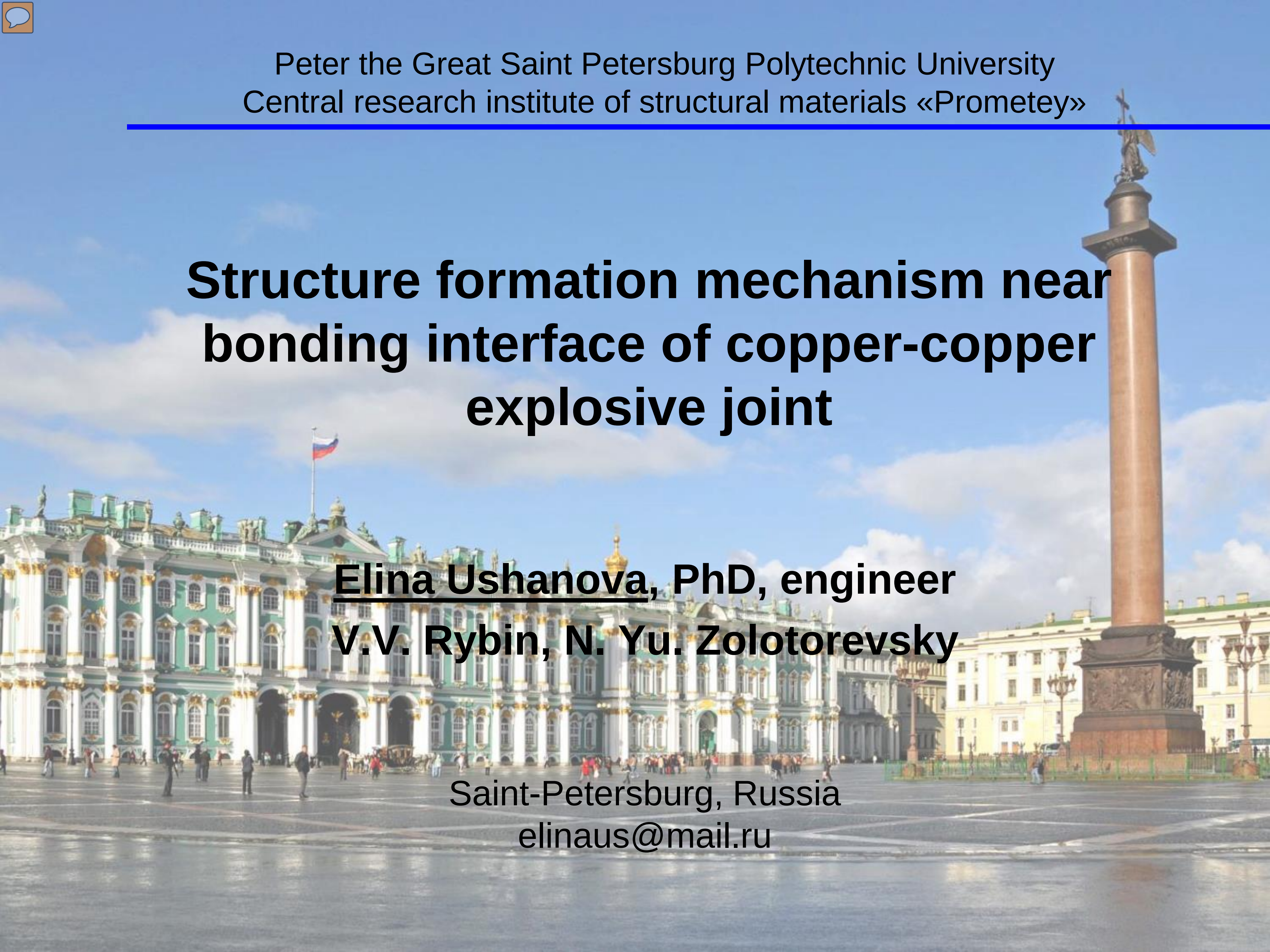

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Structure formation mechanism near bonding interface of copper-copper explosive joint

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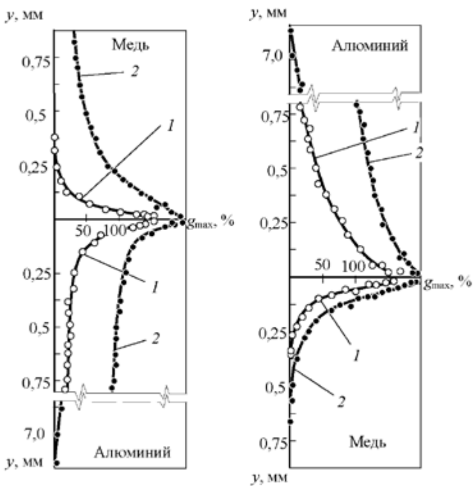
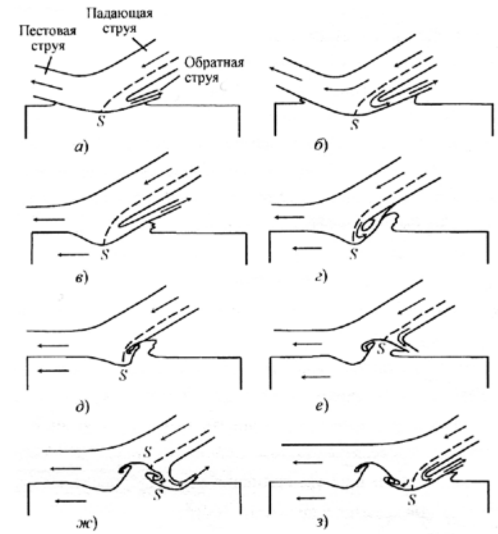
URGENCY OF AN ISSUE

REVIEW OF PRIOR WORK ON EXPLOSIVE WELDING

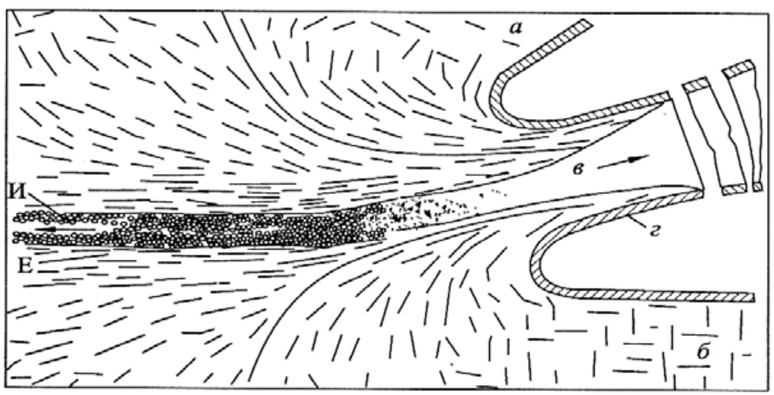
Localization of plastic deformation in narrow bond zone (NBZ)



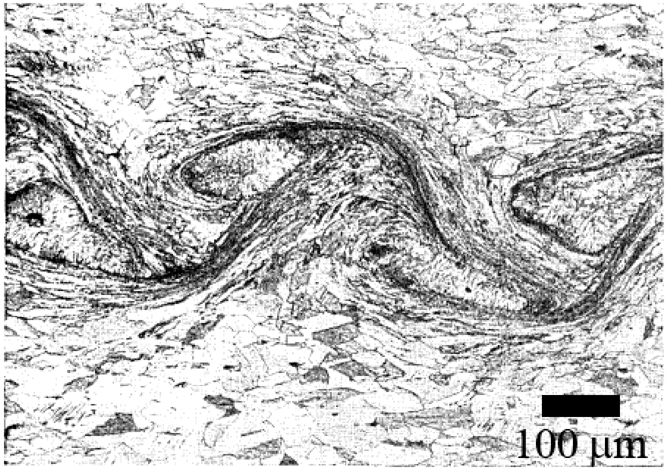
V. I. Lysak, S. V. Kuz'min, *Explosion Welding* (Mashinostroenie, Moscow, 2005)



A. S. Bahrani et all // Proceedings of the Royal Society A 296 (1967) P. 123 – 136.



M. Hammerschmidt, H. Kreye in: Shock Waves and High Strain-Rate Phenomena in Metals. Plenum Press, New York 1981 P. 961 – 973.

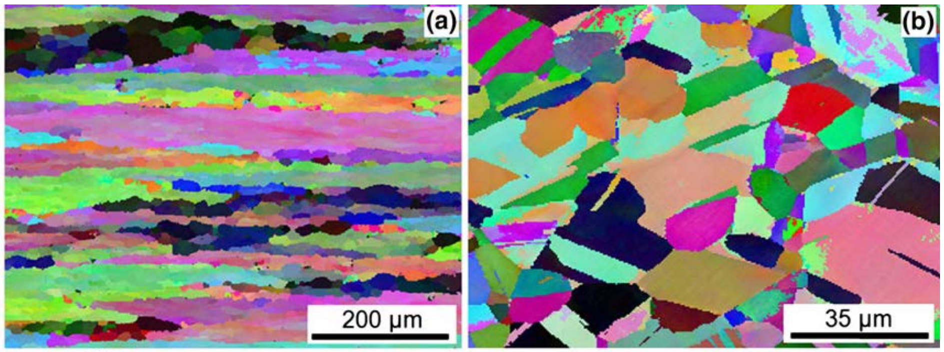


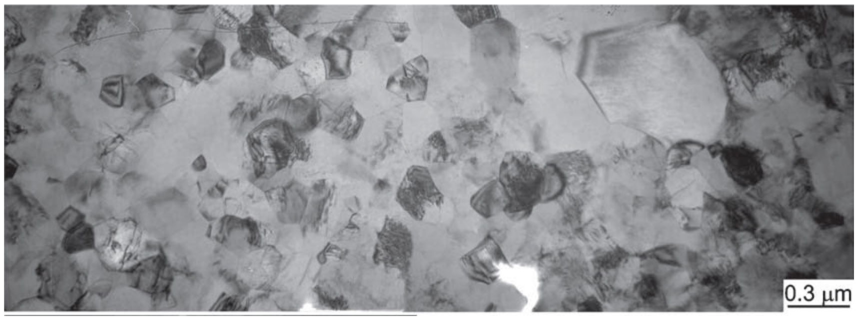
B. Crossland et all // Metallurgical Reviews 6 (1970) P. 79 – 100.

URGENCY OF AN ISSUE

REVIEW OF PRIOR WORK ON EXPLOSIVE WELDING

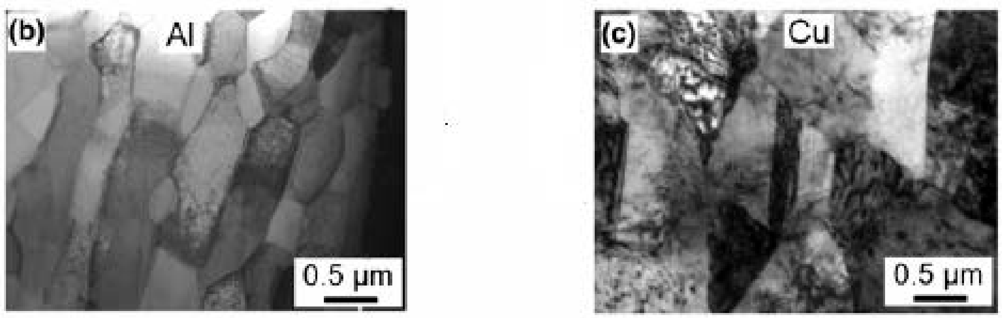
Initial structure



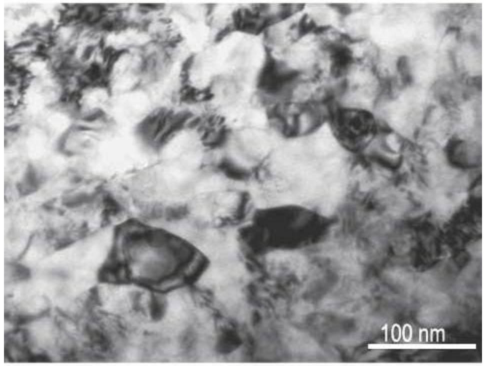


V.V. Rybin, B.A. Greenberg et all // JNN 11 (2011) P. 1 – 11

Narrow bond zone structure



H. Paul et all // Metallurgical And Materials Transactions A 44A (2013) P. 3836 – 3851.



Y. Yang et all // Metallurgical and materials transactions A. 37 A (2006) P. 3131 – 3137.

THE AIM AND OBJECTIVES

<u>The aim:</u> the study of the physical nature and the fundamental laws of the deformation structures formation during plastic deformation under high-speed loading conditions in explosive welding.

<u>Objectives:</u>

1. At the macro, meso and micro levels to carry out a systematic investigation of the morphological and crystallogeometrical features of the structural states formed in the narrow bond zone.

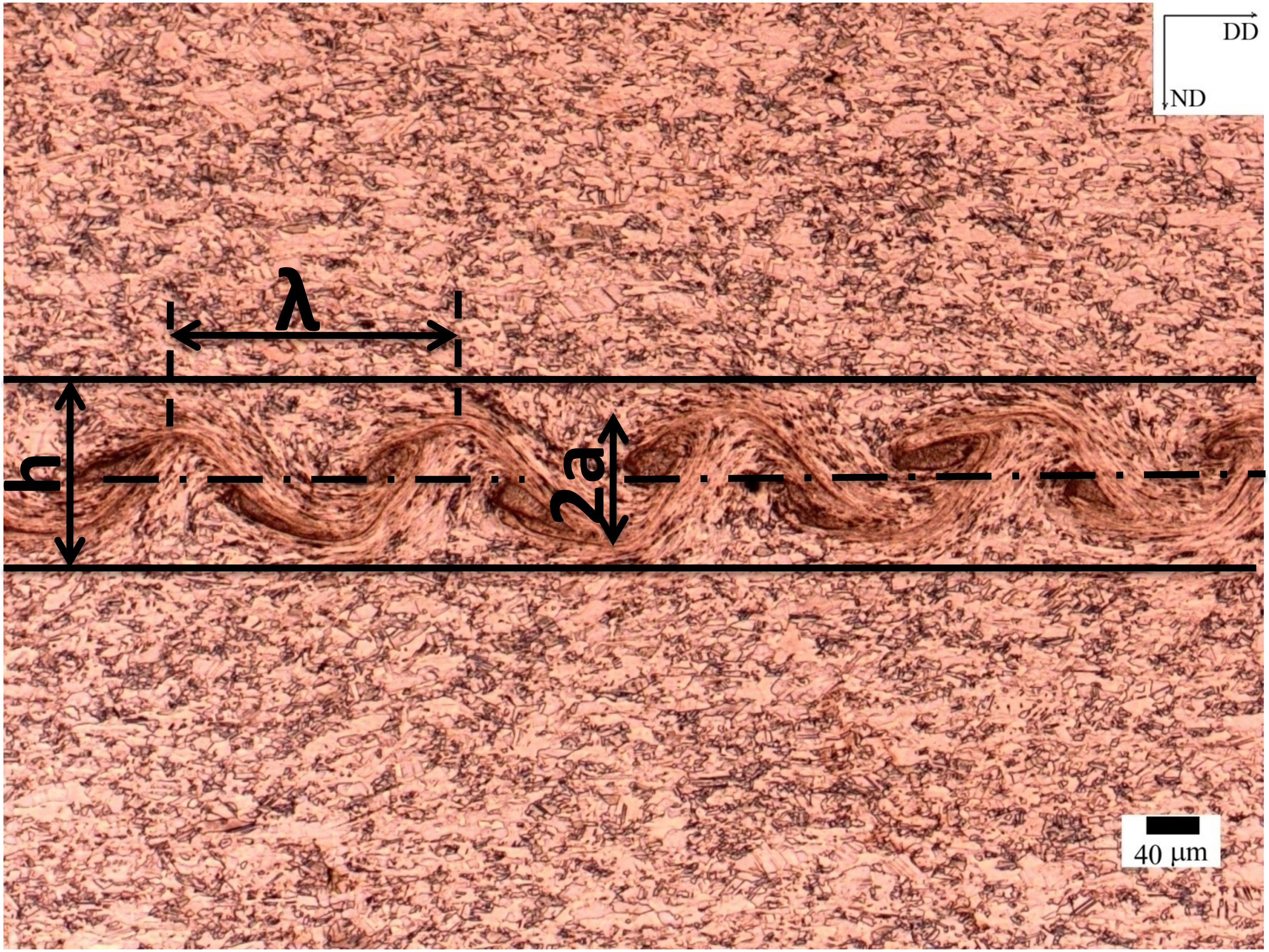
2. To study deformation structures evolution with approaching the interface.

3. To use a computer simulation of experimental misorientation distributions to determine the contributions of various structure formation mechanisms to the NBZ deformation structures forming.

MULTI-LEVEL NATURE OF PLASTIC DEFORMATION IN A NARROW BOND ZONE

COPPER – COPPER EXPLOSIVE JOINT: MACROLEVEL

h = 180 μm
λ = 285 μm
a = 60 μm

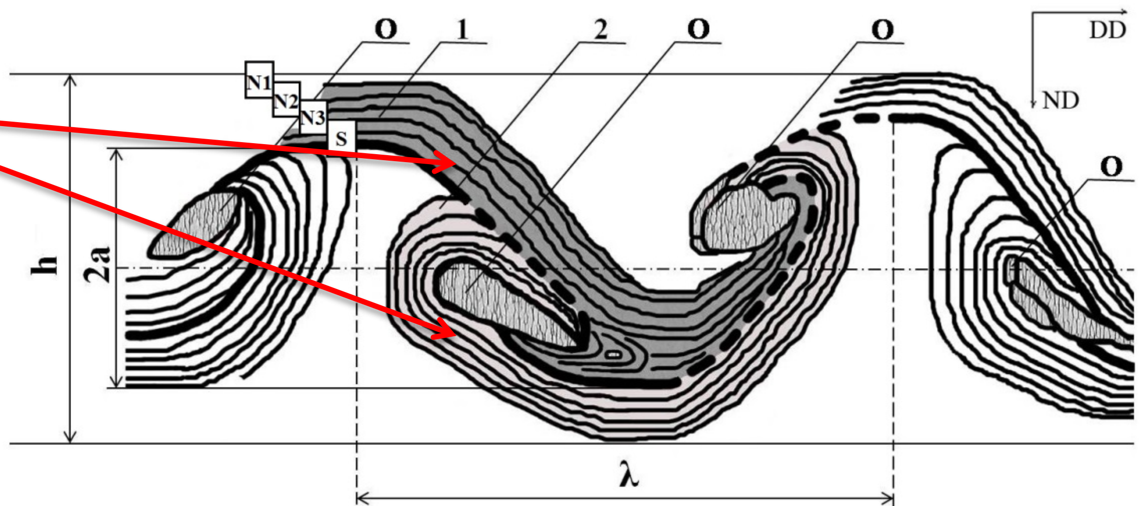


DD – detonation direction
ND – normal direction

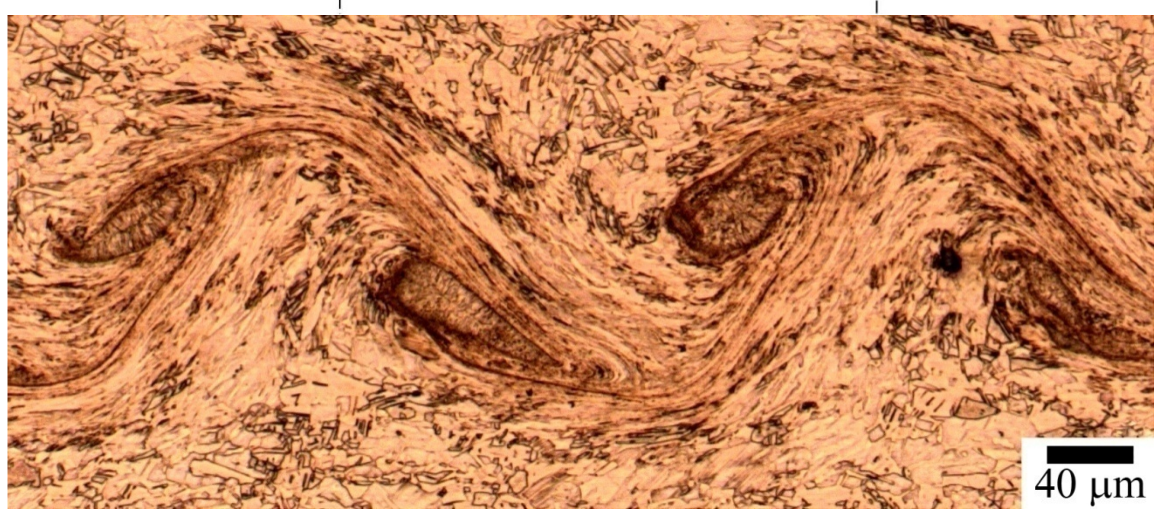
MULTI-LEVEL NATURE OF PLASTIC DEFORMATION IN A NARROW BOND ZONE

COPPER – COPPER EXPLOSIVE JOINT: MACROLEVEL

plastic stream



O – melting area
h – NBZ thickness
2a – wave height
λ – wavelengh
DD – detonation direction
ND – normal direction
1, 2 – plastic streams



MULTI-LEVEL NATURE OF PLASTIC DEFORMATION IN A NARROW BOND ZONE

THE PHYSICAL NATURE OF PLASTIC STREAMS ORIGIN

Within the hydrodynamic models:

The origin and the development of the reverse cumulative jet is possible if the mechanical behavior of metal is similar to a liquid-like or an amorphous material behavior.

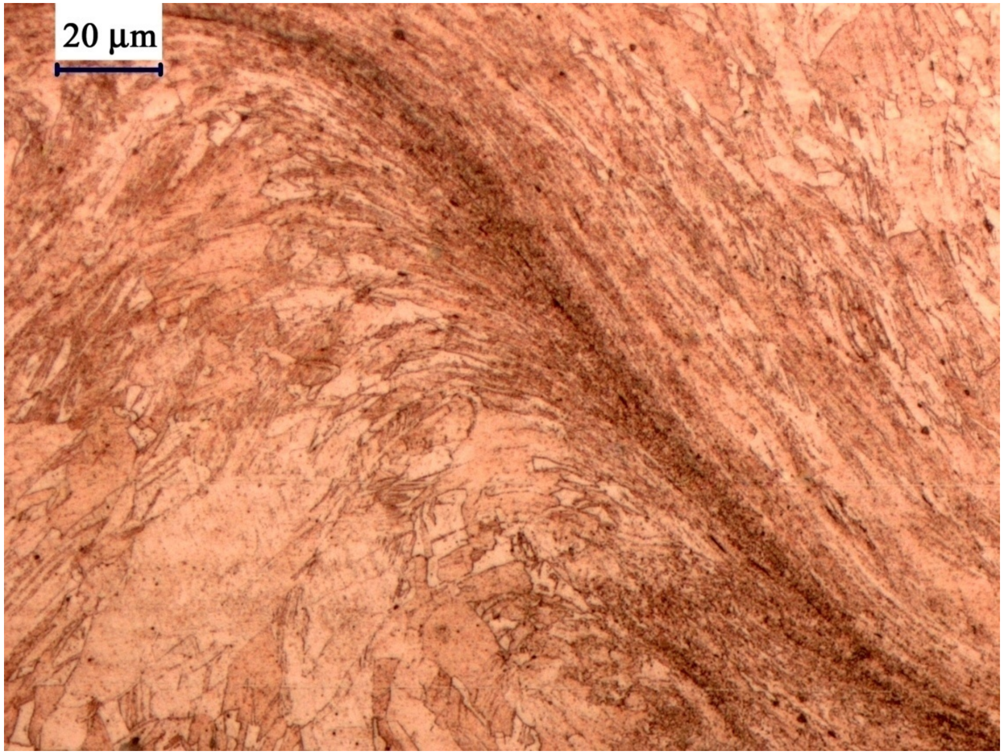
1) The inverse cumulative jet should be separated with abrupt boundary from the surrounding material maintained the crystal structure during the co-deformation process;
2) The material structure inside the inverse cumulative jet must have characteristics of crystallization processes which occur during amorphous metal cooling and the crystalline phase formation.

However, experimental evidences show, that it is not so!

MULTI-LEVEL NATURE OF PLASTIC DEFORMATION IN A NARROW BOND ZONE

THE PHYSICAL NATURE OF PLASTIC STREAMS ORIGIN

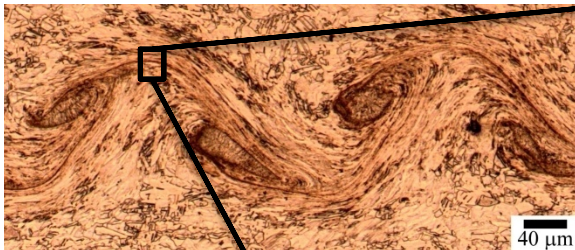
Experimental facts suggest that the material flow within the plastic streams have features of plastic deformation in a **crystalline solid**.

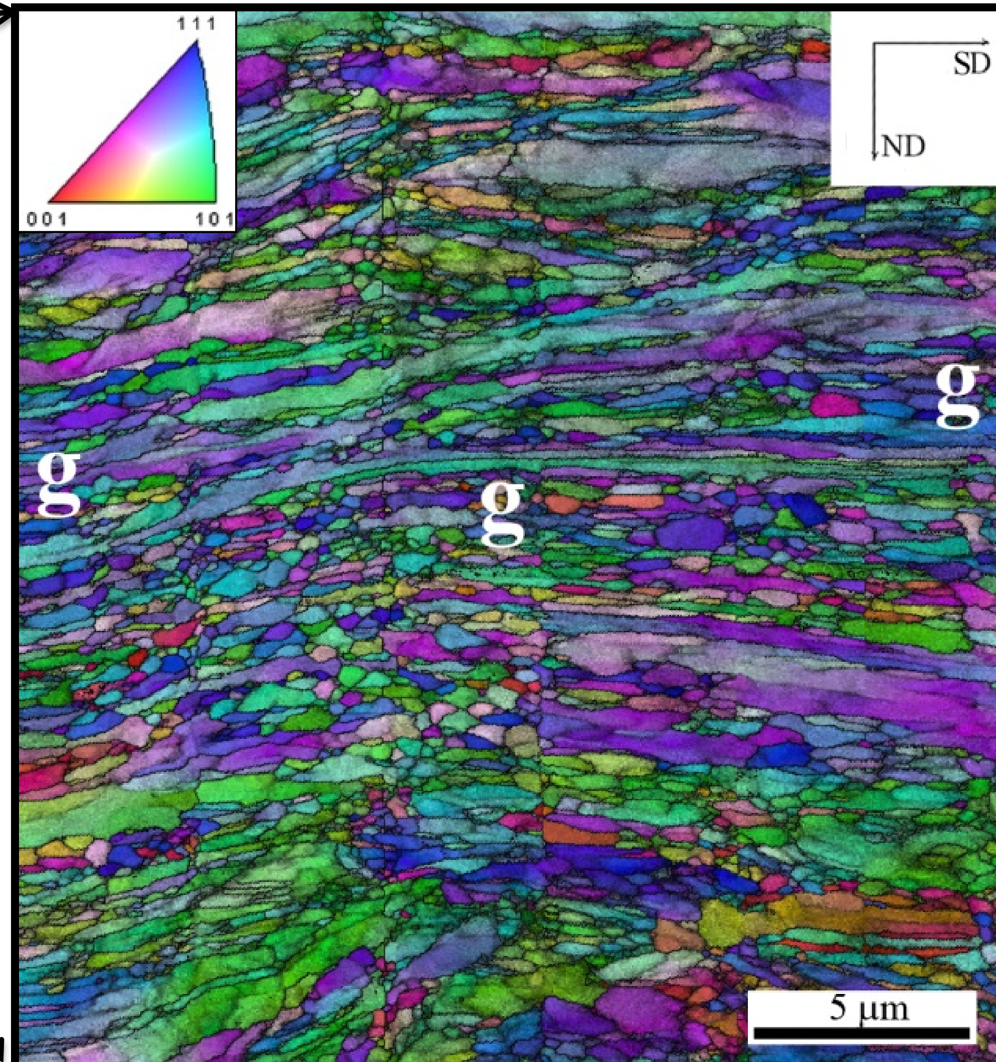


1. Plastic streams originate and end in a deformed material of cladding and base plate continuously and don't have **abrupt boundary** separated them from the surrounding material.
2. **Metal flow** inside the plastic stream is not homogeneous as for an amorphous or liquid-like material but **discrete** and consists of a set of parallel and thin deformation bands that is typically for a **crystalline solid**.

MULTI-LEVEL NATURE OF PLASTIC DEFORMATION IN A NARROW BOND ZONE

COPPER – COPPER EXPLOSIVE JOINT: MESOLEVEL



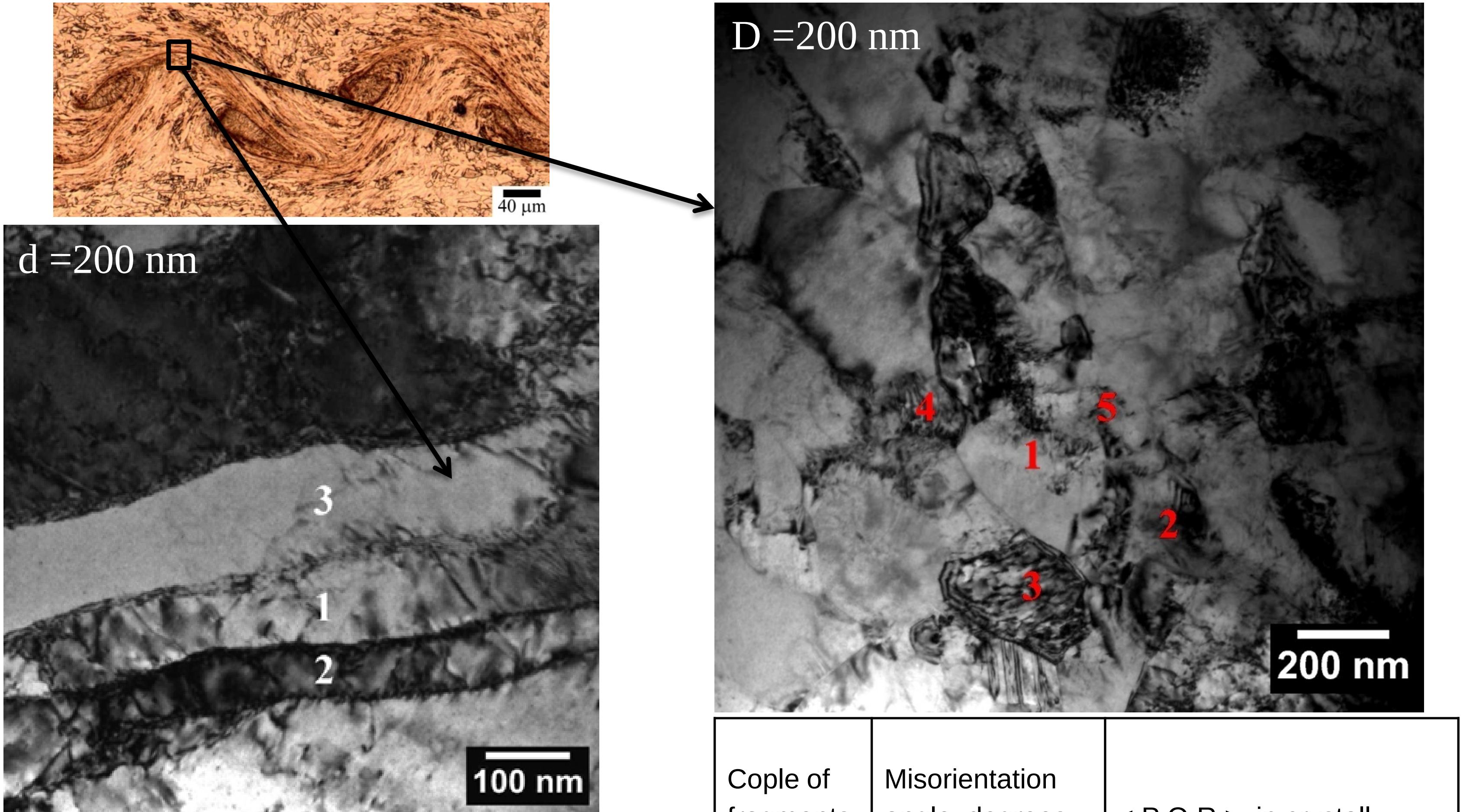


- HAGBs fraction is 83 %
- Crystallites are combined in bands in thickness of 5 µm.
- Length of mesobands is 20-50 µm
- Crystallites transverse dimension is
- <D>=200 nm

SD – direction parallel to a local region of the interface
ND – direction perpendicular to the SD

MULTI-LEVEL NATURE OF PLASTIC DEFORMATION IN A NARROW BOND ZONE

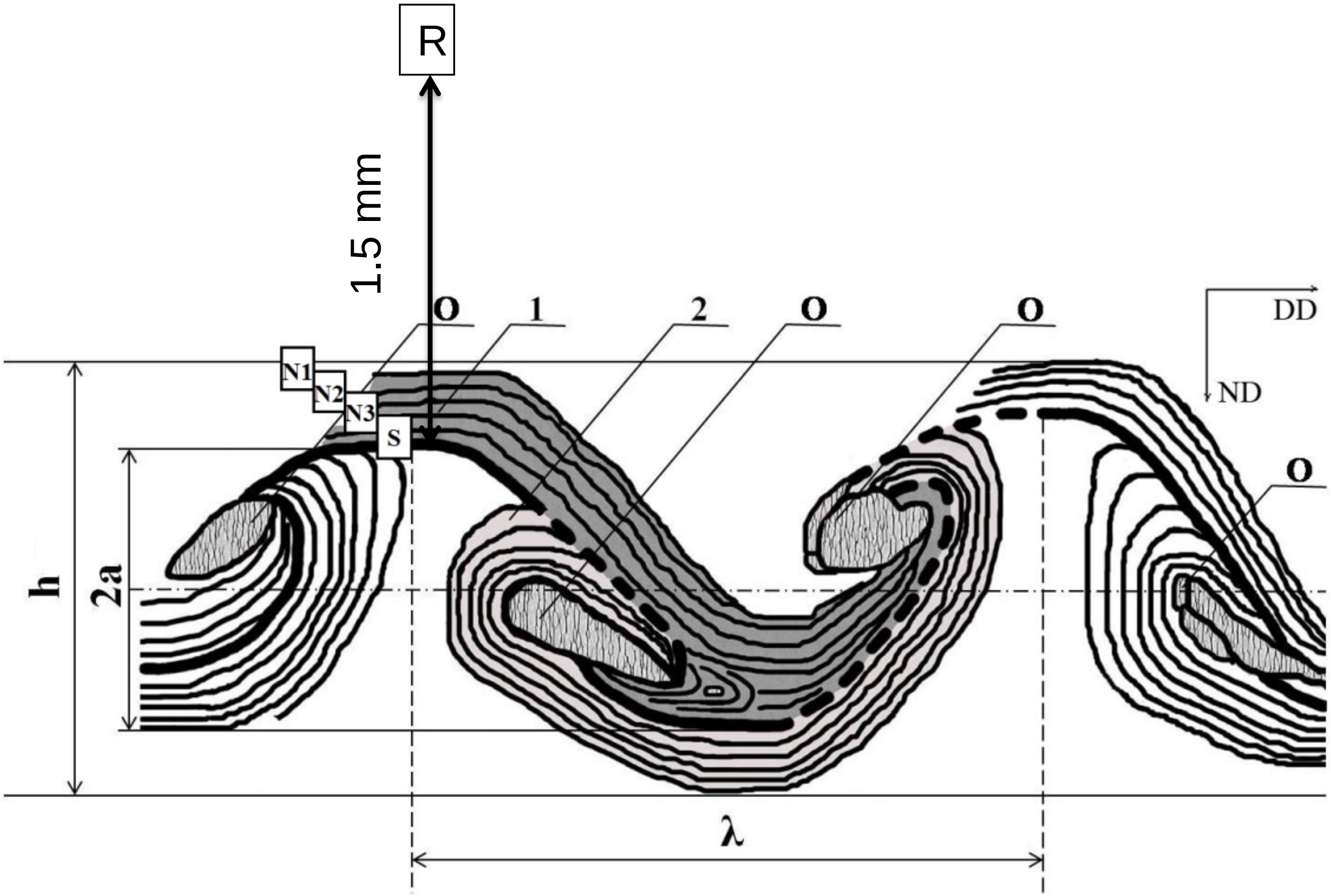
COPPER – COPPER EXPLOSIVE JOINT: MICROLEVEL



Couple of microband	Misorientation angle, degrees	< P Q R > in crystall
1-2	5,4204	-0,9326 0,2762 -0,2324
1-3	5,4607	0,9739 0,1582 0,1630

Cople of fragments	Misorientation angle, degrees	< P Q R > in crystall
1-2	50,2515	0,5205 0,7068 0,4791
1-3	55,9023	0,5875 0,6979 0,4096
1-4	37,5468	-0,8375 0,0637 0,5426
1-5	37,068	0,6766 -0,6636 -0,3191

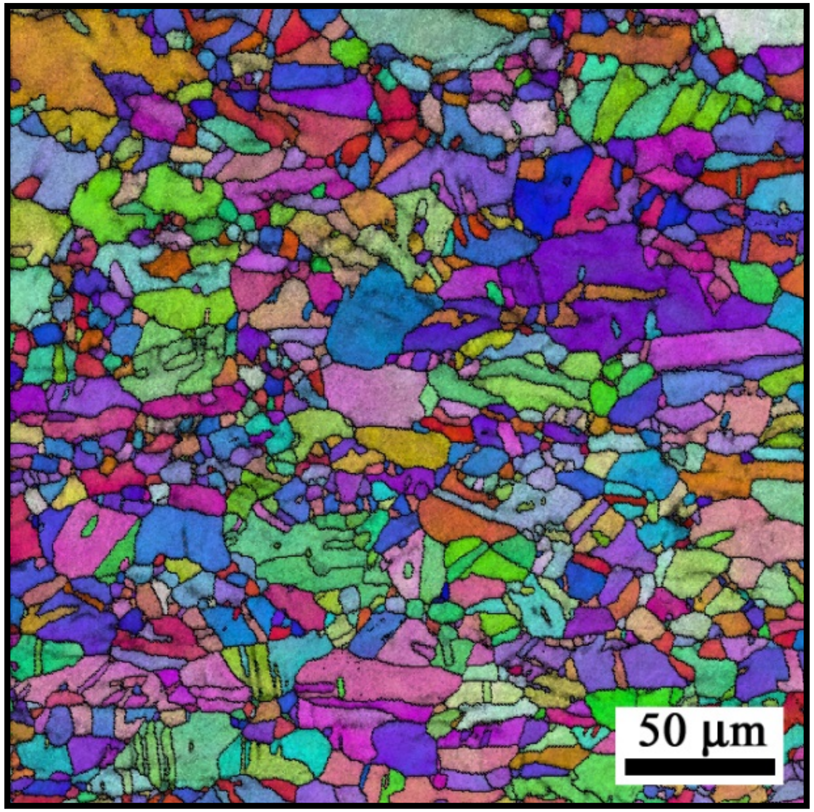
EVOLUTION OF THE DEFORMATION STRUCTURE WITH APPROACHING THE INTERFACE

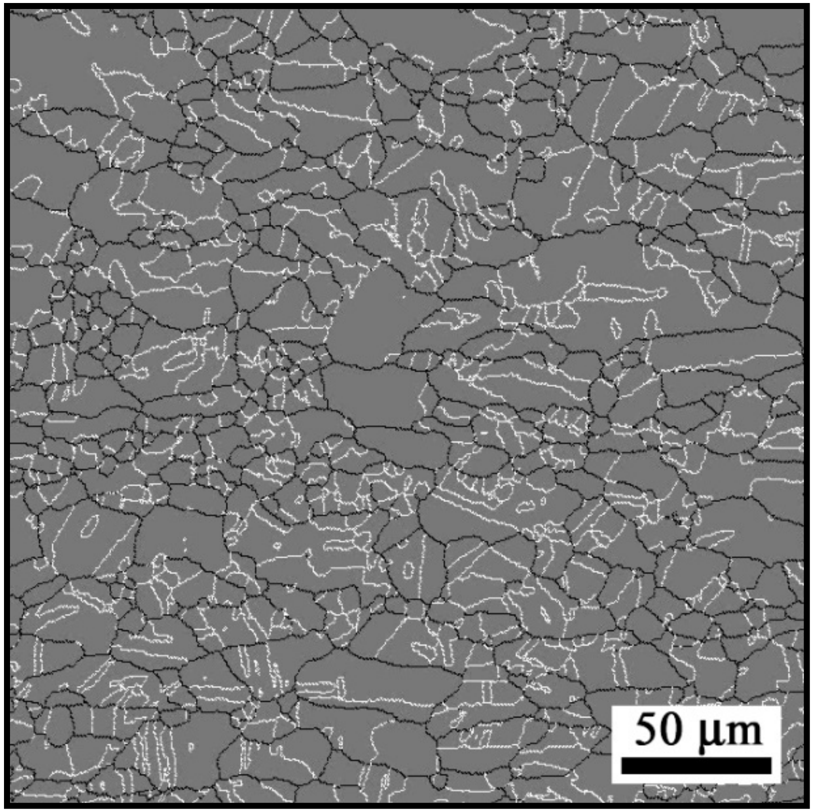


R is reference structure. ***N1*** corresponds to the beginning of NBZ. ***N2*** is located in the middle of the NBZ. ***N3*** is located at the end of the NBZ and directly adjoins the surface of the plastic stream. ***S*** is inside the plastic stream.

EVOLUTION OF THE DEFORMATION STRUCTURE WITH APPROACHING THE INTERFACE

REFERENCE STRUCTURE IS LOCATED AT A DISTANCE OF 1.5 MM FROM THE INTERFACE



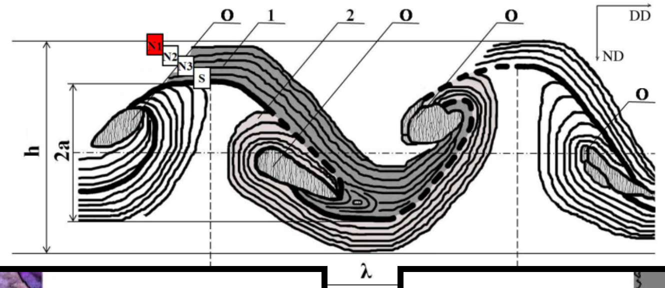


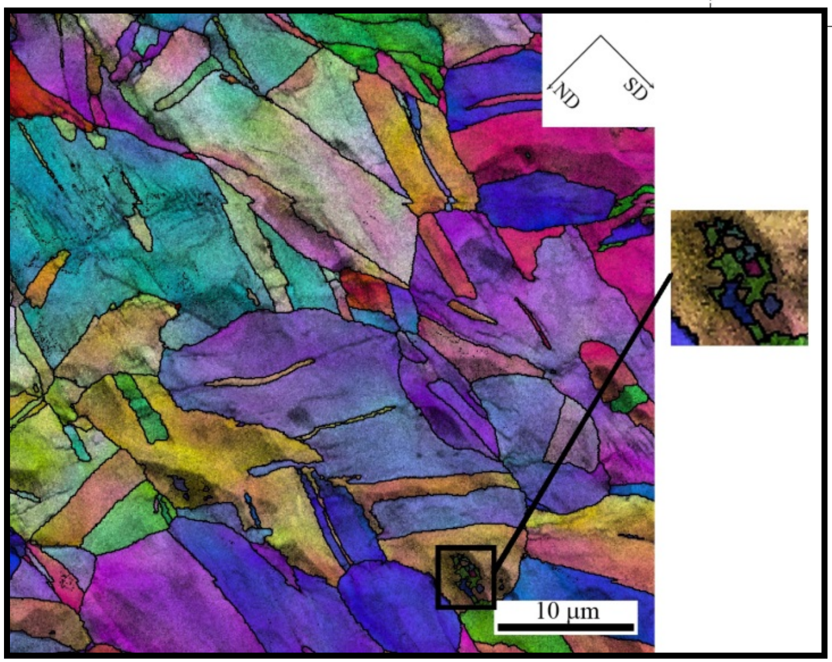
The averaged crystallite size is D_s=16.7 μm.

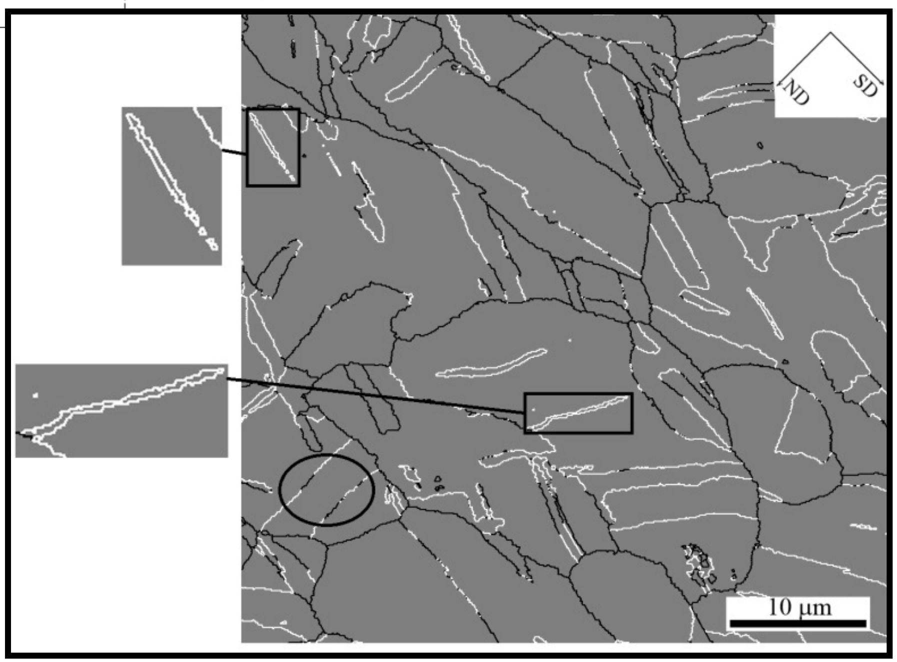
Twin boundaries fraction (Σ= 3, Σ= 9) is 50% (highlighted with white colour).

EVOLUTION OF THE DEFORMATION STRUCTURE WITH APPROACHING THE INTERFACE

REGION *N1* CORRESPONDS TO THE BEGINNING OF NBZ



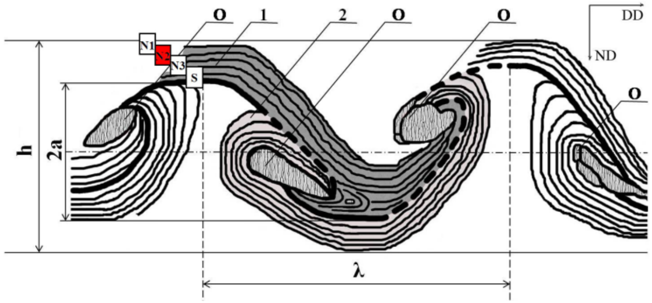


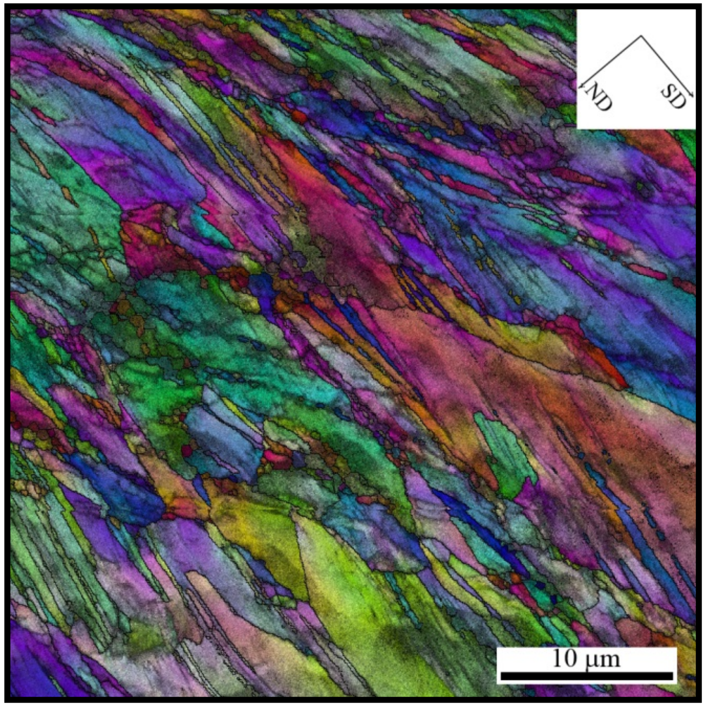


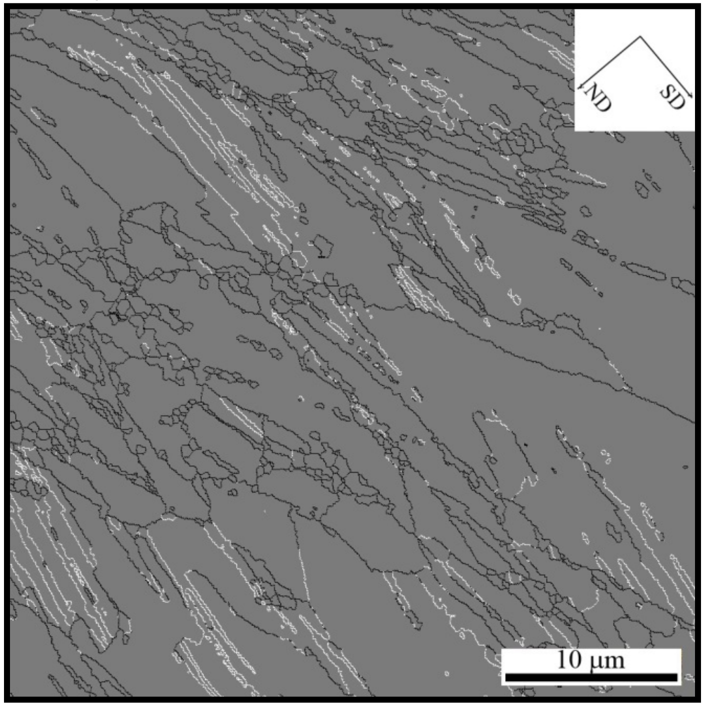
1. Fragmentation near breaks and junctions of high-angle grain boundaries (the area is marked with a rectangle).
2. Extended thin plates of deformation twins (DT).
3. Fragmentation of DT plates (the area marked with a rectangle).
4. Fragmentation of annealing twins and single boundaries (the area is marked with an oval).

EVOLUTION OF THE DEFORMATION STRUCTURE WITH APPROACHING THE INTERFACE

REGION *N2* IS LOCATED IN THE MIDDLE OF THE NBZ



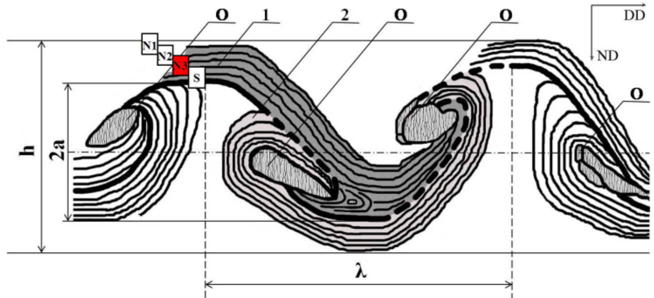


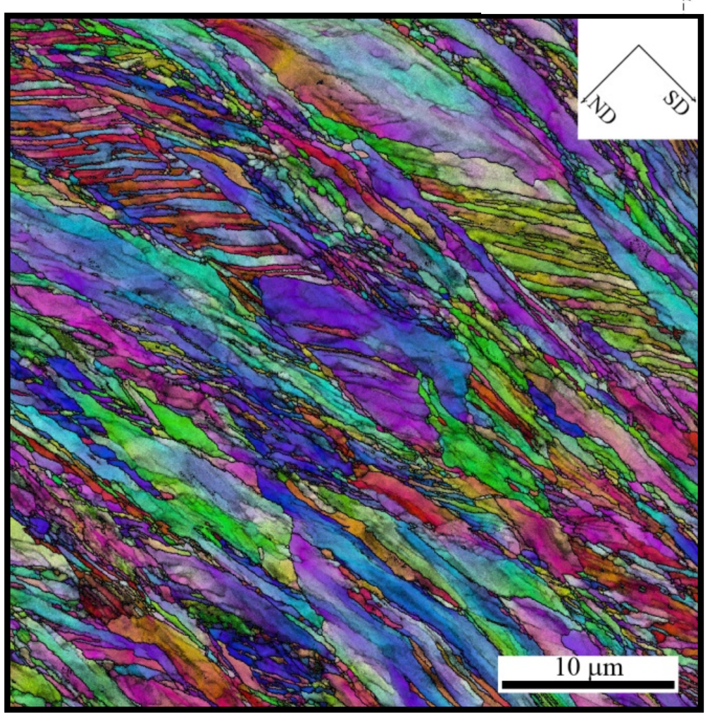


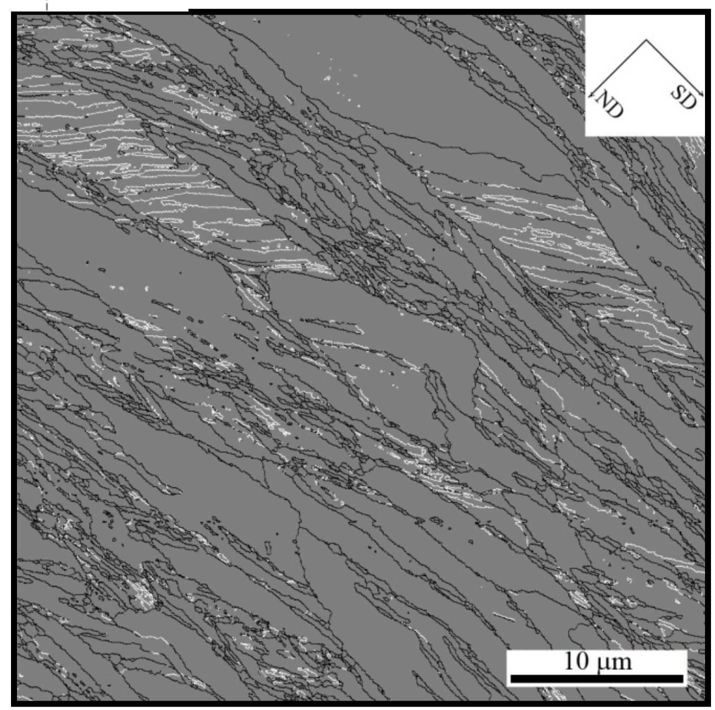
1. More pronounced chains of fragments are formed near the junctions and breaks of grain boundaries.
2. The density and length of the DT plates are increased.
3. DT plates are become more strongly fragmented and transformed into chains of misoriented fragments.

EVOLUTION OF THE DEFORMATION STRUCTURE WITH APPROACHING THE INTERFACE

REGION *N3* IS LOCATED AT THE END OF THE NBZ AND ADJOINS THE SURFACE OF THE PLASTIC STREAM



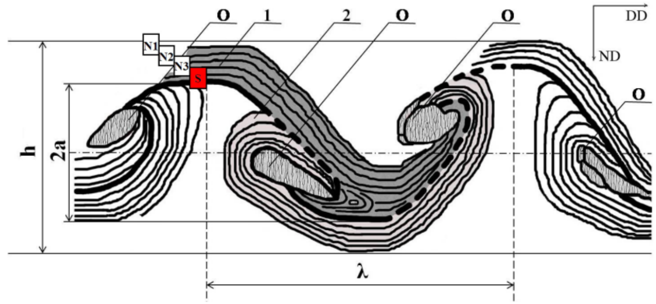


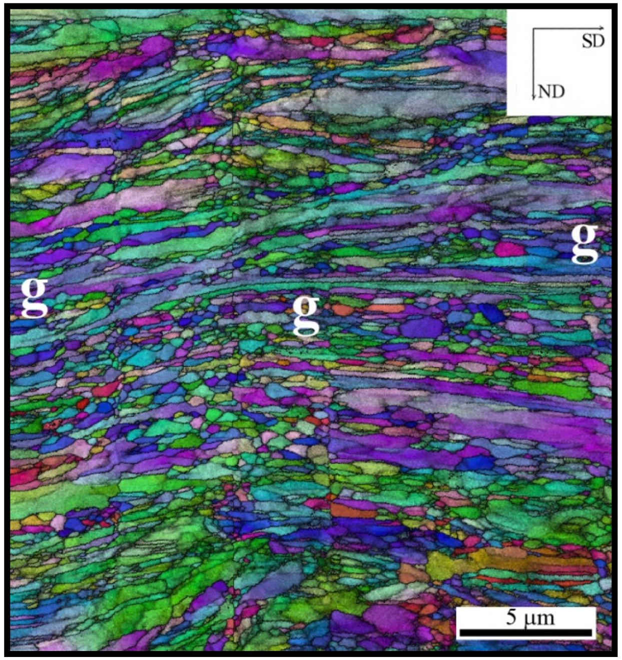


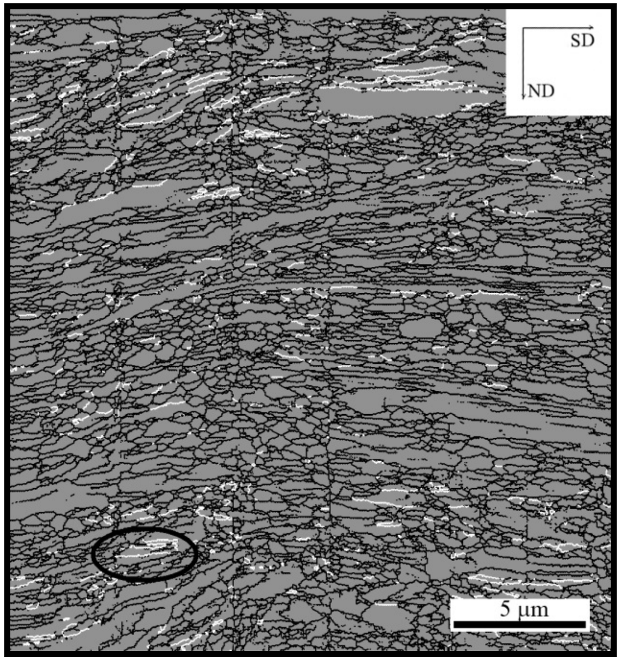
1. Pronounced fragmentation of strongly misoriented DT chains is observed.
2. **Fragmented mesobands** are formed and represent larger structural elements that have the form of bundles of several fragmented chains parallel to each other.

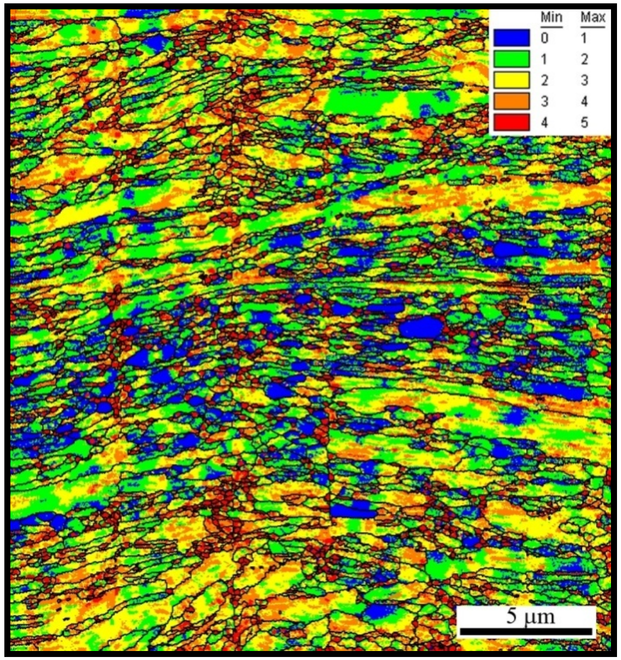
EVOLUTION OF THE DEFORMATION STRUCTURE WITH APPROACHING THE INTERFACE

REGION *S* IS INSIDE THE PLASTIC STREAM





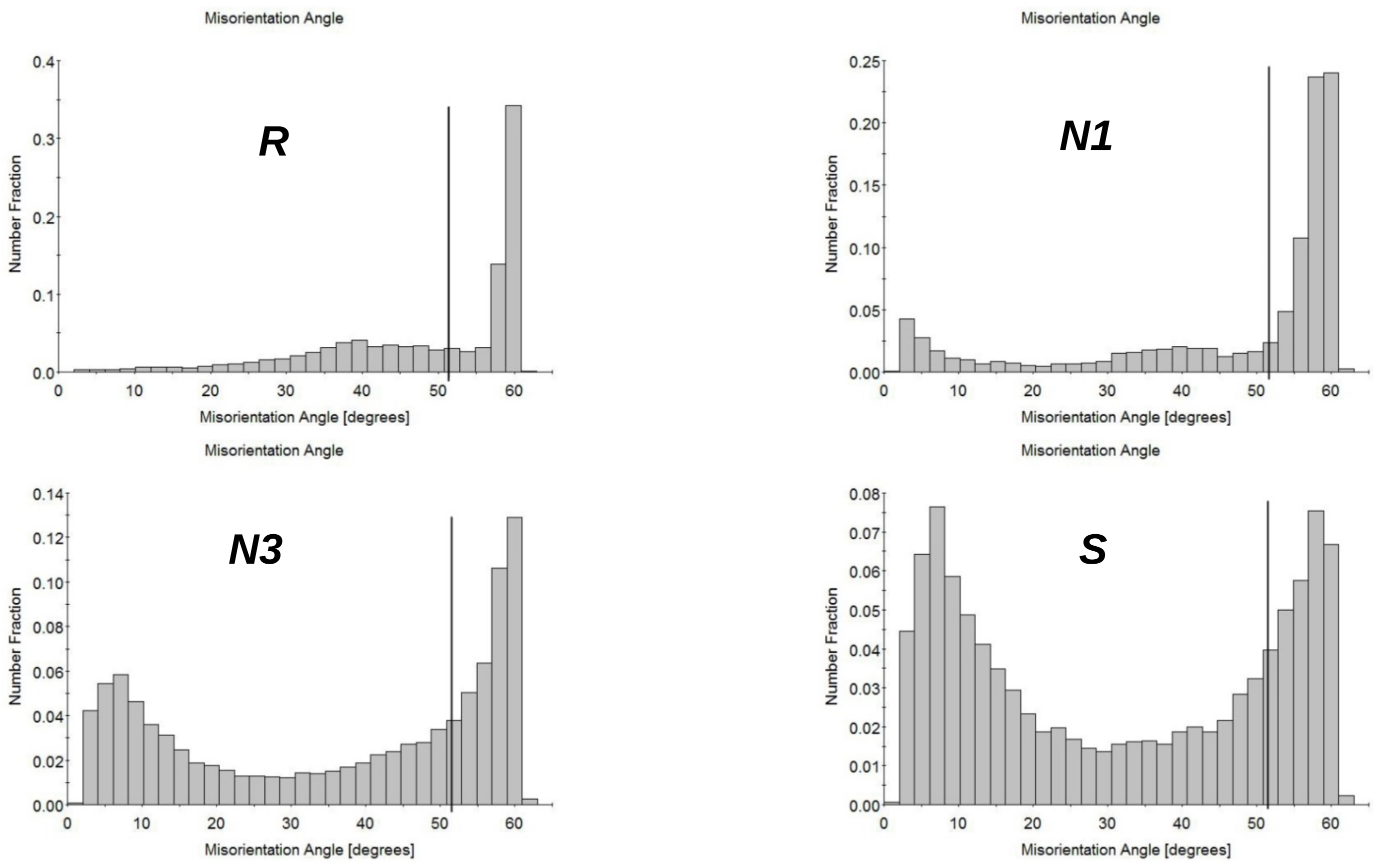




1. The plastic stream consist of the fragmented mesobands and nonfragmented areas.
2. Twin boundaries are inside the mesobands and presented the longitudinal boundaries of fragments. Sometimes thin ~ 0.3 µm DT plates are observed inside of nonfragmented areas (the area is marked with an oval).

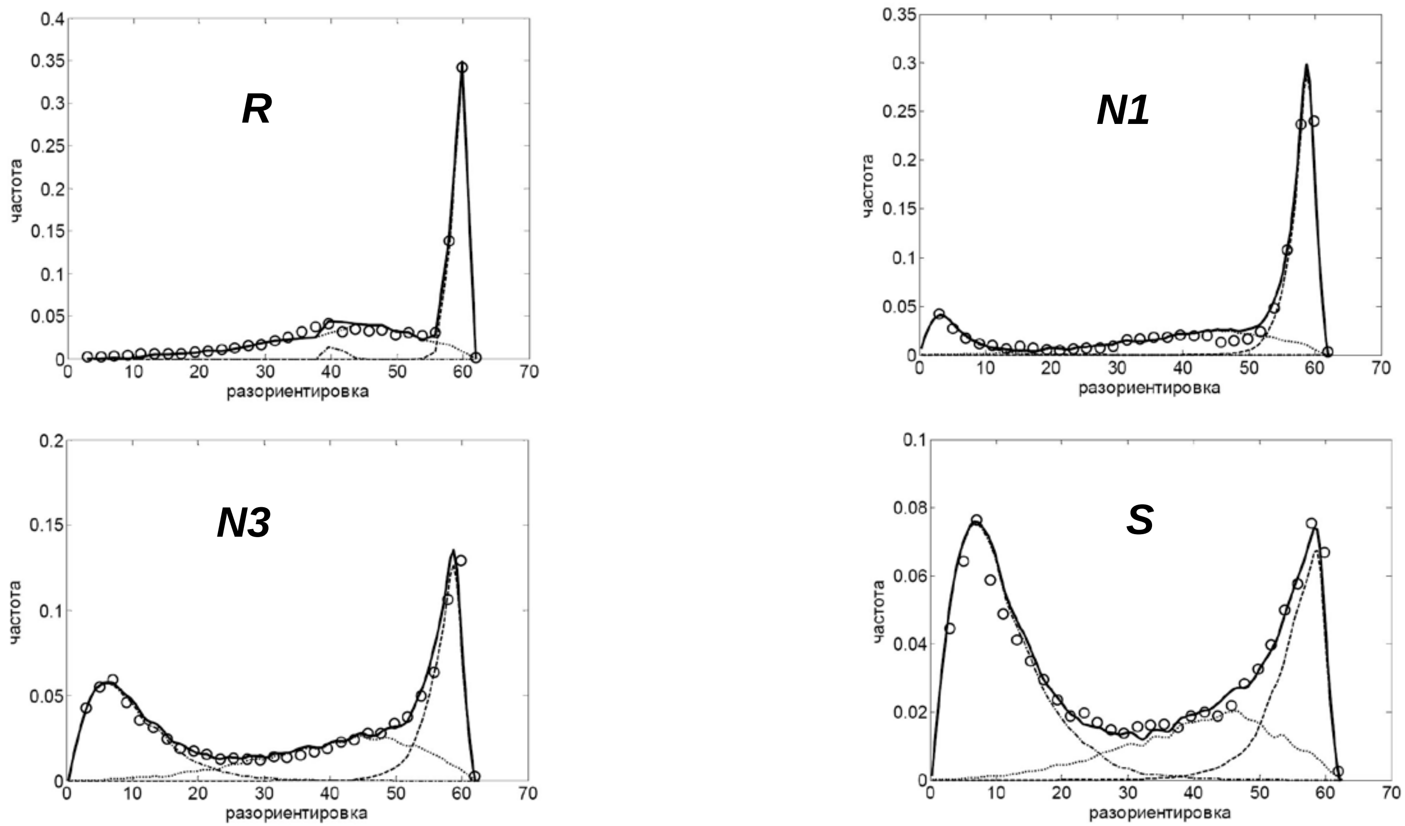
EVOLUTION OF THE DEFORMATION STRUCTURE WITH APPROACHING THE INTERFACE

MISORIENTATION DISTRIBUTION HISTOGRAMS



	Fraction of HABs, %	$\eta_{\Sigma 3}$, %	$\eta_{\Sigma 9}$, %	θ_{p1}, deg	θ_{p2}, deg	θ_{p3}, deg	θ_{min}, deg	θ_{mean}, deg
R	97,4	44,9	4,7	-	40	60	53,8	48,6
N1	88,5	31,1	0,9	3	40	60	45,7	47
N3	73	13	0,4	7	-	60	29,5	36
S	66,6	8	0,8	7	-	58	29,5	31,2

COMPUTER SIMULATION OF MDFs: COMPARISON OF EXPERIMENTAL (ROUND SYMBOLS) AND THEORETICAL (LINE) DISTRIBUTIONS OF MISORIENTATIONS



Thin dotted lines show partial distributions corresponding to different mechanisms of fragmentation; thick continuous lines correspond to integral distributions.

	η_{fr} , %	η_{ch} , %	$\eta_{tw\ (\Sigma 3)}$, %	$\eta_{\Sigma 9}$, %	ε	ξ
R	-	50	47 (44,9)*)	3	0,1	0,005
N1	13	32	55 (31,1)	-	0,5	0,012
N3	35	33	32 (13)	-	1,4	0,078
S	50	25	25 (8)	-	1,6	0,006

CONCLUSIONS

1. At the macro-, meso- and microstructural levels a systematic study of morphological and crystallogeometrical features of deformation structures in NBZ of copper – copper weld was carried out.

2. In areas directly adjacent to the interface the phenomenon of abnormal localization of metal plastic flow was discovered which is at the macrolevel is realized in the form of generation and the development of specific structural elements – plastic vortex-like streams.

3. It is shown that each plastic stream consists of curved and parallel to each other deformation mesobands in a thicknessof 5 μm each of which consists of a misoriented fragments of average transverse dimension of 200 nm.

4. The evolution of deformation structures within NBZ with approaching the copper – copper weld interface was researched.

5. An analysis of misorientation distributions within the fragmented structure detected in NBZ allowed to identify and classify the mechanisms of the deformation structures formation operating in NBZ of copper – copper weld. They are: 1) the fragmentation of grain volumes, 2) the dynamic deformation twinning, 3) the fragmentation of random and twin boundaries, 4) the recrystallization. Using computer simulation of misorientation distributions, the contributions of above mechanisms to the structure formation in the NBZ were determined.

Thank you for your attention!

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