Paton Electric Welding Institute
of the NAS of Ukraine

Pressure Welding of Nickel Superalloys (NS) and Titanium Aluminides for Advanced Gas Turbine Engines (GTE)

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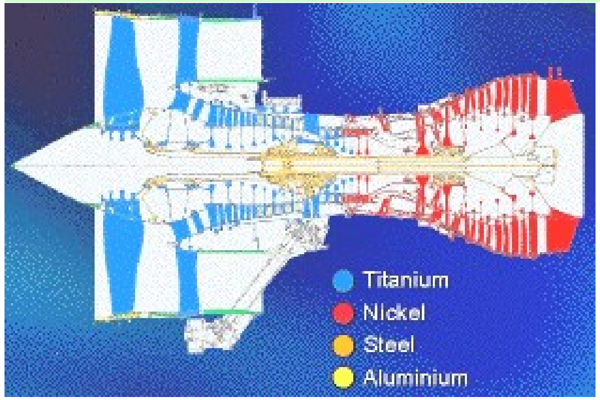
Relevance of the work

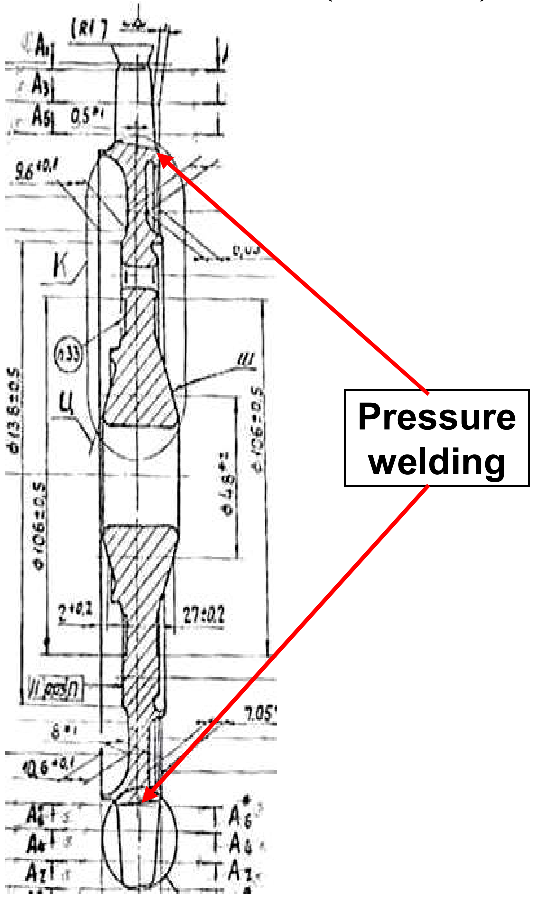
Development of Advanced Gas Turbine Engines (GTE) with application of welded components is an urgent task for domestic aircraft engine production

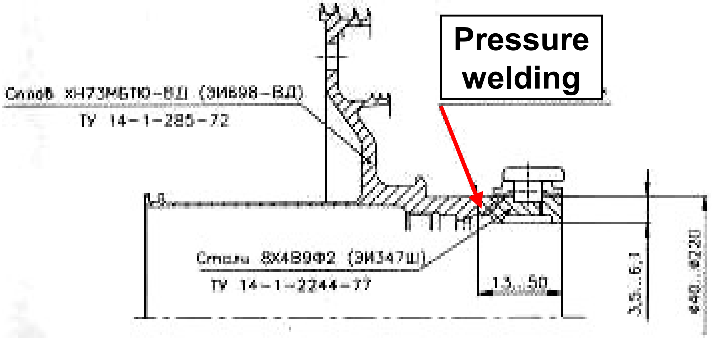
Object of study 1:

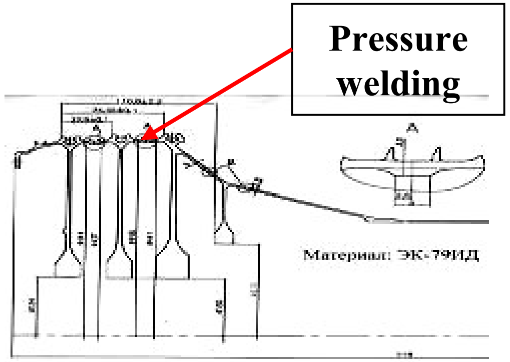
Welded monowheels ("blisks")



Welded "blisks" (TWI)







Component of "*shaft-disc*" type
Alloy EI698+steel 8X4B9Ф2 (EI347)

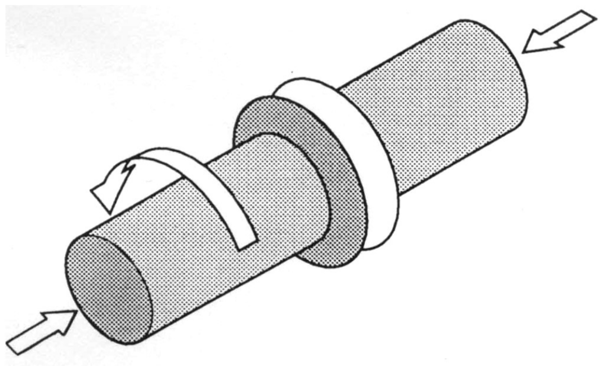
Component of *"disc-disc"* type (EK79-ID)

"Blisk" (disk alloys EI698 or EP741NP to blade (cast) alloy VZhL12U)

Promising welded structures of GTE components from nickel superalloys (NS)
(SC «INVCHENKO-PROGRESS», JSC «Motor Sich», Zaporozhje)

Main problems in pressure welding of NS

- High deformation resistance, low ductility, narrow deformation temperature interval of NS;
- Susceptibility to cracking – solidification, hot and strain ageing cracks;
- Formation of defects of the type of lacks-of-penetration and oxide films;
- Metal degradation in the joint zone – change of the structure, strengthening phase morphology, lowering of mechanical property values



Scheme of friction welding (FW)

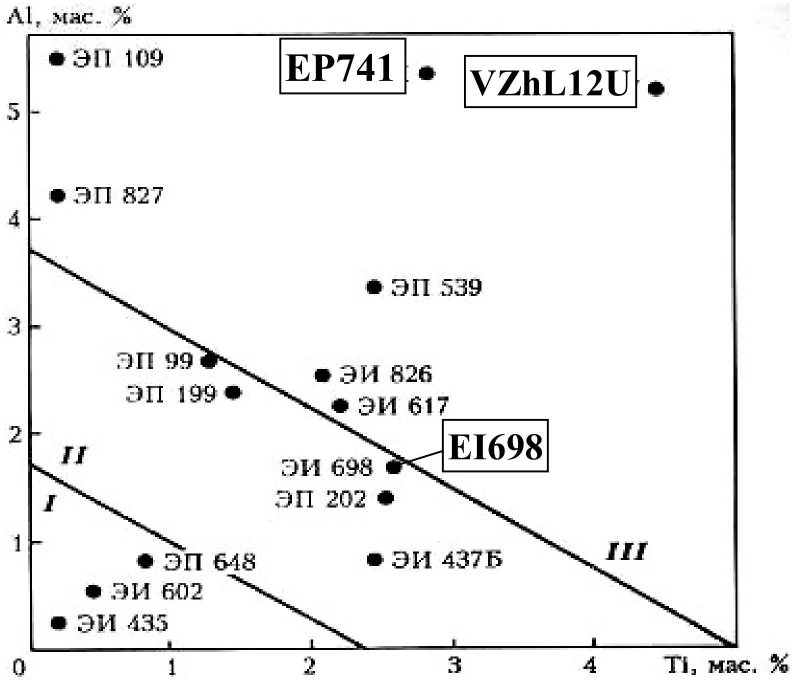
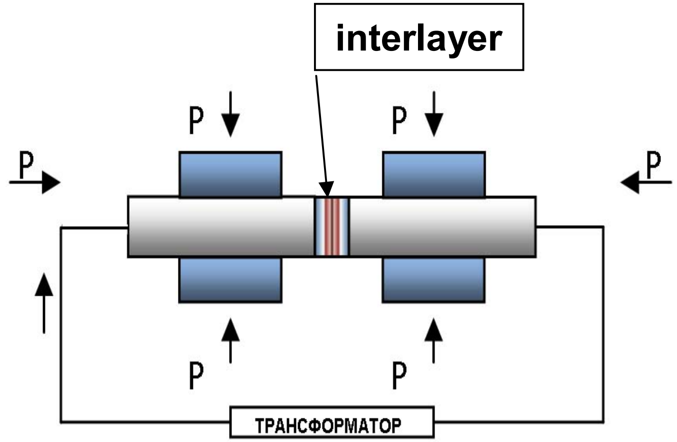


Diagram of evaluation of cracking susceptibility of nickel NS
region I – not susceptible, II – moderately susceptible,
III – susceptible in welding and heat treatment

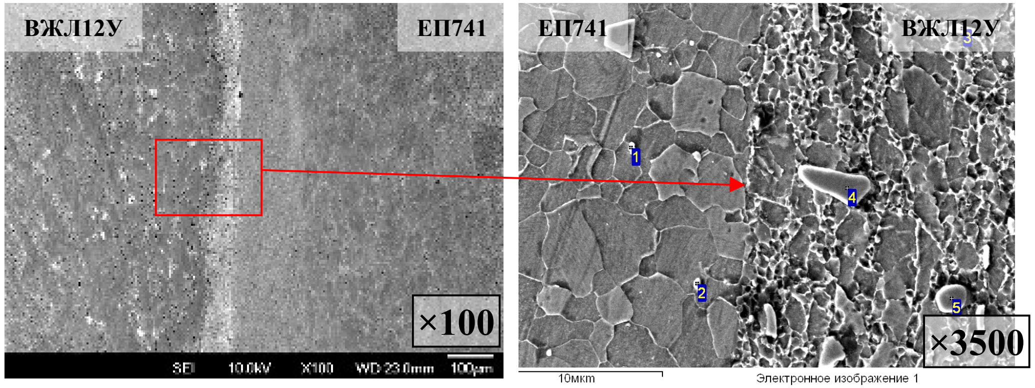
- **Application of RBW with interlayers**



Scheme of resistance butt welding (RBW)

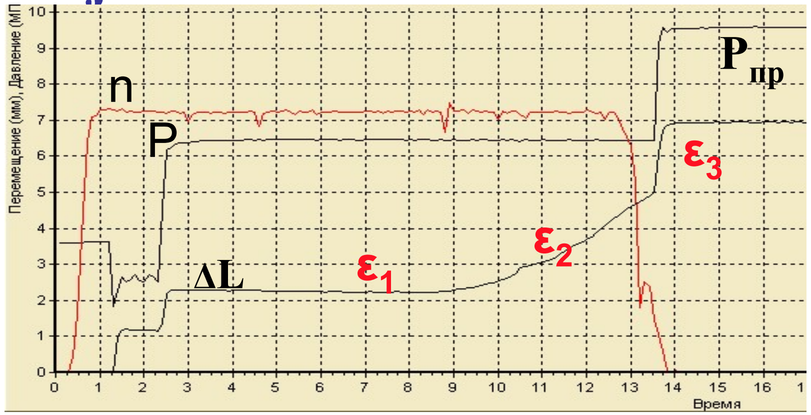
In keeping with the diagram of weldability evaluation, VZhL12U, EP741NP alloys are susceptible to cracking in welding

Formation of VZhL12U + EP741NP joints at combined FW

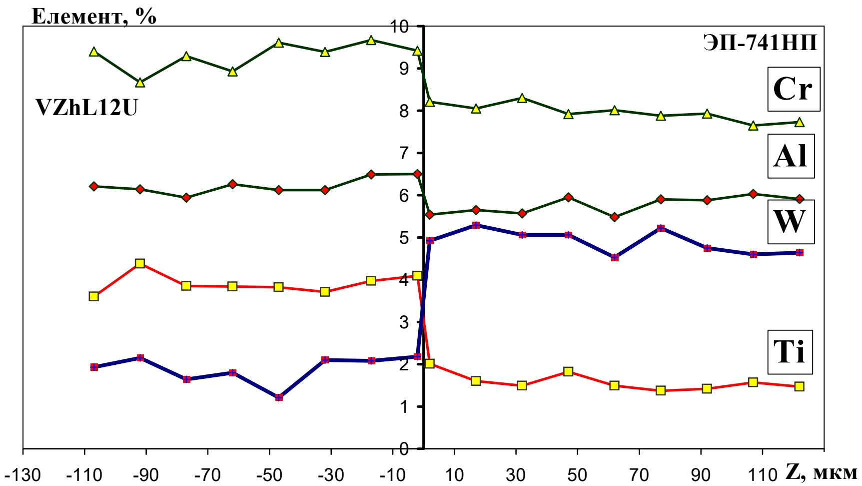


Microstructure of solid-phase joint without cracks:

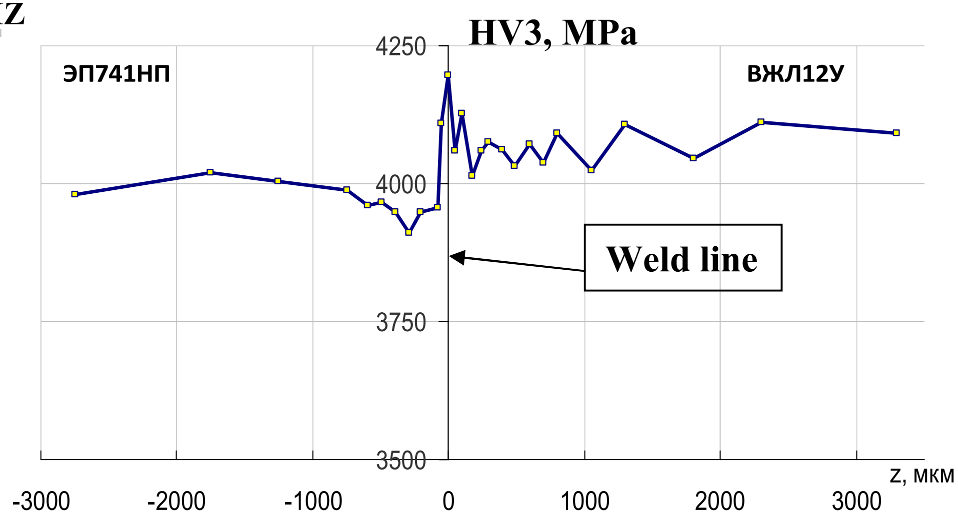
- dispersed carbides are uniformly distributed in the matrix;
- particles of γ'_{eut}-phase of VZhL12U alloy are dissolved in TMIZ



Cyclogram of the process of combined FW
(deformation rate $\varepsilon_3 = 1\ s^{-1}$)



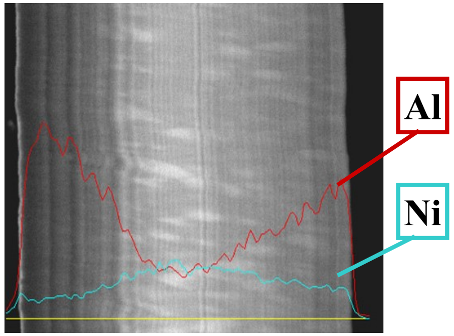
Results of EDS-analysis of the joint zone.
Sections of intermediate composition (melt) are absent



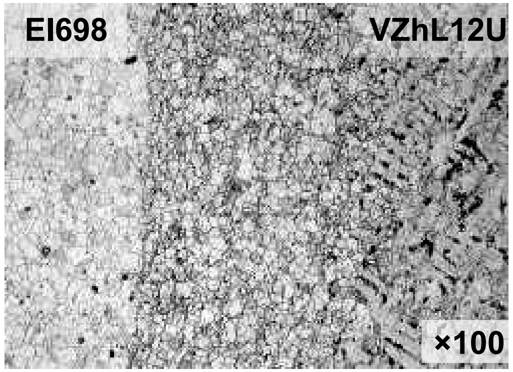
Distribution of microhardness, MPa

- ➢ An algorithm of the quality of NS dissimilar joints was developed, in which metal regions in the liquid or solid-liquid state are pressed out of the billet cross-section due to high deformation intensity ($\varepsilon_3 = 1\ s^{-1}$) and solid-phase nature of joint formation without any defects or cracks is ensured.
- ➢ Strength values of the joints are on the level of alloy BM

RBW of EI698 and VZhL12U alloys with application of gradient Ni/Al NF



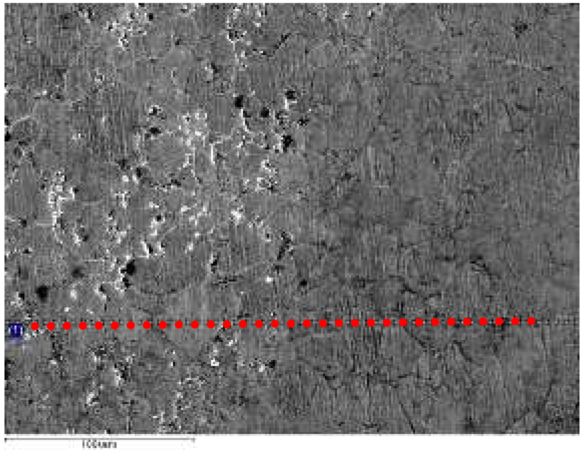
Gradient Ni/Al foil

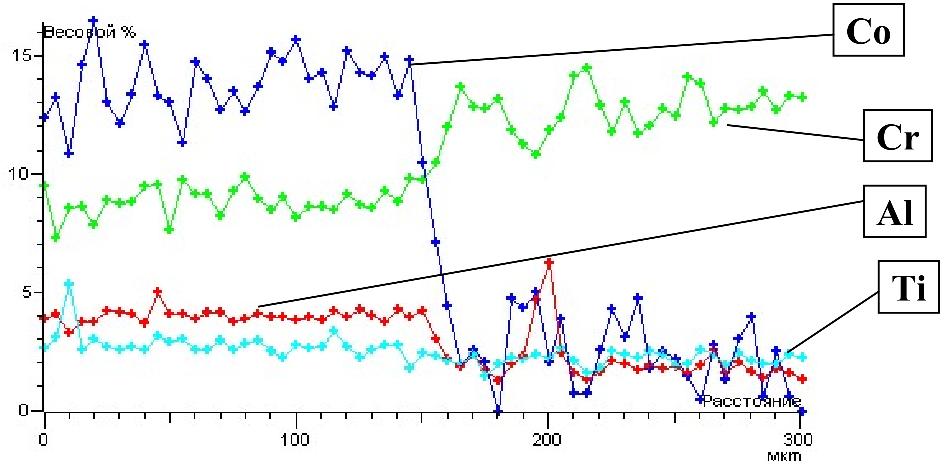


Thermal and deformation effects at NF application in RBW:

- ❑ NF application under the conditions of high specific power at RBW promotes local heat generation, formation of a thin layer of the melt and fast activation of the surfaces being welded over the entire cross-section of the billets.
- ❑ NF application ensures intensification of shear deformation in the contact zone at minimum energy input and formation of solid-phase joints without a cast nugget, lacks-of-penetration or cracks

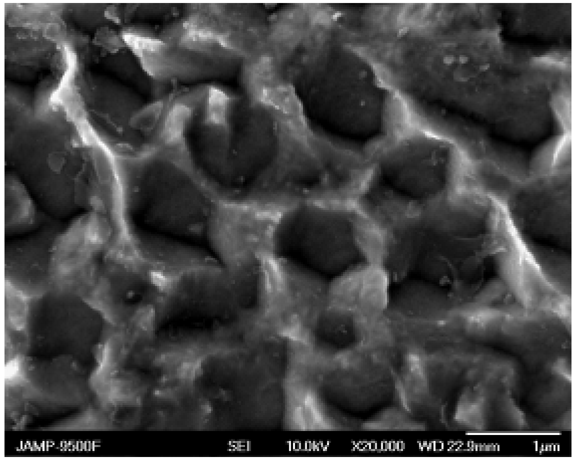
Microstructure and distribution of elements in the joint at RBW with application of NF of Ni/Al system



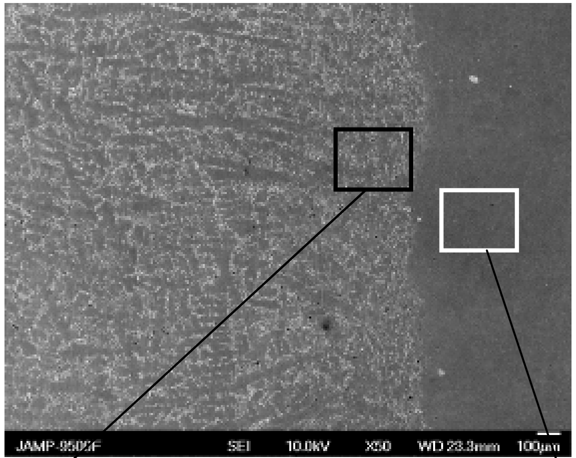


- ❑ Metal of the joint zone has a fine-grained dynamically recrystallized structure from the side of both the alloys, and no cast metal regions or defects (oxide films, cracks)
- ❑ Abrupt change of alloying element concentration at transition from EI698 alloy to VZhL12U alloy is indicative of solid-phase nature of joint formation
- ❑ No structural inhomogeneity in the form of NF remains is found in the butt joint

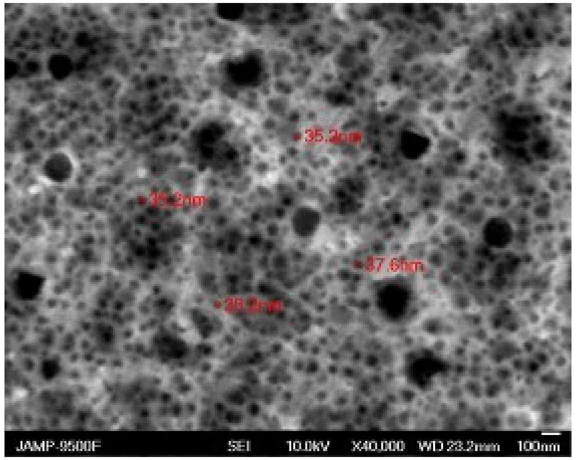
Distribution of strengthening γ‘-phase in the joint of disk EI698 alloy and cast VZhL12U alloy in as-welded condition



γ‘-phase in VZhL12U BM, ×20000

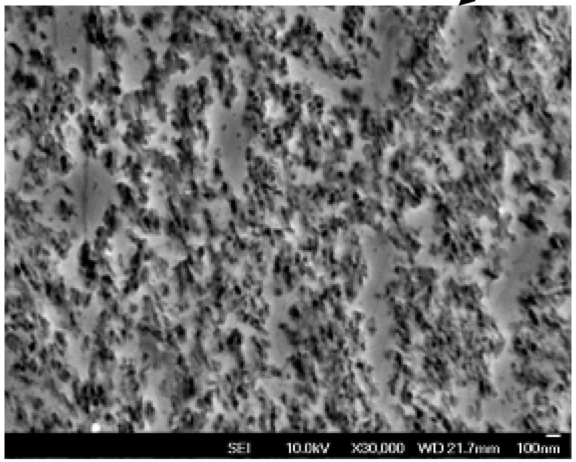


Joint zone, ×50

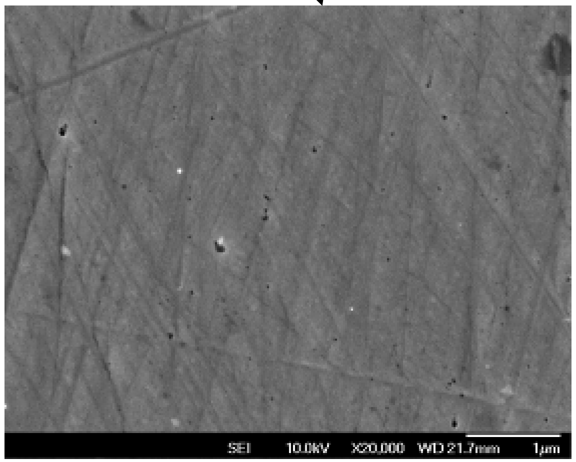


γ‘-phase in EI698 BM, ×40000

Auger-microprobe JAMP-9500F, “Jeol”



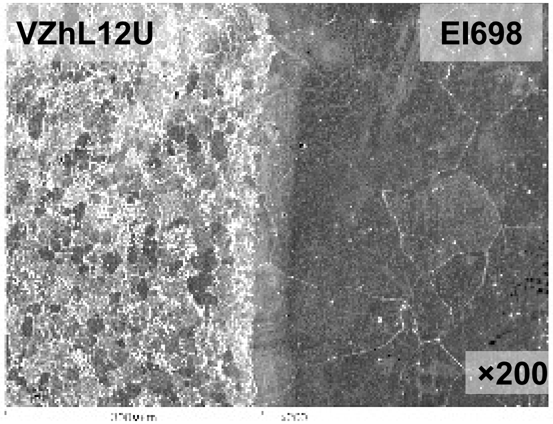
Dispersed γ‘-phase in JZ from VZhL12U side, ×30000

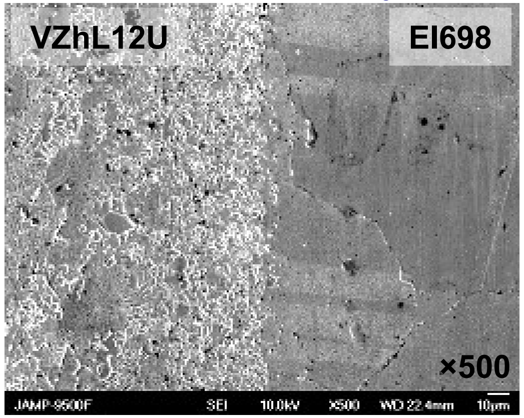


Absence of γ‘-phase in JZ from EI698 side, ×20000

In as-welded condition γ‘-phase in the joint zone from the side of disk EI698 alloy dissolves completely to the depth of 3000 ~µm, and from the side of cast VZhL12U alloy dispersed particles of γ'-phase of up to 20 nm size are observed that is indicative of its dissolution during welding and re-precipitation during cooling of the joint

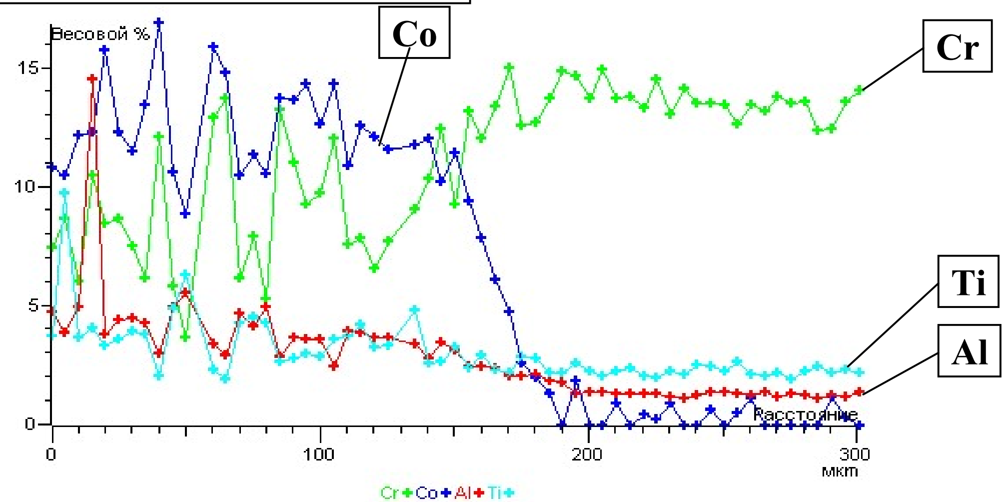
Joints of EI698 and VZhL12U alloy after heat treatment (HT)





HT objective is to ensure normative values of mechanical properties of the joints due to grain coarsening from the side of EI698 alloy and recovery of the morphology of strengthening γ‘-phase from the side of both the alloys

Microstructure and distribution of elements in RBW joint after heat treatment



❑ **<u>Heat treatment provides:</u>**

- **recovery of microstructure and morphology of strengthening γ‘-phase from the side of EI698 alloy;**
- **recovery of normative values of mechanical properties of the joints, including those of long-term strength**

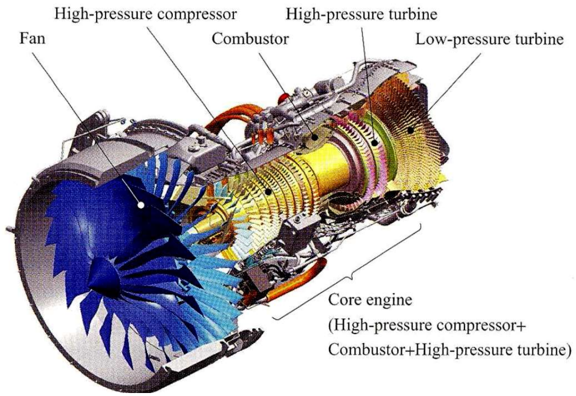
Object of study 2: Welded joints of titanium aluminides γ-TiAl for promising structures of aviation GTE

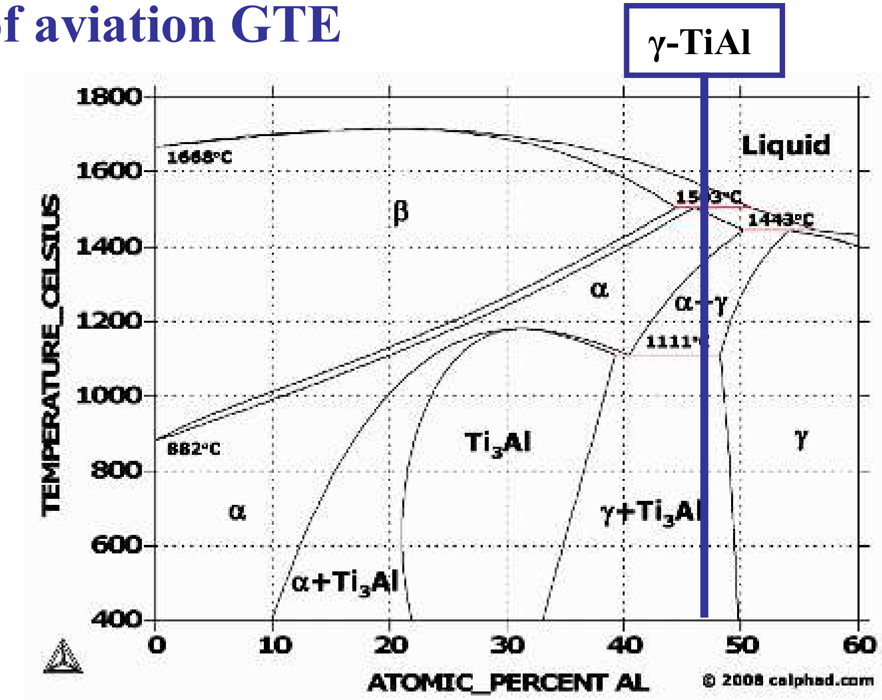
Alloys based on titanium aluminide:

– γ-TiAl (Ti-47Al-2Cr-2Nb);

– α_2-Ti_3Al (Ti-30Al);

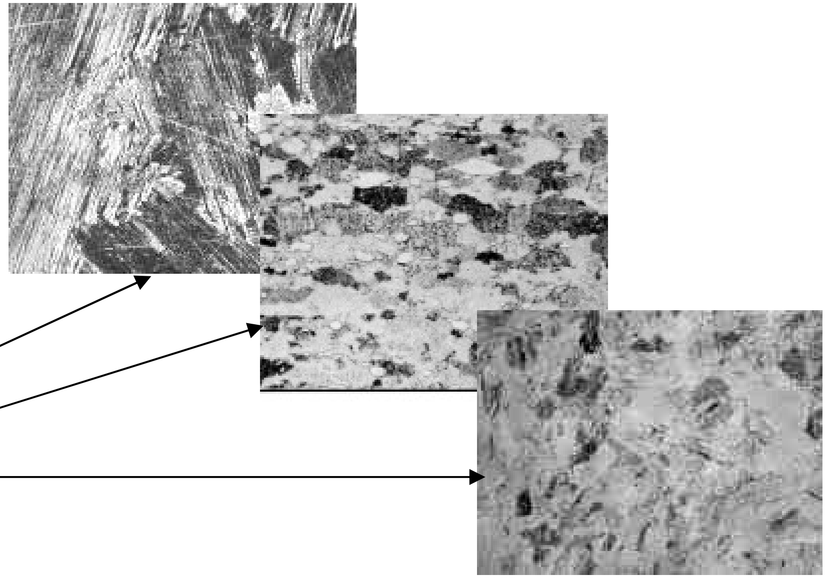
– ortho-alloys Ti_2NbAl (Ti-30Al-24Nb)





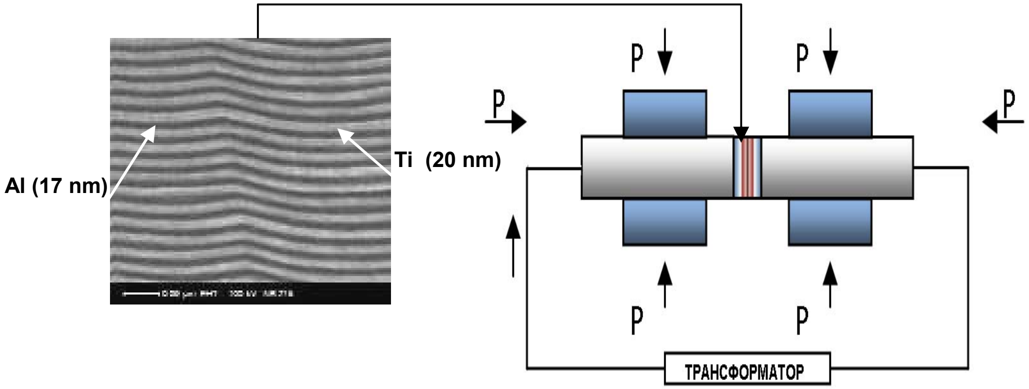
Mechanical properties of γ-TiAl alloy at different types of microstructure

Структура	Механические свойства γ-TiAl		
	$\sigma_в$, МПа при 20°C	δ, % при 20°C	δ, % при 700-800°C
Пластинчатая	350…400	0,5-1	3-10
Рекристаллизованная	450-580	1,5-4	50-83
Бимодальная	400-550	1-2,5	40-80

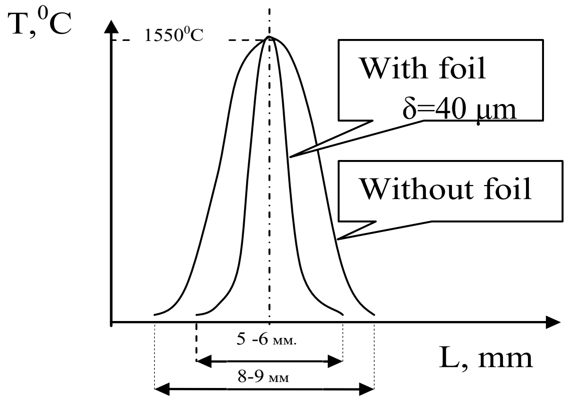


Resistance butt welding (RBW) of γ-TiAl alloy with application of nanolayered foils

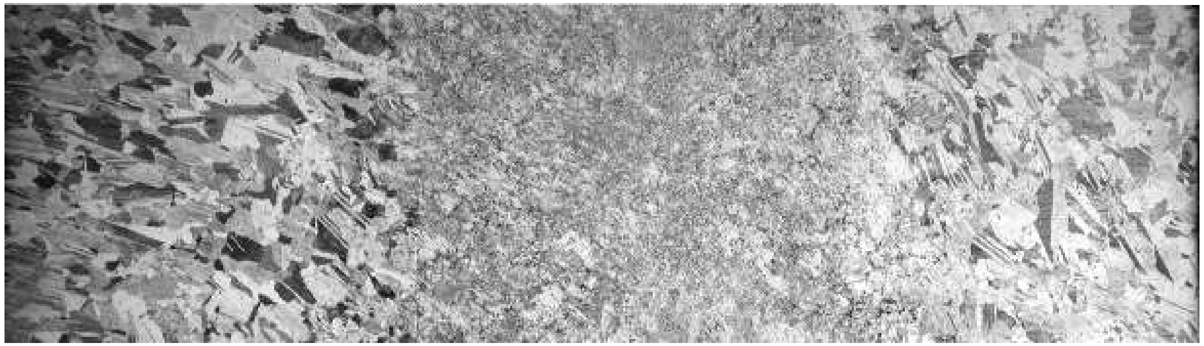
Problem: at RBW of γ–TiAl alloys cracks form in the joint zone
Causes: - low ductility of γ–TiAl,
- nonuniformity of heating by the depth and cross-section of the billets,
- high level of welding stresses, because of considerable heat input in welding



Scheme of RBW through Ti/Al NF (δ=40 μm)

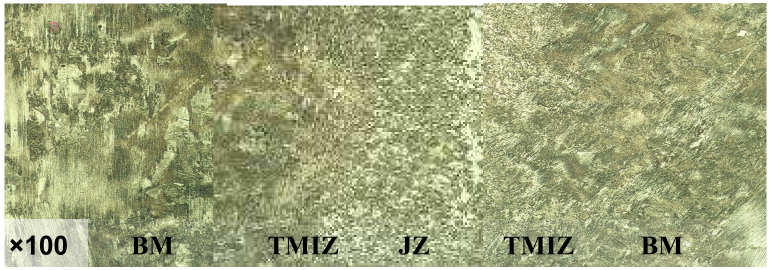


Temperature field at RBW of γ–TiA alloy



Thermal effect of nanofoil application: Local and uniform heat generation over the cross-section in the contact zone due to increase of contact resistance and running of SHS reaction in the nanofoil, that ensures activation of the surfaces being welded at significantly smaller heat input, degree of deformation, and level of welding stresses

Resistance butt welding of intermetallic γ-TiAl alloys with application of nanolayered foils



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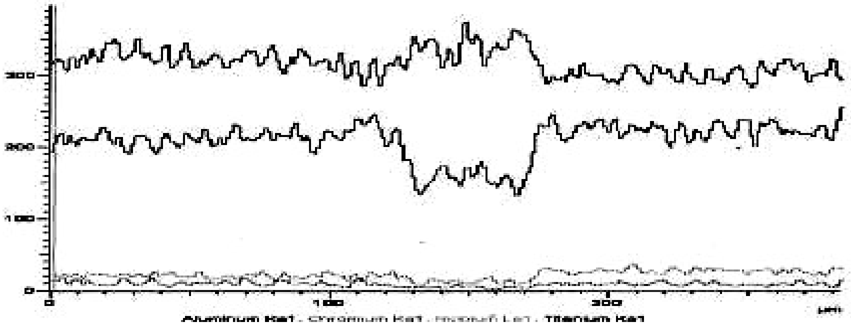
Deformation effect of NF application:

localization and intensification of shear plastic deformation in the contact zone, which is realized predominantly by intergranular slipping, i.e. it has “superplasticity” features



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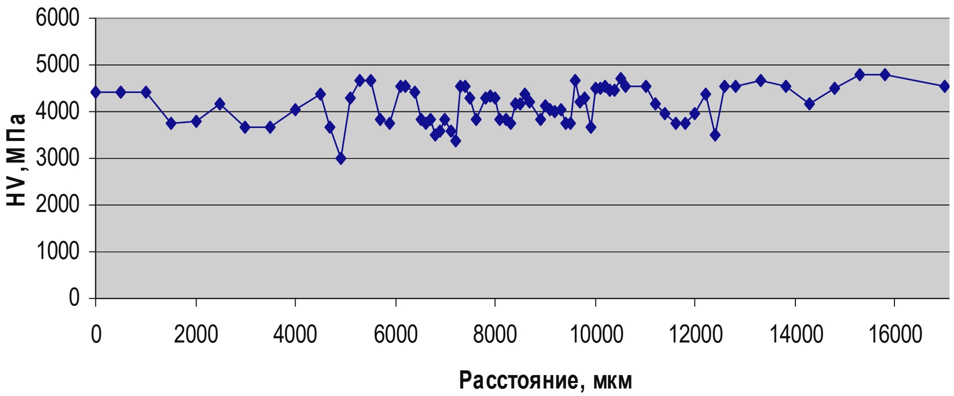
Structural effect of nanofoils:

— enhancement of metal deformability in the joint zone due to formation of a more ductile recrystallized structure and duplex structure in TMIZ, that prevents cracking;



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Microstructure (a), distribution of elements (b) and microhardness of metal (c) in the joint zone of γ-TiAl alloy at RBW

Samples of joints after rupture testing (fracture runs through BM)

Mechanical properties of the joints after TH are on the level of BM values