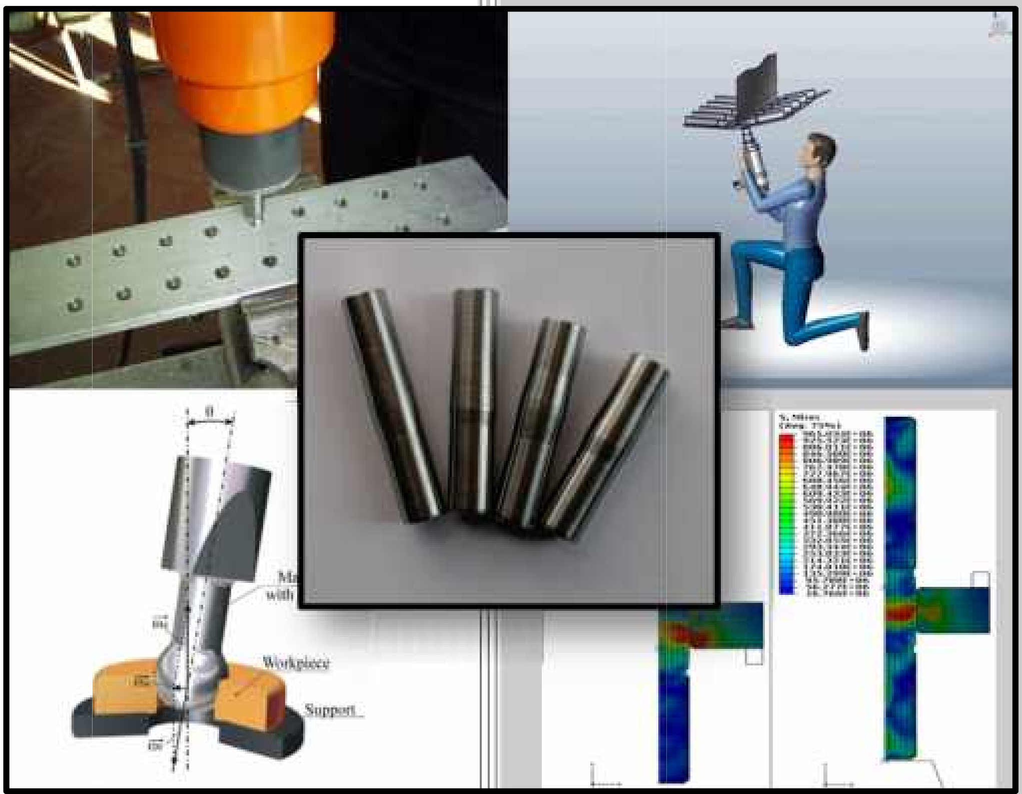
Single-Impact Mandrelling of Holes

TRAINING MODULE

for Young Researchers, Master and Doctoral Students



2014

National Aerospace University
"KhAI"

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Prepared in the frame of the FP7 KhAI-ERA project activities

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This training module was jointly prepared by The National Aerospace University “KhAI” and Fraunhofer IFF in the frame of FP7 KhAI-ERA project training development activities. It is intended for Young Scientists, Master and Doctoral Students.

Included to this issue training module is dedicated to the technological process and equipment for impulse mandrelling process of holes of aluminum aircraft structures. Great attention is paid to theoretical and experimental studies of possibility of realisation of this technology using hand-held pneumatic hammers.

Available on-line at http://khai-era.khai.edu/en/site/training-modules.html

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Foreword

Mandrelling is a method of finishing formation of previously drilled round and cross profile holes by means of surface plastic or volumetric plastic deformation. The tool performs rectilinear translation along the hole axis. SM is successfully employed on milling and drilling machines, lathes and machining centers, etc. and that significantly broadens their manufacturing potentials. When

In general, SM on conventional machine tools can be applied in two directions:

- formation of holes with high requirements for precision of size and shape and minimum roughness;
- formation of holes of wide tolerance diameter where the aim is to achieve residual stresses of maximum absolute value, spread at maximum depth.

The latter case is typical of bolt holes where the basic requirement is maximum fatigue strength of the material round the hole. In this case, it is necessary to know the residual stress field around a hole formed by mandrelling. Quantitative knowledge of residual stresses is necessary to simulate the stress field after applying an external load to a structural element in order to evaluate static or dynamic strength, fatigue strength including.

In conventional manufacture finishing, forming of holes by means of plastic deformation has a substantial advantage over cutting from the point of removing microcracks on the surface layer of the hole. This advantage is expressed in removing microflaws (irregularities, seizures) from the hole surface as a result of plastic deformation of microroughnesses. Treatment by using tools having constant size has an additional advantage and it is that deformations penetrate deeper, respectively, residual stresses around the hole are always compressive and are spread at relatively greater depth. The action of the compressive zone can be compared to brackets which close the existing cracks and impede the formation of new ones. An alternative of classical methods of finishing forming of holes by means of plastic deformation using a tool of constant size is mandrelling by spherical or conical mandrel. The advantages of this method, when the compressive zone around the hole is retained, are that it is carried out on conventional machine tools which have comparatively low power consumption, lower roughness is obtained, greater strengthening and microhardness of surface layer.

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O.V. Tryfonov
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Researcher, PhD
Deals with issues finite element analysis of impulse technologies, simulation modelling of technological processes

Content

Training Module 5

Single-Impact Mandrelling of Holes

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National Aerospace University «KhAI»

2014

Introduction

Thorough analysis of the causes which have led to accidents and failures shows that one of the most important reasons is the fatigue of the material around bolt holes as a result of cyclic load. Fatigue life of structural elements with bolt holes depends mainly on the law of residual stress distribution around these holes. For instance, residual compressive circumferential normal stresses around the hole change the type of the operating stress cycles: from symmetric into asymmetric (for cyclic bending) or reduce operating stress magnitudes to minimum values (for cyclic tension) and this enhances fatigue life and load-carrying capacity of structures.

The type of residual stresses (tensile or compressive) depends on the type of the manufacturing process of hole formation. When formation is by cutting, residual stresses can be tensile at the surface and compressive in the internally located layers or vice versa. Tensile stresses at the surface obtained by cutting can reduce fatigue life of the respective structural element up to 30%.

Training Objectives

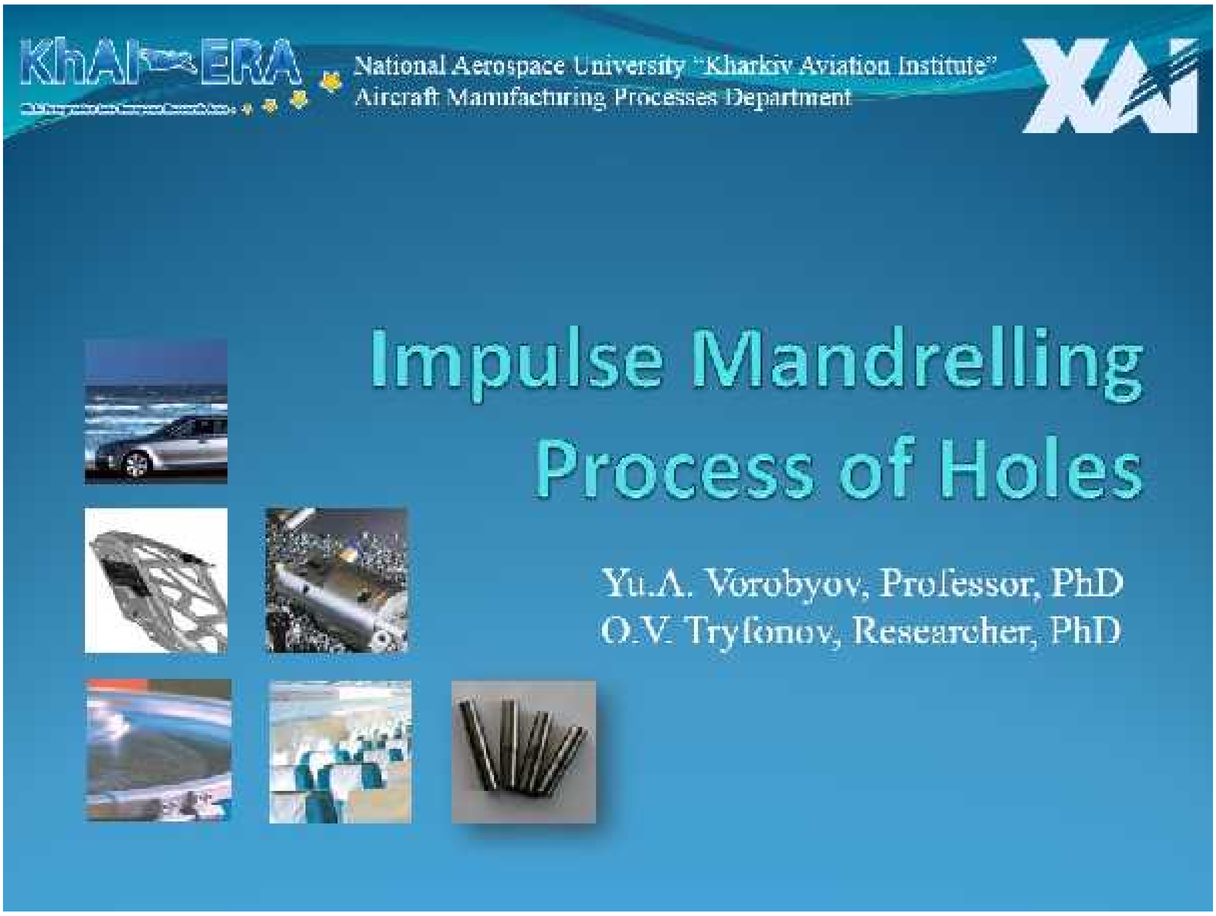
- ✓ The objectives of the study are the approach to the development of impulse mandrelling technology using hand-held pneumatic impulse hammers in the field of aircraft structures assembly; theoretical and practical approach to the experimental studies and numerical studies using modern finite-element computational systems.

Module components

- ❖ General provisions in impulse mandrelling technology
- ❖ General information concerning advantages of impulse mandrelling over split mandrelling
- ❖ The main principles of implementation of impulse mandrelling using hand-held pneumatic hammers
- ❖ Experimental investigation of the impulse mandrelling process
- ❖ General approach to the finite-element modelling of impulse mandrelling technology
- ❖ Results of finite-element model verification against the results of experimental studies

Target audience

Training Module is intended for Young Scientists, Master and Doctoral Students.


KhAI-ERA
National Aerospace University "Kharkiv Aviation Institute"
Aircraft Manufacturing Processes Department
Impulse Mandrelling Process of Holes
Yu.A. Vorobyov, Professor, PhD
O.V. Tryfonov, Researcher, PhD

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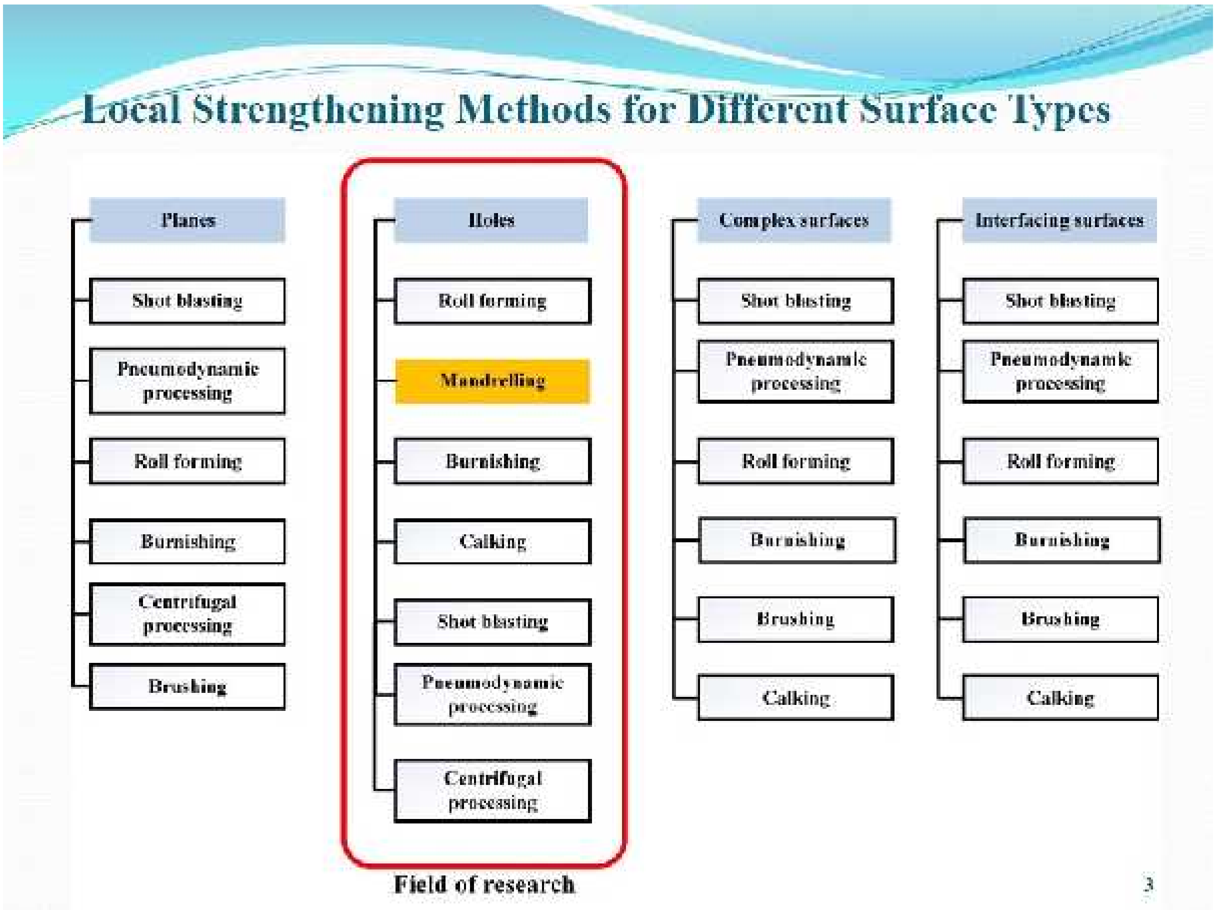
Local Strengthening Methods for Different Surface Types
Planes
Shot blasting
Pneumodynamic processing
Roll forming
Burnishing
Centrifugal processing
Brushing
Holes
Roll forming
Mandrelling
Burnishing
Calking
Shot blasting
Pneumodynamic processing
Centrifugal processing
Complex surfaces
Shot blasting
Pneumodynamic processing
Roll forming
Burnishing
Brushing
Calking
Interfacing surfaces
Shot blasting
Pneumodynamic processing
Roll forming
Burnishing
Brushing
Calking
Field of research
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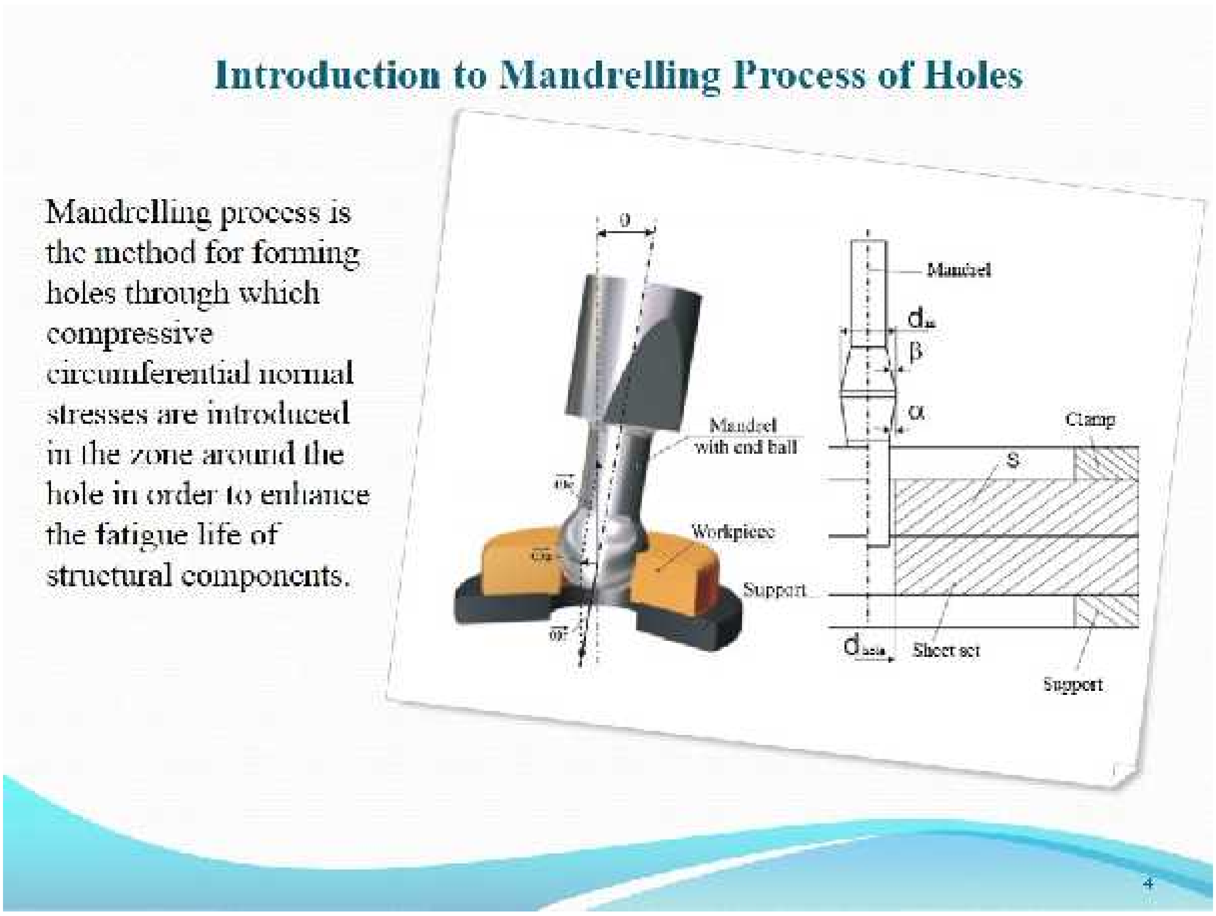
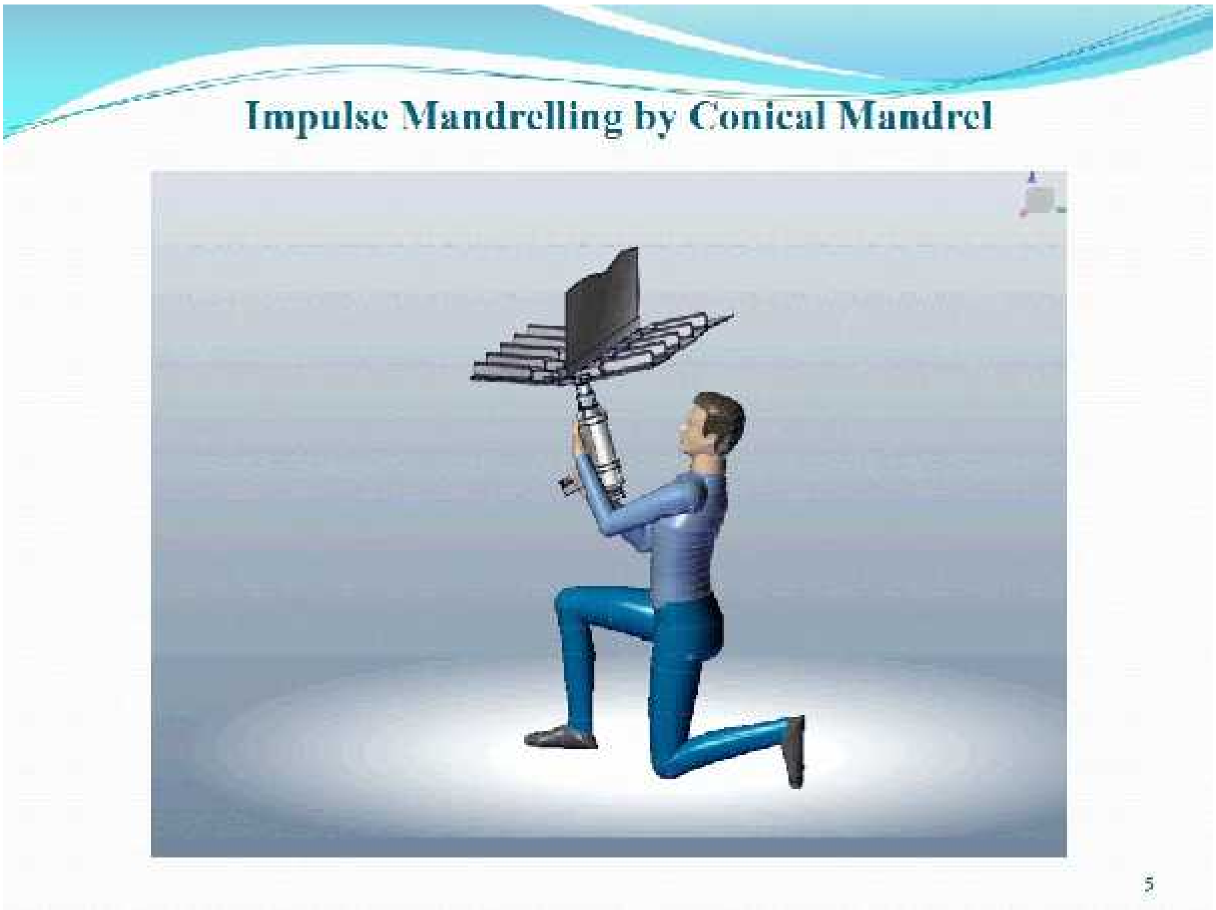

Introduction to Mandrelling Process of Holes
Mandrelling process is the method for forming holes through which compressive circumferential normal stresses are introduced in the zone around the hole in order to enhance the fatigue life of structural components.
Mandrel with end ball
Workpiece
Support
Mandrel
β
α
Clamp
S
Sheet set
Support
4


Impulse Mandrelling by Conical Mandrel
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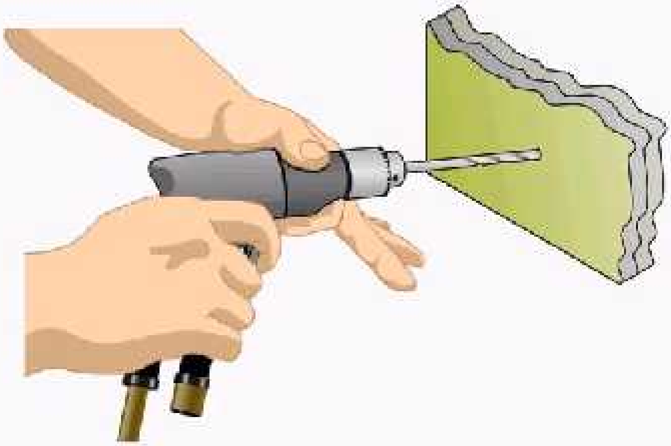
Mandrelling by Split Sleeve Method
1. Drill start hole with start drill.
6

Mandrelling by Split Mandrel Method



1. Drill start hole with start drill.

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Impulse Mandrelling by Conical Mandrel

Benefits over split Mandrelling:

- smaller number of process steps;
- the impulse mandrelling with a conical mandrel method reduces cost by eliminating the expendable split sleeve;
- higher quality of the treated hole surface: lower roughness is obtained; greater strengthening and micro-hardness of the surface layer are produced;
- symmetric shape of resulting residual stress zone;
- stability of the sleeveless process; during the split sleeve process the width of the split in the sleeve enlarges as the mandrel major diameter is pulled through;
- improved fatigue lives of the worked structural components owing to the absence of stress concentrators in the compression field;
- final reaming exception: this prevents damage of the strengthened surface layers;
- can be performed on conventional machine tools (as on special machines);
- a simple tool is used.

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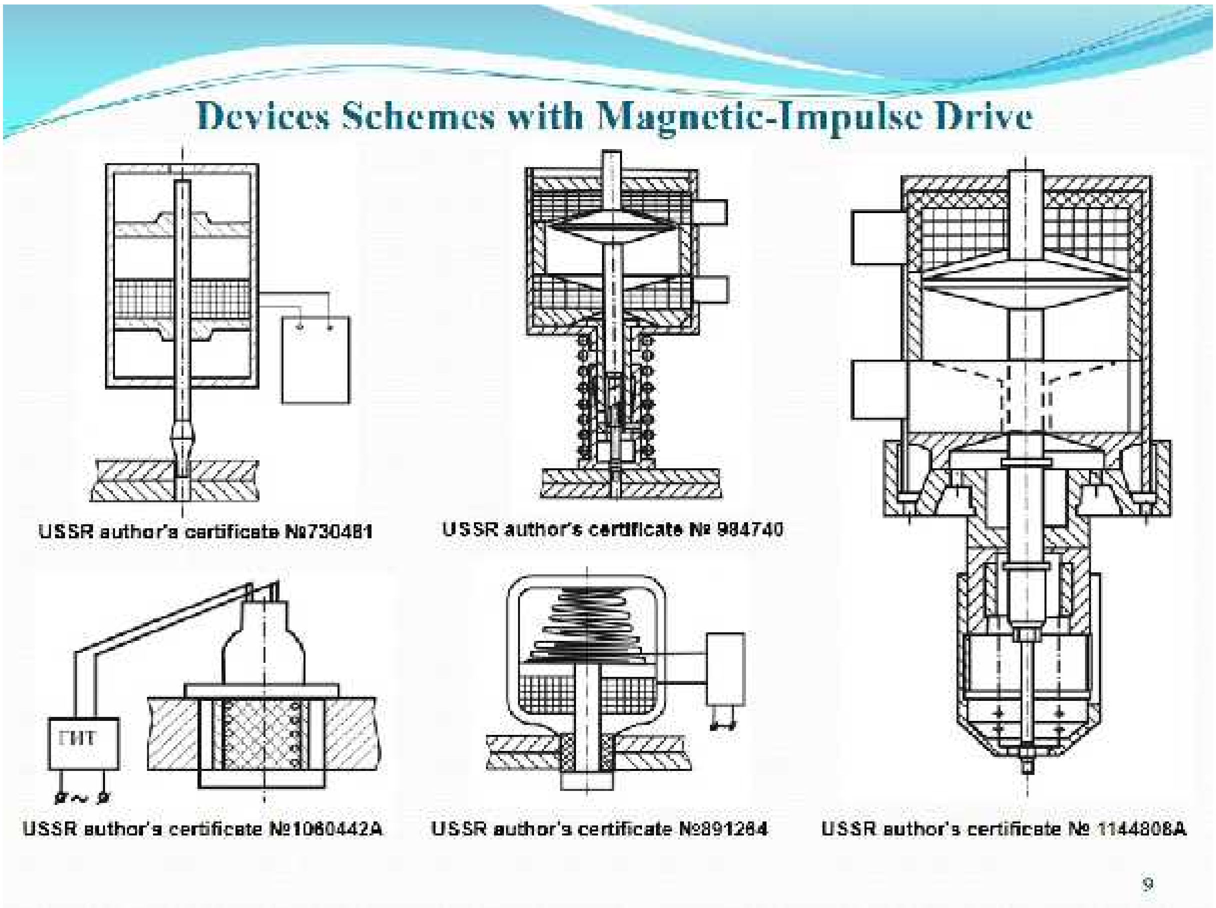
Devices Schemes with Magnetic-Impulse Drive
USSR author's certificate №730481
USSR author's certificate № 984740
USSR author's certificate №1060442A
USSR author's certificate №891264
USSR author's certificate № 1144808A
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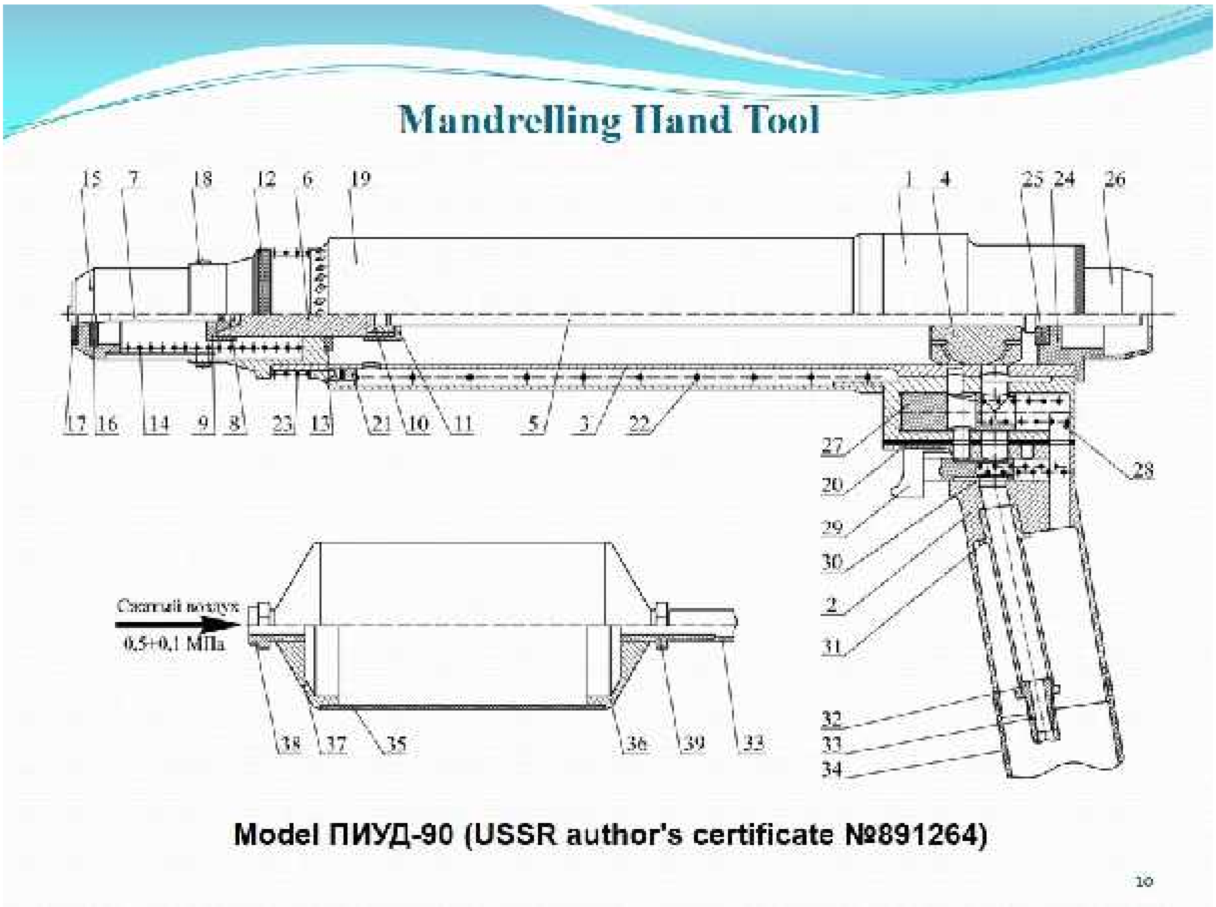
Mandrelling Hand Tool
Model ПИУД-90 (USSR author's certificate №891264)
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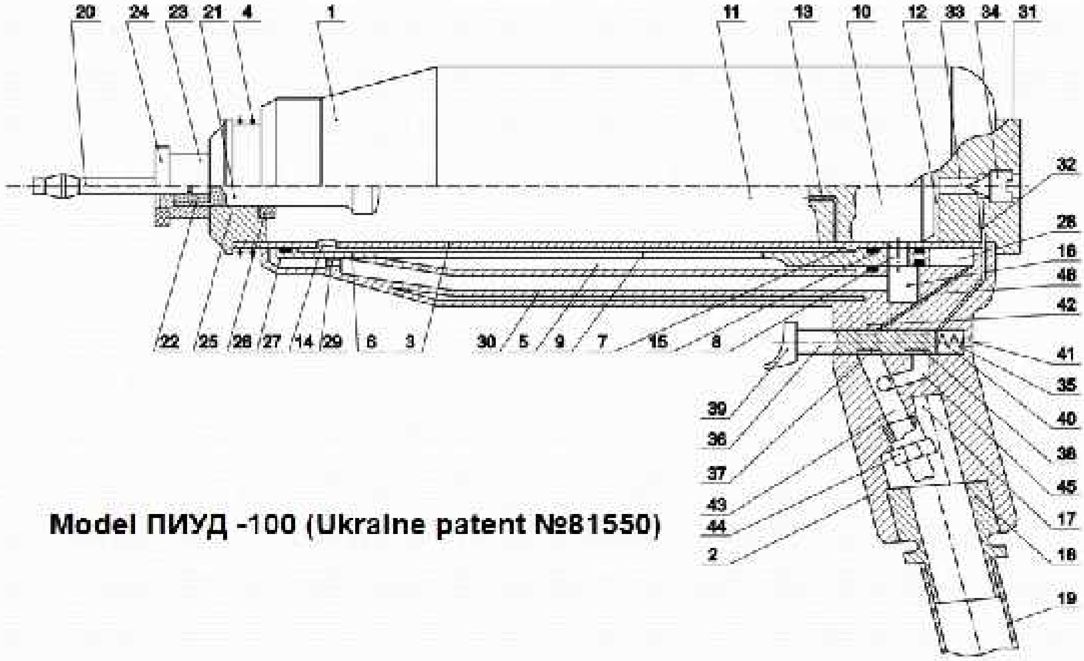
Mandrelling Hand Tool



Model ПИУД -100 (Ukraine patent №81550)

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Technical Characteristics of the Devices for Holes Mandrelling

Index name and measure unit		The value of technical and economic indicators			
		МБЗ-4 с ПГНМ 1-250 (UkrRIAT)	МИУ-П1 (KhAI)	ПИУД-90 (KhAI)	ПИУД-100 (KhAI)
Energy source		Compressed air, pressure 0,5 ± 0,1 MPa	Electrical energy is 220V, 50Hz	Compressed air, pressure 0,5 ± 0,1 MPa	Compressed air, pressure 0,5 ± 0,1 MPa
Compressed air consumption, m³/cycle		0,076	-	0,002	0,002
Power (energy), kW (J)		0,6	5,0	4,5(90)	5(100)
Weight, kg	device	2,5	3,6...4,2	no more than 4,0	no more than 6,6
	actuator (receiver)	14,6	525,0	(1,0)	(built in)
Overall dimensions, mm	device	208×60×207	110×265×110	570×260×77	440×222×104
	actuator (receiver)	505×270×280	670×760×950	(90×90×300)	(built-in)
The number of workers operating the device		2	1	1	1
Productivity, holes per minute		2	5	10	10

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Experimental Investigation of the Impulse Mandrelling Process
Test samples
Mandrels
Hole diameter gaging
Mandrelling by using ПНП-5,5 press
Mandrelling by using impulse riveting hammer
Lobing profile gaging
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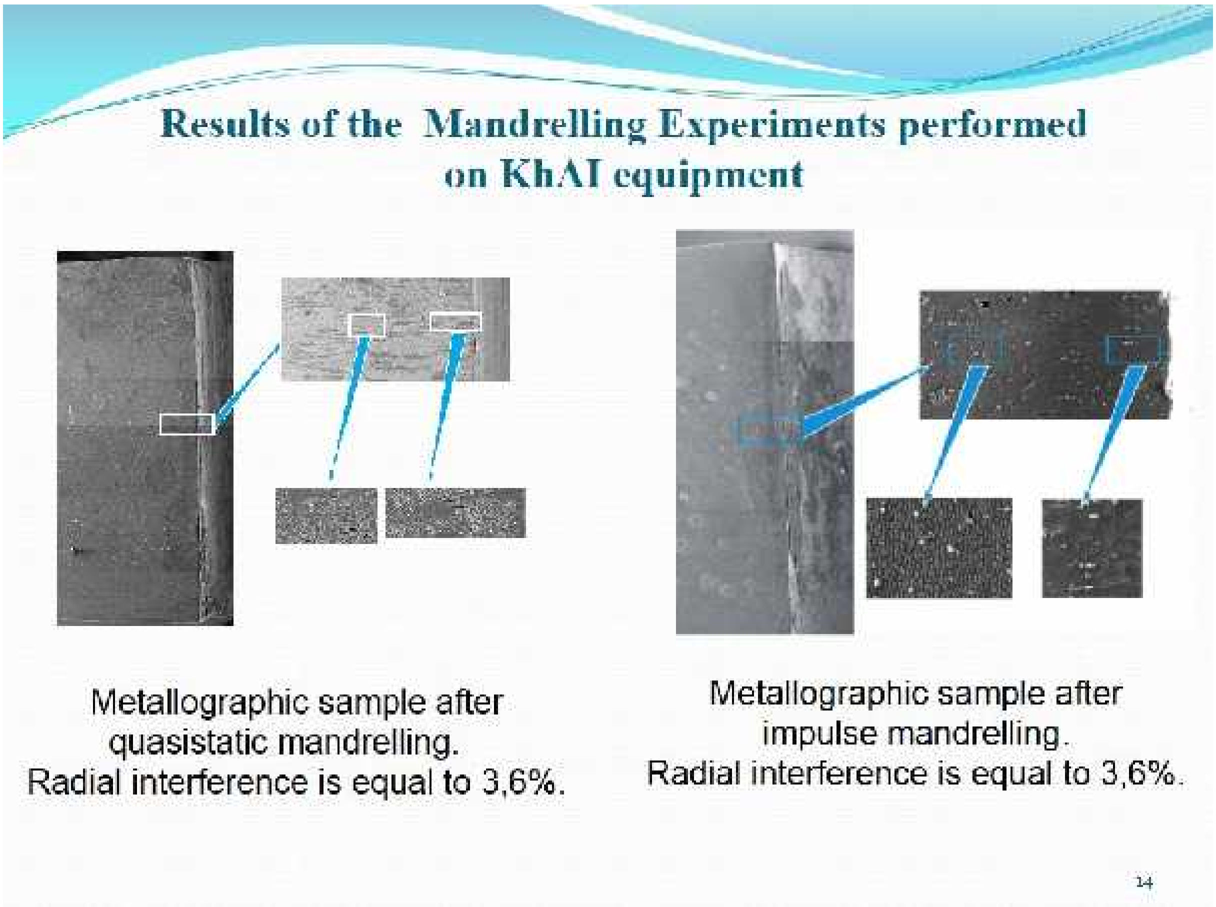
Results of the Mandrelling Experiments performed on KhAI equipment
Metallographic sample after quasistatic mandrelling.
Radial interference is equal to 3,6%.
Metallographic sample after impulse mandrelling.
Radial interference is equal to 3,6%.
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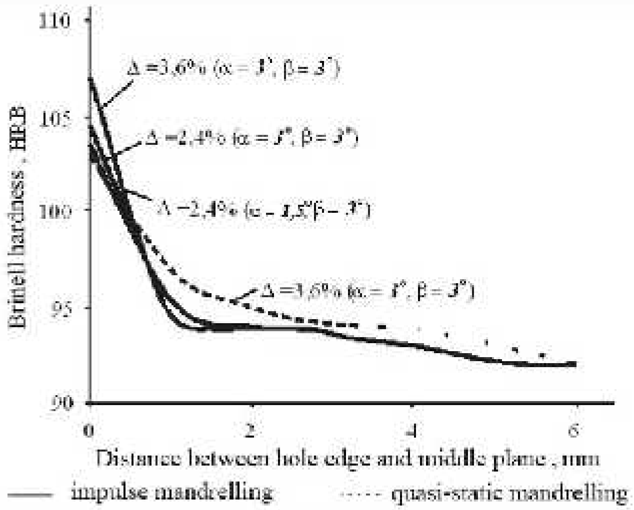
Gaging of the Mandrelled Test Samples

Hardness tester



Brinell hardness after impulse and quasi-static mandrelling

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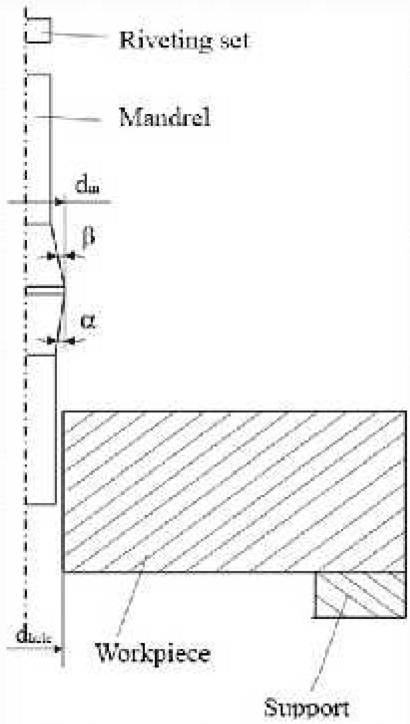
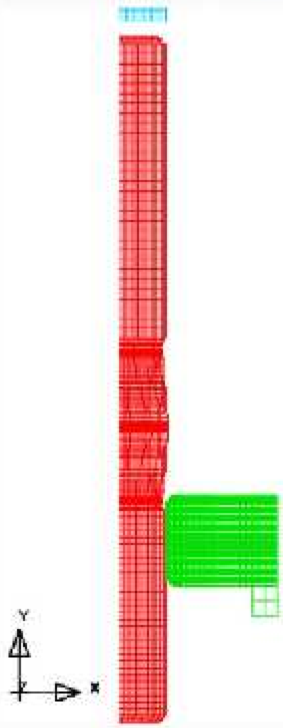
Scheme and Finite-Element Model of the Mandrelling Problem





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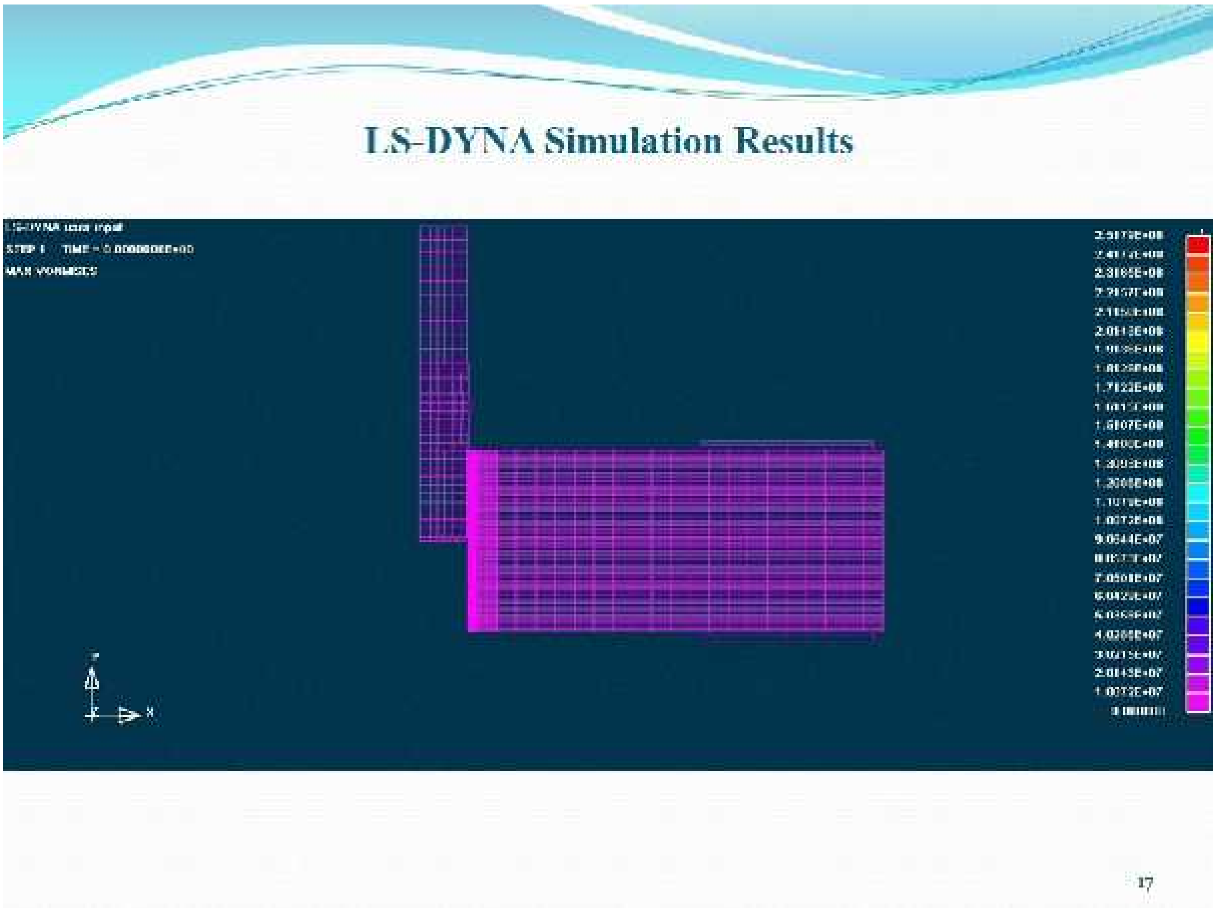
LS-DYNA Simulation Results
MAX VONMISES
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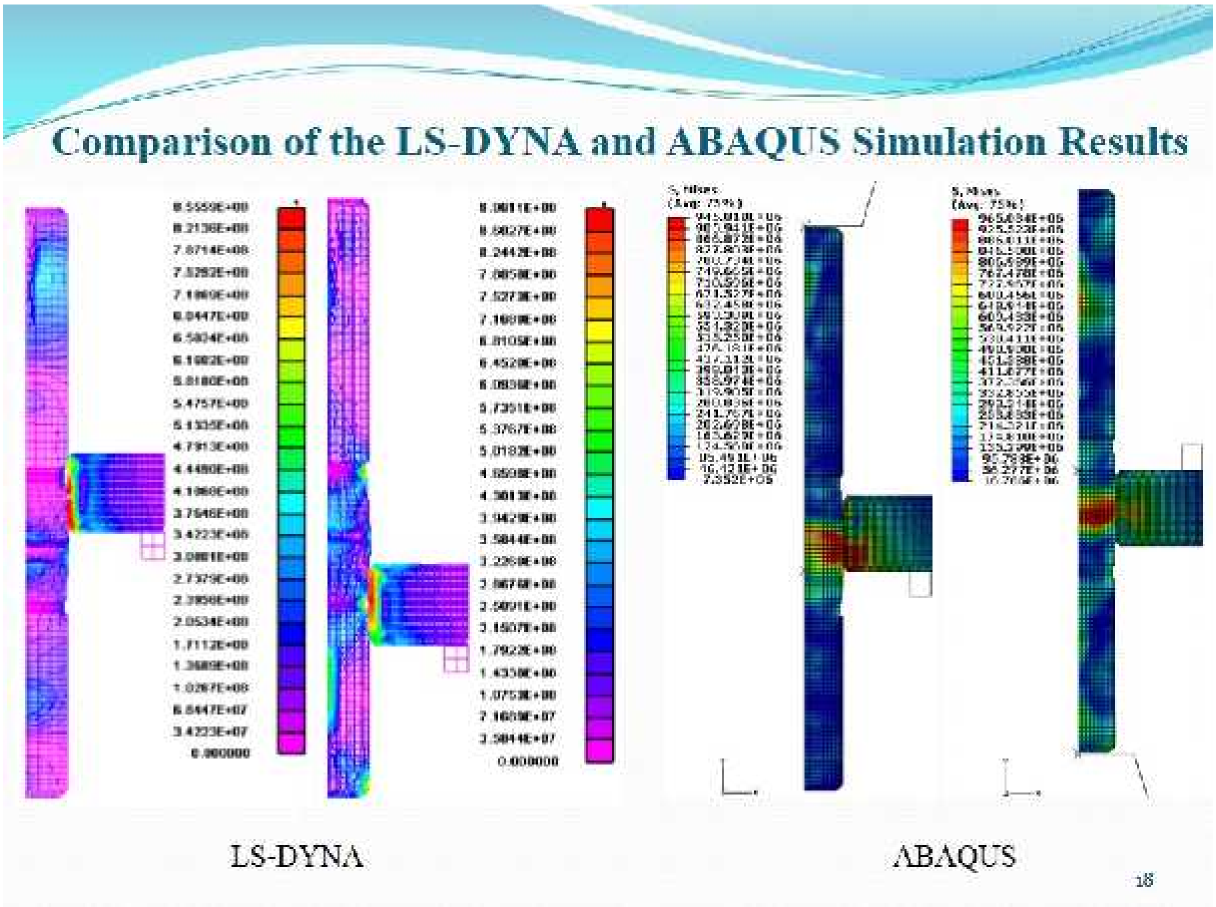
Comparison of the LS-DYNA and ABAQUS Simulation Results
LS-DYNA
ABAQUS
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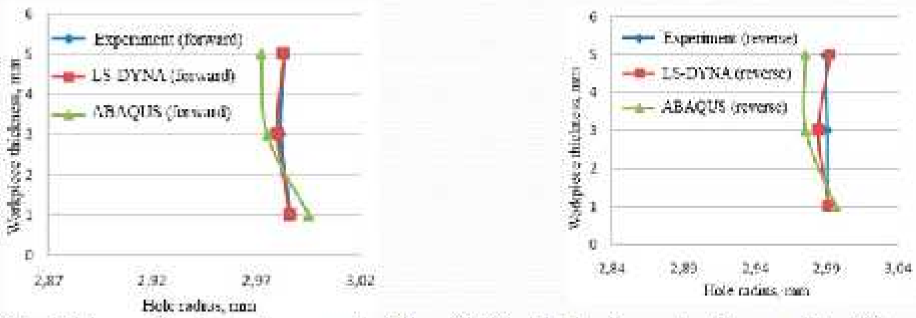
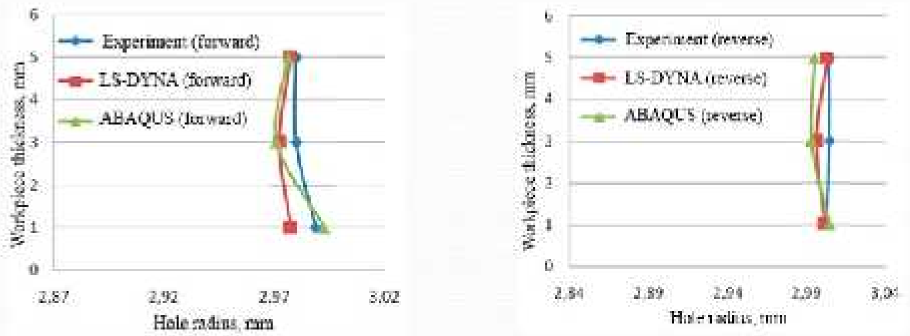
Comparison of the Simulation and Experimental Results



Hole lobing after impulse mandrelling (initial hole diameter is equal to 5,9 mm)



Hole lobing after impulse mandrelling (initial hole diameter is equal to 5,95 mm) 19

Conclusions

- In conventional manufacture finishing, forming of holes by means of plastic deformation has a substantial advantage over cutting from the point of removing microcracks on the surface layer of the hole. This advantage is expressed in removing microflaws (irregularities, seizures) from the hole surface as a result of plastic deformation of microroughnesses.
- Holes mandrelling process under which compressive circumferential normal stresses are introduced in the zone around the hole enhance the fatigue life of structural components.
- Mandrelling can be applied in two directions: formation of holes with high requirements for precision of size and shape and minimum roughness; formation of holes of wide tolerance diameter where the aim is to achieve residual stresses of maximum absolute value, spread at maximum depth.
- Simulation results show good agreement with experimental data. LS-DYNA is more appropriate system because numerical simulation of impulse mandrelling in LS-DYNA gives a smaller error (15%) in comparison with ABAQUS (45%).

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