

SIMULATION OF WELDING IN THE REPAIR OF GAS PIPELINES WITH STEEL SLEEVES

Radoslav Koňár
***Jaromír Moravec**
****Miloš Mičian**

University of Žilina
Faculty of Mechanical Engineering
Univerzitná 1, 010 26, Žilina, Slovak Republic
radoslav.konar@fstroj.uniza.sk

* Technical University of Liberec
Faculty of Mechanical Engineering
Studentská 2, 461 17, Liberec 1, Czech Republic
jaromir.moravec@tul.cz

** University of Žilina
Faculty of Mechanical Engineering
Univerzitná 1, 010 26, Žilina, Slovak Republic
milos.mician@fstroj.uniza.sk

Abstract

The theoretical part of the paper deals with basic information about repair of gas pipeline with steel repair sleeves and simulation programme SYSWELD. The experimental part includes analysis of boundary conditions in two-pass fillet welding joint. By analyzing the boundary conditions welding speed, temperature cycles, macrostructural analysis and its digitization can be determined. Using these boundary conditions welding process in programme SYSWELD was simulated. The results of the simulation are illustrated by means of temperature fields and temperature cycles.

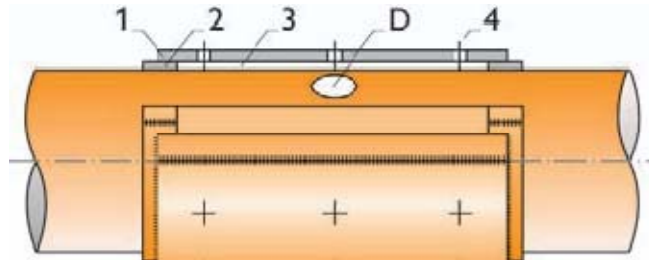
Introduction

The article deals with the issues of repairing defects in steel gas pipes, in particular of permanent repairs employing steel sleeves.

1 Permanent repair of defects in gas pipelines employing steel sleeves

The Steel Repair Sleeves can be used for permanent repairing of high pressure gas pipeline defects without interrupting its operation. With using these repair methods, we can repair defects such as internal and external corrosion, gouges, dents, grooves, arc burns, cracks, defective girth welds, laminations and leaks [2].

The steel sleeve is composed of segmented steel casing, fitted on two steel distance rings, which defines the space between the sleeve and the repaired pipe. This space is filled with glass beads and epoxy (composite). When epoxide is cured, it provides a perfect transmission of stresses from the pipeline to the sleeve, while there is an equal stress distribution in the pipeline and the sleeve. The type of the material and the thickness of the sleeve and distance rings must be same as those of the repaired pipeline. Required mechanical properties of composites are obtained after 24 hours of curing. Good space filling composites are checked through the inspection holes [2].



1–steel segmented sleeve, 2–distance rings, 3–composite, 4–inspection holes, D–pipeline defect, ++–weld.

Fig. 1 Principle repairs gas pipeline using steel repair sleeve [2]

Depending on the seriousness and type of defect on the pipeline sleeves can be divided to:

- cold sleeve – steel casing fitted on two steel distance rings is welded only longitudinal butt weld,
- hot sleeve - steel casing fitted on two steel distance rings is welded longitudinal butt weld and also is welded with fillet weld to distance rings [2].

2 SYSWELD

SYSWELD is a Finite Element software that simulates all usual welding processes such as MMA, MIG, TIG, spot welding, laser welding, heat treatment like bulk hardening, surface hardening, tempering and hardening and tempering, as well as thermo-chemical treatment like case hardening, carbonitriding, nitriding [1].

The software calculates dimensional variations and distortions of parts, hardness, strength and strain at break of the material in use, plus residual stresses, during and at the end of the welding or heat treatment process [1].

Simulation of a welding process requires two successive analyses:

- first a thermo-metallurgical analysis,
- followed by a mechanical analysis.

2.1 Definition of heat source in SYSWELD

Temperature $T(x,y,z,t)$ is the function of coordinates in volume and time. Precious determination of temperature field during welding (that means mainly shape and size of heat affected zone) is the first and very important step for real determination of right material structure. Therefore finding the right mathematical description for heat source is very important for numerical simulations. Simulation system SYSWELD used for numerical calculations of heat following heat sources: 2D Gaussian model – for surface thermal treatment of material, 3D Gaussian model – for simulation of welding with high power density in impact area and 3D Glodak model – for shielded metal arc welding, submerged arc welding, GTAW, GMAW. Because of its versatility this type of heat source will be closely described [3].

2.2 Goldak model of heat source

This type of heat source can be used for most fusion welding conventional methods. Combination of two interlocking ellipsoids describes the real state so far best. By contrast to previous heat source the double-ellipsoid heat source is described by two equations individually for each ellipsoid. Compared to ellipsoid heat source in following equations there

are parameters f_1 and f_2 . These are constants which influence the energy flow intensity into the material (into individual ellipsoids) and the valid equation for them is:

$$f_1 + f_2 = 2 \quad (1)$$

Double-ellipsoid heat source is shown in *Fig.2* and is describes by following equations (2) and (3).

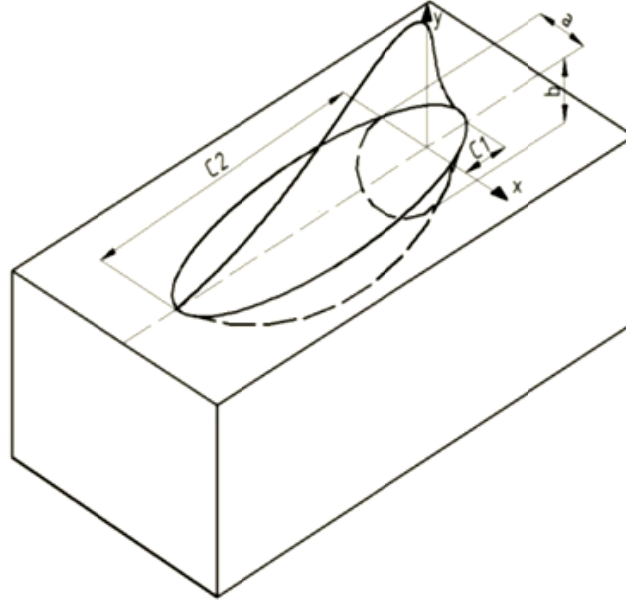


Fig. 2 Goldak double ellipsoidal heat source model [3]

$$q(yx, \xi) = \frac{6 \cdot \sqrt{3} \cdot f_1 \cdot Q}{a \cdot b \cdot c_1 \cdot \pi \cdot \sqrt{\pi}} \cdot e^{-\frac{kx^2}{a^2}} \cdot e^{-\frac{ly^2}{b^2}} \cdot e^{-\frac{m\xi^2}{c_1^2}} \quad (2)$$

$$q(yx, \xi) = \frac{6 \cdot \sqrt{3} \cdot f_2 \cdot Q}{a \cdot b \cdot c_1 \cdot \pi \cdot \sqrt{\pi}} \cdot e^{-\frac{kx^2}{a^2}} \cdot e^{-\frac{ly^2}{b^2}} \cdot e^{-\frac{m\xi^2}{c_1^2}} \quad (3)$$

Where location of heat source is given by equation:

$$\xi = z_k - v(\tau - t) \quad (4)$$

where:

$q(x, y, \xi)$	$[W \cdot m^{-3}]$	- heat flow density into the material,
Q	$[W]$	- overall heat,
$a, b, c_{1,2}$	$[m]$	- coordinates of fusion zone,
x, y, z	$[m]$	- coordinates of point,
f_1, f_2	$[-]$	- constants influencing energy flow intensity distribution into material,
τ	$[s]$	- overall welding time,
t	$[s]$	- instantaneous welding time,
v	$[m \cdot s^{-1}]$	- welding velocity,
ξ	$[m]$	- location of heat source in dependence on welding time,
z_k	$[m]$	- z-coordinate at the close of welding.

For using double-ellipsoid model it is necessary to know size of the fusion zone (parameters $a, b, c_{1,2}$). These parameters are determined on the basis of carried out experiments. Parameters are taken from the macro-scratch patterns. Non-modified double-ellipsoid model of heat source has already been used since 1997. During the following years experiments were carried out which claimed that this model (thus model in non-modified form) isn't possible to be used as a general source for all methods of fusion welding. Hence in these days double-ellipsoid heat source in a non-modified form is used. The modification lies in the change of constants in exponent. It is possible to use the modified source for most fusion welding methods except for welding methods with high concentration of energy like e.g. welding by laser, plasma or electron beam.

3 Experimental part

This experiment includes the analysis of boundary conditions for the simulation of welding in the repair of gas pipelines with steel sleeve and welding simulation using this boundary condition for two-pass weld.

3.1 Experimental sample

The model used for the experiment was compounded of two 60° pipe sections of materials L360NB (pipe and distance ring). The pipe has a diameter of 323,9 mm, pipe thickness 10mm and length 260 mm. Distance ring has a diameter of 333,9 mm, ring thickness 10mm and length 90 mm. Welding joint was welded using the MMA process. Experimental sample was welded with two fillet passes of weld. These passes of weld are only a part of the finished weld.

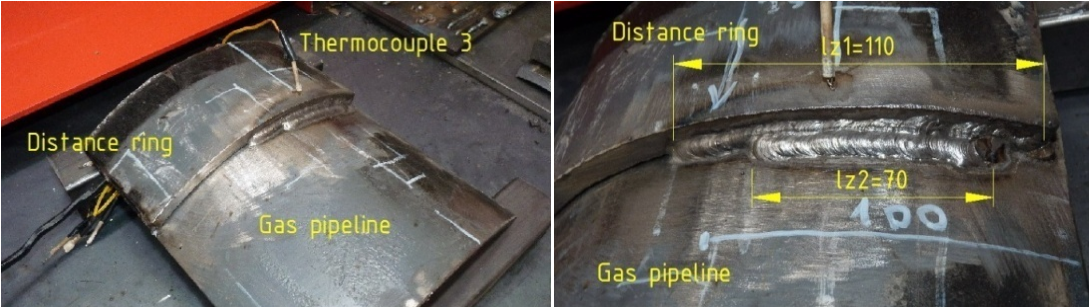
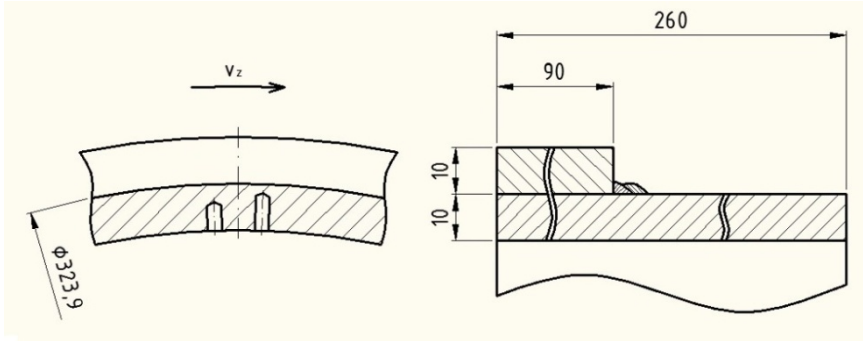


Fig. 3 Experimental sample, scheme (up), real sample (down)

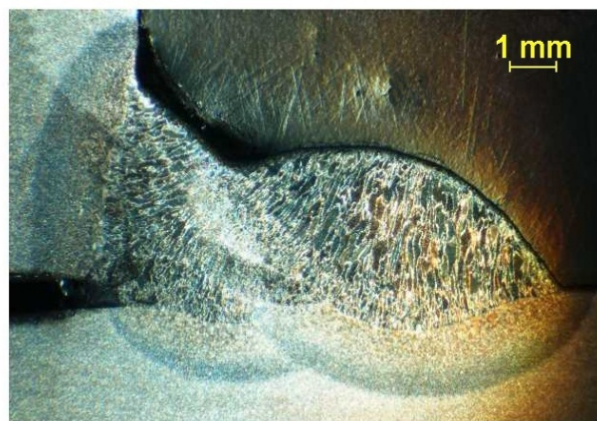
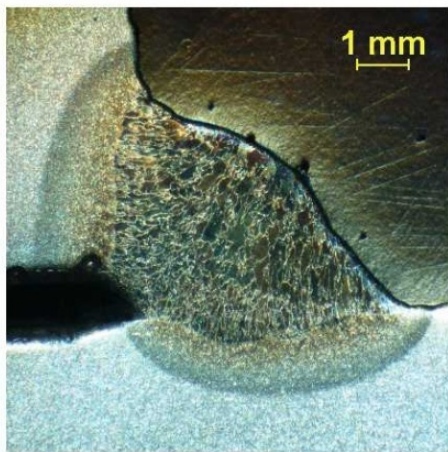
3.2 Experimental measurements during and after welding

During welding there were measured welding parameters, welding time and thermal cycles in three points. After welding the weld was analysed. The complete analysis of weld for simulation in simulation programme SYSWELD contains:

- parameters of welding (U_w , I_w),
- cross-sectional geometry of the welds (weld metal, heat affected zone),
- welding speed (s_w),
- temperature cycles.

Tab. 1 Parameters of welding

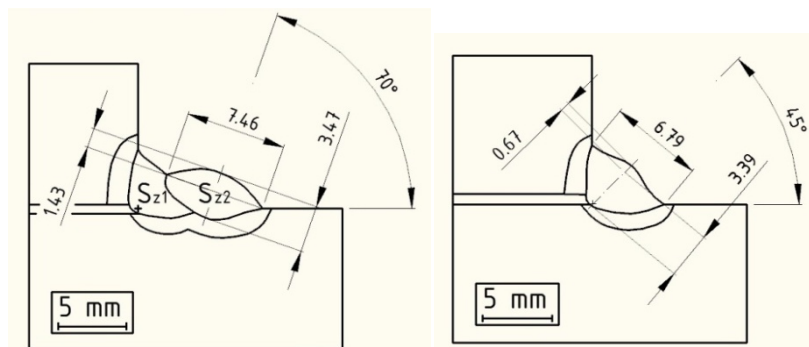
Parameters of welding				
Weld	U_w [V]	I_w [A]	s_w [mm.s ⁻¹]	Q_r [J.cm ⁻¹]
Weld 1	23,6	92	2,2	7895
Weld 2	23,6	92	2,25	7719



U_w - welding voltage, I_w - welding current, s_w - welding speed, Q_r - real heat input ($\eta=0,8$)

Fig. 4 Macrostructural analysis

Digitized weld macrostructures (Fig. 4) we get from cross-sectional parameters of welds (Fig. 5), which are necessary for the definition of Goldak heat source model.



$S_{z1} = 17,2 \text{ mm}^2$ - weld surface, $S_{z2} = 16 \text{ mm}^2$

Fig. 5 Digitized cross-sectional parameters of the weld

Temperature cycles were measured by three thermocouples. Their location is shown on Fig. 6.

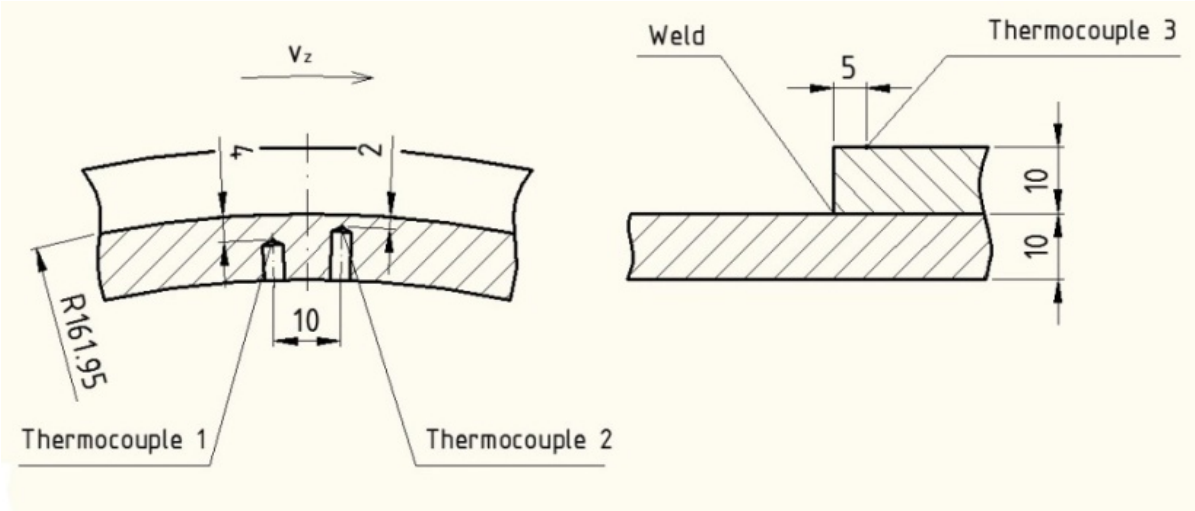


Fig. 6 Location of thermocouples

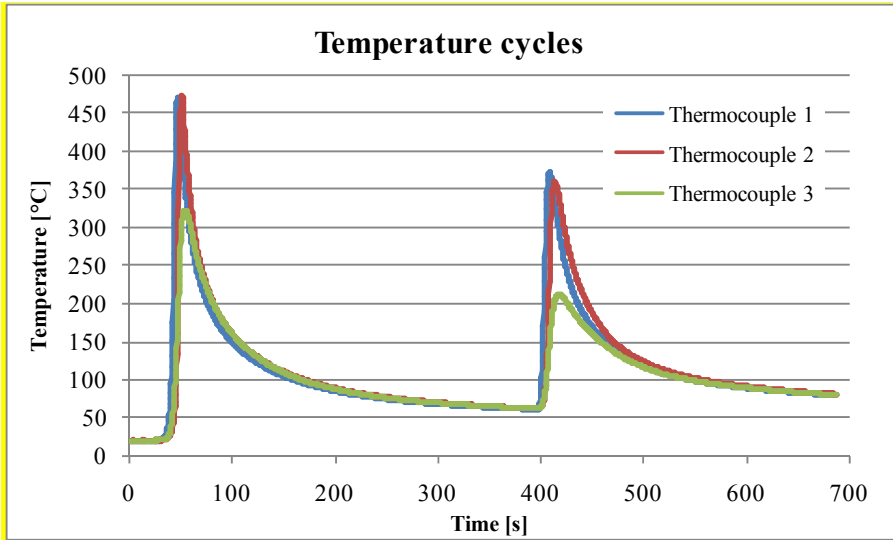


Fig. 7 Temperature cycles in three thermocouples

Temperature cycles are shown on Fig. 7 and their characteristic attributes in Tab. 2.

Tab. 2 Characteristic attributes of temperature cycle

Characteristic attributes of temperature cycles			
1. pass of weld			
Thermocouple	T_{max} [°C]	r300 [°C.s ⁻¹]	t100 [s]
1	465	9,78	113
2	480	10,6	117
3	322	6,5	112
2. pass of weld			
Thermocouple	T_{max} [°C]	r300 [°C.s ⁻¹]	t100 [s]
1	373	8,7	136
2	360	8,5	144
3	212	-	126

4 Simulation in program SYSWELD

Numerical simulation process consists of several following steps:

1. Creating geometrical model and its distribution to FEM mesh,
2. Definition input data and boundary condition,
3. Simulation and presentation of results.

The model has the same geometrical dimensions as the experimental sample. Preparation and distribution of geometrical model to FEM mesh was created in VisualMesh. VisualMesh is a programme designed for meshing 3D geometrical models. Meshed FEM model can be seen on the Fig. 8. Distribution model has 61591 finite elements and 50918 nodes. The smallest element used in the FEM model is in the area of the weld with the dimension of 1,0mm×1,0mm×1,5mm.

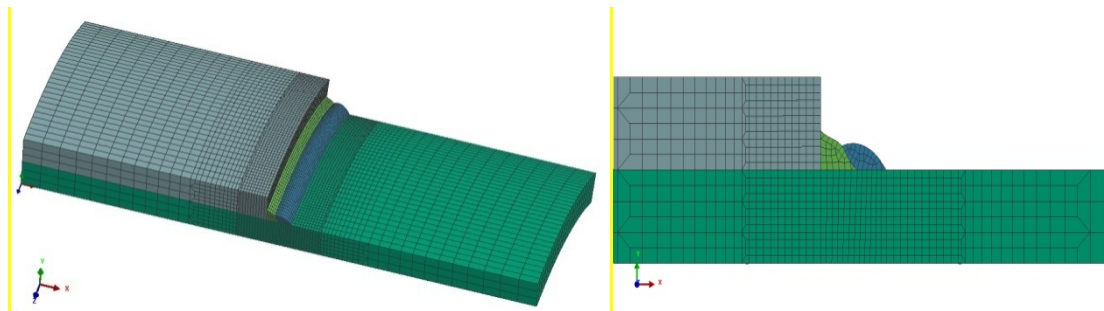


Fig. 8 FEM model

Input data and boundary conditions used for simulation are: material database of the model was steel S355J2G3, but material of experimental sample was steel L360NB. We could use this database, because both of steels have the same mechanical and physical properties. Parameters of Goldak model and welding speed are in Tab. 3. In the simulation, temperature fields and temperature cycles were simulated for both passes of weld. Graphic results of the simulation are on the Fig. 9. and Fig. 10.

Tab. 3 Parameters of Goldak model and welding speed

Weld pass	Parameters of Goldak model					Welding speed [mm.s ⁻¹]
	a [mm]	b [mm]	c ₁ [mm]	c ₂ [mm]	Q [W]	
1.	2,5	5	2	5	2000	2,2
2.	3,5	2	2	5	1400	2,2

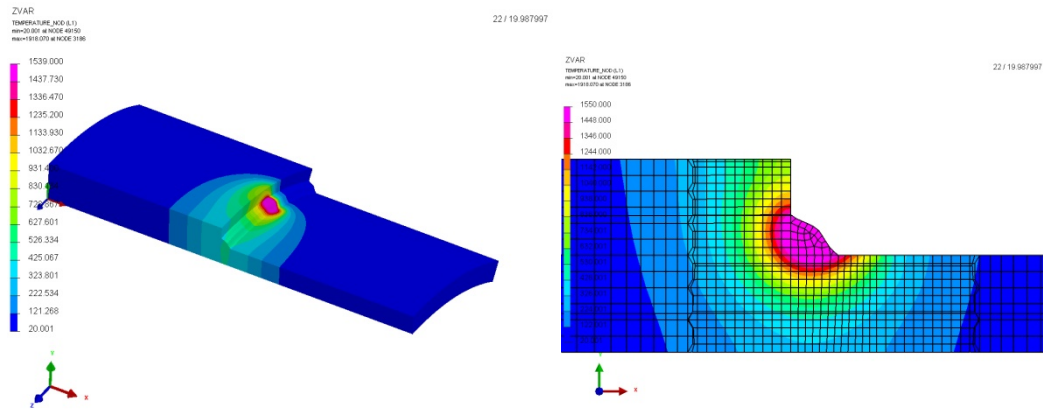


Fig. 9 Simulated temperature fields for the first pass of weld

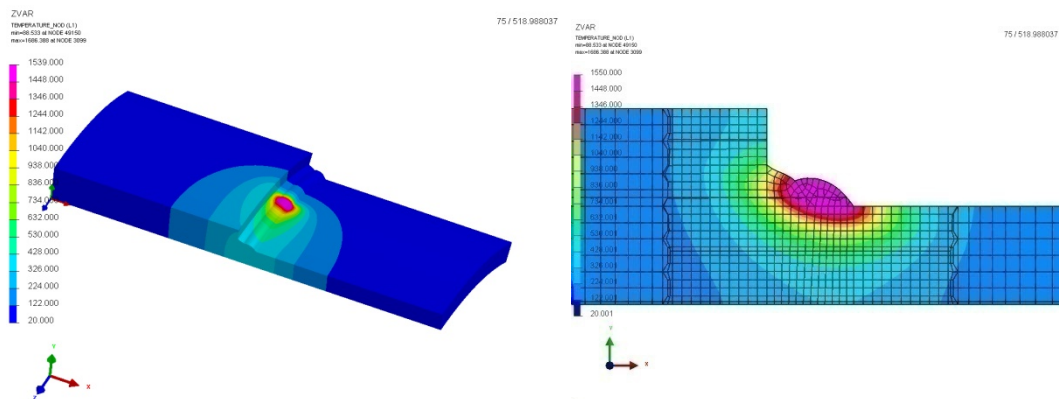


Fig. 10 Simulated temperature fields for the second pass of weld

Temperature cycles (Fig. 11, Fig. 12) were illustrated in three finite nodes. Temperature cycles were plotted in the same points, which were measured experimentally.

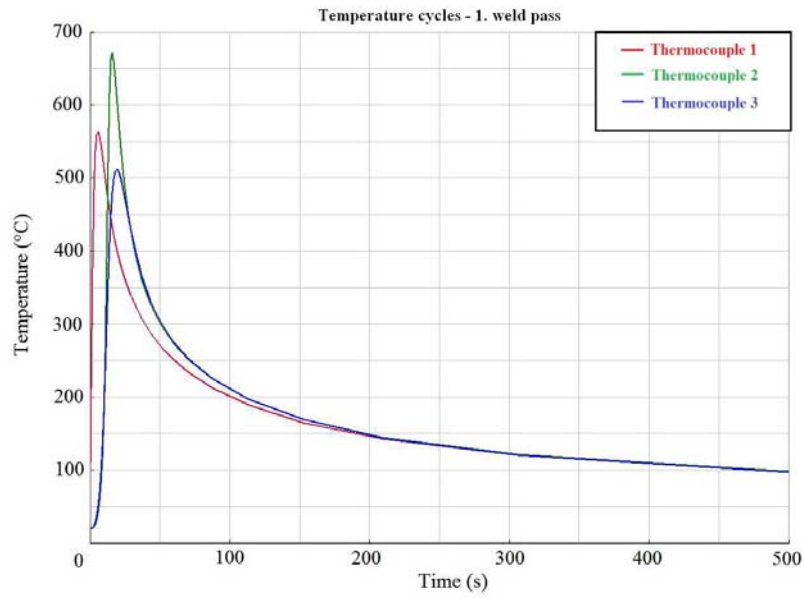


Fig. 11 Simulated temperature cycles for the first weld pass

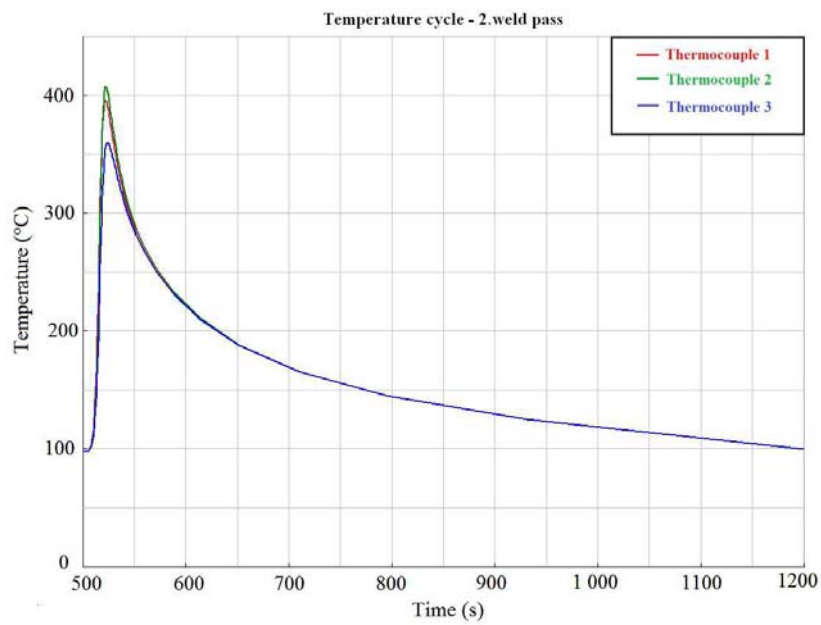


Fig. 12 Simulated temperature cycle for the second weld pass

Tab. 4 Maximal temperature of simulated temperature cycles

Thermocouple	T_{\max} [°C]	
	1 st weld pass	2 nd weld pass
1	556	390
2	670	410
3	510	365

Conclusion

The theoretical part of the paper includes information about repair of gas pipeline with steel repair sleeves and welding simulation in programme SYSWELD. The experimental part includes analysis of boundary conditions and simulation of welding in the repair of gas pipelines with steel sleeves. There are results of simulation for two-pass weld. Results of simulation and experiment are not the same. The same results can not be reached because they are influenced by many factors (boundary condition, input data, definition of heat source).. Welding simulation has become a strong tool in technological practice. It helps to solve complex problems in welding efficiently and in a relatively short time.

Acknowledgments:

This work has been supported by Scientific Grant Agency of Ministry of Education of the Slovak republic, grant VEGA No. 1/0186/09 and VEGA No. 1/0150/08.

Literature

- [1] MORAVEC, J. *Simulace tavného svařování - simulační program SYSWELD*. In *Zvárač*. ISSN 1336-5045, 2009, vol. VI., issue 2., p. 9-12.
- [2] PAŘÍZEK, P.; BRYNYCH, A., STUKBAUER, M. *Trvalé opravy ocelových potrubí bez přerušení provozu aplikací objímek*. In *Plyn*. vol. LXXXVI., online: http://www.ceps-as.cz/download/Opravy-ocelovych-potrubí-bez-preruseni-provozu-aplikaci-objimek_PLYN_2006-11.pdf, 2006.
- [3] MORAVEC, J. *Numerical simulations utilization for welding hardly weldable materials based on iron aluminides*. Technical university of Liberec, first edition, 2010. ISBN 978-80-7372-682-9, 2010.

SIMULACE SVAŘOVÁNÍ PŘI OPRAVĚ PLYNOVODNÍHO POTRUBÍ POMOCÍ OBJÍMEK

Teoretická část článku se zabývá základními informacemi o opravách plynovodních potrubí pomocí ocelových objímek a simulačním systémem SYSWELD. Experimentální část zahrnuje analýzu okrajových podmínek pro proces simulace dvouvrstvého obvodového svaru. Součástí analýzy okrajových podmínek je vyhodnocení svařovacích parametrů, rychlosti svařování, teplotních cyklů, makrostrukturální rozbor a její digitalizace. Využitím těchto okrajových podmínek byl nasimulován proces svařování v systému SYSWELD. Výsledky simulace jsou vykresleny pomocí teplotních polí a teplotních cyklů.

SCHWEISSSIMULATION BEI DER REPARATUR DER GASLEITUNGEN MIT STAHLHÜLSE

Der theoretische Teil des Manuskripts beschäftigt sich mit grundlegenden Informationen über die Reparaturen der Gasleitungen mit Stahlhülsen und das Simulationsprogramm SYSWELD. Der experimentelle Teil umfasst die Analyse der Randbedingungen der Simulation des Doppelschichtschweißens. Teil der Analyse der Randbedingungen ist es, die Schweißparameter, Schweißgeschwindigkeit, Temperatur-Zyklen, makrostrukturelle Analyse und ihre Digitalisierung zu bewerten. Mit diesen Randbedingungen wurde der Schweißprozess im Programm SYSWELD simuliert. Die Ergebnisse der Simulation werden mit Hilfe von Temperaturfelder und Temperaturzyklen dargestellt.

SYMULACJA SPAWANIA W NAPRAWACH RUROCIĄGÓW GAZOWYCH PRZY POMOCY STALOWYCH TULEI

Część teoretyczna artykułu dotyczy podstawowych informacji na temat naprawy gazociągu z użyciem stalowych tulei i przy pomocy systemu symulacji SYSWELD. Część doświadczalna obejmuje analizę granicznych warunków spawania dwuprzebiegowego. Analiza obejmuje także ocenę parametrów spawania, prędkość spawania, cykle temperatury, analizę makrostrukturálną i jej digitalizację. W wyniku zastosowania warunków granicznych dokonano symulacji procesu spawania w systemie SYSWELD. Wyniki symulacji zostały przedstawione za pomocą pól temperatury i cyklów temperatury.