ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 2012
Seria: TRANSPORT z. 76 Nr kol. 1865

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OPTIMIZATION OF DIMENSIONS OF COLD SLEEVE REPAIRED PIPING WITH REGARD TO COHESIVE FAILURE

Summary. The aim of this paper is first to determine the state of stress of the welded node in the cold sleeve for different geometrical variants of the pipeline loaded with inner pressure. Next is simulated the process of polymer separation from the pipeline surface and sleeve with the usage of cohesive finite elements. In the end the sleeve dimensions are optimized with respect to maximum integrity to the repaired sleeve.

Keywords. Reparing pipes, Cold sleeve, Stress of welded joint, Cohesive finite elements.

OPTYMALIZACJA ROZMIARÓW ZIMNEJ OBEJMY NAPRAWIANEGO RUROCIĄGU Z UWZGLĘDNIENIEM ZAKŁÓCENIA INTEGRALNOŚCI

Streszczenie. Celem niniejszego artykułu jest najpierw określenie naprężenia spawanego węzła z zimną obejmą, z zastosowaniem kohezyjnych elementów skończonych dla oddzielnych wariantów geometrycznych rurociągu obciążonego wewnętrznym podciśnieniem. Następnie symulowany jest proces oderwania polimeru od powierzchni rurociągu oraz obejmy. Na końcu optymalizowane są rozmiary obejmy z uwzględnieniem maksymalnej integralności naprawianego rurociągu.

Słowa kluczowe. Naprawa rurociągu, zimna obejma, Naprężenie spawanego węzła, metoda kohezyjnych elementów skończonych.

1. INTRODUCTION

Older metal pipelines have a lot of different types of material failures or defects. Defects are identified during different actions on the pipelines, as are internal inspection methods, or other activities like making a control probes, pipeline rehabilitation, searching gas-escape and similarly. Comparable carrying capacity of repair of the damaged pipe with the pipe without disturbance can be achieved by applying steel sleeves filled with composite epoxy. Repairing pipes with cold sleeve we can reduce stresses at failure, and provide sufficient resistance pipelines for the next operation. The disadvantages of these methods and sleeves used by them are a low resistance and low axial tensions security protection in case of seepage pressure medium and short lifetime repairs [3]. Installation of the proposed sleeve takes place in the full operation of the pipeline. The repaired place of the pipeline is first

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cleaned from the original coating, and for getting the maximal adhesion strength between the polymer and the pipeline surface and the sleeve is achieved by quality surface pretreatment as well as the pipeline surface and the inner surface of the sleeve. Subsequently, the split sleeve is mounted on the pipe and the space between the sleeve and the pipeline is defined distance prisms. Then the sleeve is welded by the classical ”V” weld and is sealed with bandimex clamp and shrink wrap (Fig. 1). The tension spring is creating space and conditions for a continuous, integral filling of the space between the sleeve and the repaired pipe. Finally, by using the filler the space between the sleeve and the pipe is filled by polymer.

2. PROBLEM FORMULATION

On the basis of the technical documentation supplied was necessary to determine the stress state of the welded joint with the cold sleeve and polymer adhesion for three different geometrical variants of pipe under internal gas pressure 7.35 MPa and axial force acting in closed pipe. The modified PROTEGOL was used for the filling space between sleeve and pipe. We note that PROTEGOL is polymer successfully used as anticorrosion protection on steel pipes and constructions placed under ground. It is one of the materials with the highest quality, which is used for the rehabilitation of transit pipeline.

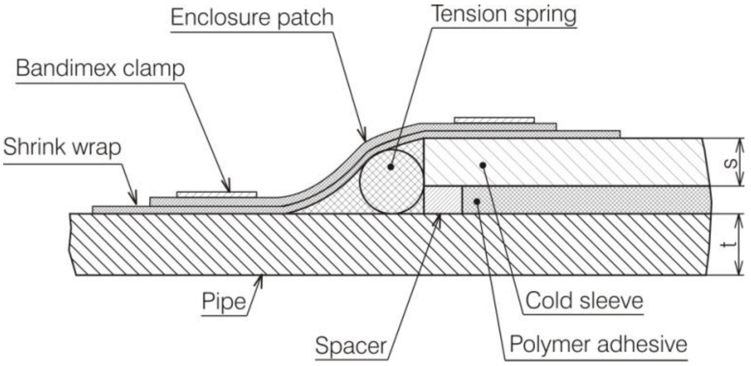

Fig. 1. Cut pipe with installed cold sleeve
Rys. 1. Przekrój rurociągu z zainstalowana zimną obejmą

The size and shape of the weld was created in the sense of the norm STN 131075 (Slovak technical norm). In Fig. 1 is a cut through the pipe with an installed cold sleeve. For simulation a pipe with diameters 1220 and 1420 mm were considered.

3. EXPERIMENTAL INESTIGATION

To get material input data into finite element (FE) simulation were made two experimental tests. To determine the material properties of the modified polymer PROTEGOL tensile tests of test specimens were carried out in accordance with standard norm BS EN 10002-1. The results of this test are given in Fig. 4 and they show the statistical behaviour of the specimens with a large variance of maximum force. The maximum force required to tear the specimen is in the range < 200, 500 > [N]. In our opinion a large variance of maximum force is mainly due to the chemical composition of polymer, surface and internal inhomogeneity of the material and method production of polymer, because the conditions of carrying out the test were the same.

Fig. 2. Test sample
Rys. 2. Badana próbka

Fig. 3. Tearing of the test specimen
Rys. 3. Rozrywanie próbki

The next test, which was necessary to obtain input data for the FE simulation by using cohesive FE was the tearing test. For this test cylindrical test specimen were made (Fig. 2). The specimen was attached to the ZWICK tensile machine. Fig. 3 displays the tearing of the specimen in the tensile machine. Like it was in a tensile test the results show a large variance of the tearing force. The maximum tearing force is 4150N (Fig. 5).

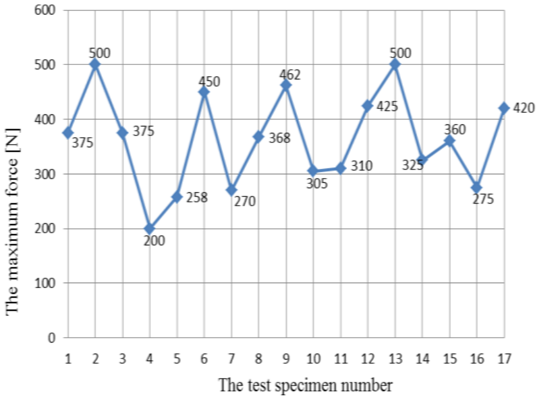

Fig. 4. The results of tensile test
Rys. 4. Wyniki próby ciągnięcia

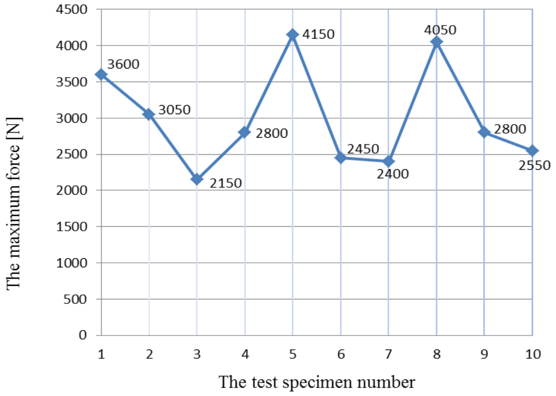

Fig. 5. Tearing force
Rys. 5. Siła przy oderwaniu

4. FINITE ELEMENT CALCULATIONS

Finite element modelling has been applied to determine stresses and separation of polymer from the surface of the pipe. The simulation was performed for pressurized pipe with operating pressure p = 7.35 MPa followed by depressurization to atmospheric pressure. Based on above given tests, we decided to use two-parameter Mooney-Rivlin hyperelastic constitutive model [3]. To determine the parameters of Mooney-Rivlin model we break 10 specimens. Three samples were used to tune the attachment to tensile testing machine and 4 specimens for optical tuning of the spray for system ARAMIS [4]. From performed FEM calculations we have evaluated the separation of polymer from the surface of the pipe and the sleeve using the parameter d_n, respectively DPARM. Value 1 is total separation of surfaces and 0 is total adhesion.

Calculation of contact and tangential slip is based on the type of contact element and the position of the point of contact detection. This mode of debonding defines a mode of separation of the interface surfaces where the separation normal to the interface dominates the slip tangent to the interface. The normal contact stress (tension) and gap behavior is plotted in Fig. 6. The simulation model was created to solution three geometric variations: Variant 1 - pipe Ø1220, thickness 15.9 mm, Variant 2 - pipe Ø1220, thickness 13.5 mm and Variant 3 - pipe Ø1420, thickness 15.6 mm. The used PROTEGOL was the strongest polymer variant, F_{max}=500 N, and the weakest polymer variant, F_{max}=270 N. The lowest separation force between the polymer and metal was F=2150 N and highest was F=4150 N. The applied statically determinate boundary conditions are described in Fig. 7. Gas pressure load is marked by red colour in Fig. 7.

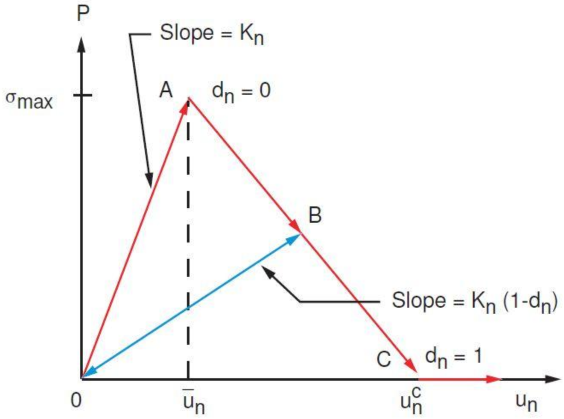

Fig. 6. Normal contact stress and curve of contact gap for bilinear material of cohesive zone

Rys. 6. Normalne naprężenie stykowe oraz krzywa szpary stykowej

Another load that needed to be considered is the axial load due to gas pressure in closed pipe. This load is calculated as $F_O = p\,.S$, where S is cross sectional area of pipe. For pipe with outer diameter D = 1220 mm and thickness t = 15.9 mm, the resulting applied load is F_O = 7.35 x 3.14x 594.1**2 = 8.146.10^6 N. Pipe and sleeve are made from steel 11 523 (S355J0). Elasticity modulus in tension is E= 206.0 GPa and Poisson's number is 0.30. In Fig. 8 is graph deformation-stress for polymer PROTEGOL. The maximum deformation is cca 64% and maximum stress is cca 4.5 MPa.

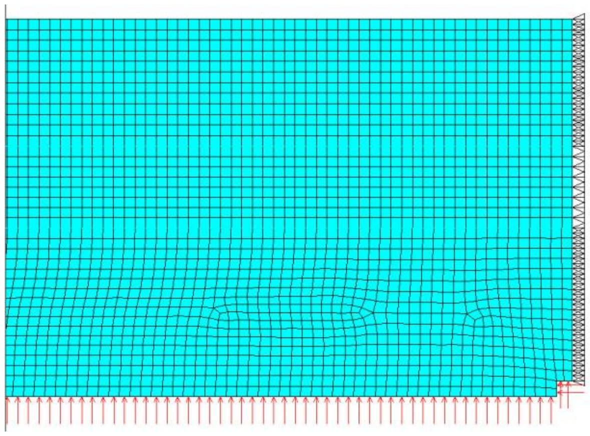

Fig. 7. Boundary conditions

Rys. 7. Warunki skrajne

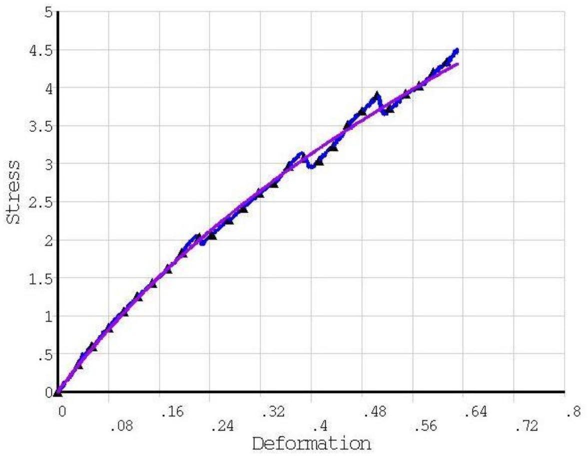

Fig. 8. Stress – deformation

Rys. 8. Zależność deformacja-naprężenie

The FEM calculation was performed as a nonlinear analysis with elasto-plastic material properties of pipe and sleeve. For a description of the behaviour of steel under applied load the yield stress was used multilinear isotropic model defined by commands TB, TBTEMP and TBPT in ANSYS software [2]. Was used plane element PLANE82, contact element CONTA171 and contact element TARGE169 [2].

5. ANALYSIS RESULTS AND OPTIMIZATION

In terms of the limit state of the load carrying capacity, vessels or piping are appreciated in terms of the primary stresses which are results of acting a pressure in a piping and self-weight.

After applying the axial force the stress values for all variants are given in tab.1 and the distribution of the von Mises stress and values of the safety factors for all variant are given in [5]. From tab. 1 it can be seen that maximum value of the von Mises stress is $(\sigma_{von})_{\max} \cong 392$ MPa. This value reaches almost the yield strength and occurs in the tip of the incomplet weld root. It is a singularity caused by an sharp corner, i.e. transition between the pipe and the incomplet weld root.

From tab.1 it can be seen that the most critical variant of tearing is variant 2. The value of DPARAM =0.669 and contact gap is – 0.100 mm. By comparing values of the contact gap and parameter DPARAM with values from tab. 5.2 we can see that axial force has positive effect on tearing. It eliminates a risk of tearing the sleeve and the pipe from the polymer a risk of tearing the sleeve and the pipe from the polymer. This effect is logical and simulation results confirm this. Value of DPARAM in the middle of the sleeve is equal to zero. It is worth noting that in variant 2 a nonzero value of DPARAM is also the middle of the sleeve in contrast to other variants.

Table 1

Results in MPa for operating pressure p = 7.35 MPa

		Variant 1	Variant 2	Variant 3
Radial displacement (**u$_r$**)		-0.544	-0.641	-0.758
Radial stress (**σ_r**)	Depressurized	3.812	5.609	6.04
	Pressurized piping	90.826	112.037	107.729
Circumferential stress (**σ_t**)	Depressurized	-121.059	-130.894	-145.38
	Pressurized piping	347.888	414.005	412.931
Axial stress (**σ_A**)	Depressurized	- 31.09	-35.957	-37.031
	Pressurized piping	282.299	339.009	339.089
Von Misses stress $(\sigma_{von})_{max}$	Depressurized	123.102	131.233	147.416
	Pressurized piping	329.108	391.191	391.627
Contact gap		-0.060	-0.100	-0.086
D-param		0.418	0.669	0.569

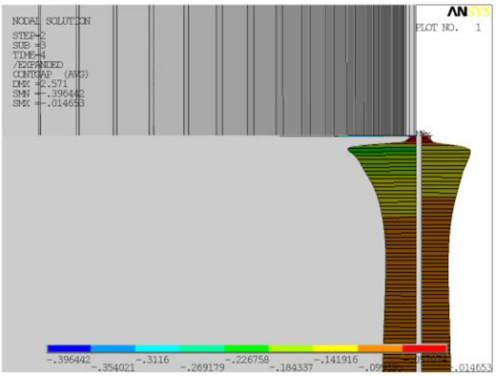

Fig. 9. Distribution of contact gap for variant 2, p= 7.35 MPa

Rys. 9. Przebieg szpary stykowej dla wariantu 2, p = 7.35 MPa

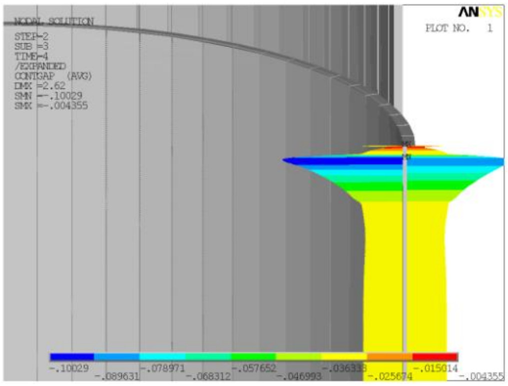

Fig. 10. Detail of distribution of contact gap for variant 2, p= 7.35 MPa with considering axial force

Rys. 10. Przebieg szpary stykowej dla wariantu uwzględniającego siłę osiową

To optimize the design with respect to the tearing of the polymer layer, we executed several analyzes of altered polymer layer thickness and the thickness of the sleeve. To change the thickness of the polymer layer 9 analyzes were performed. The thickness of the polymer layer was varied in the range 4-8 mm in increments of 0.5 mm and is described in Fig. 11. From the figure we can see that DPARAM parameter has a maximum value for thickness 7 mm. Other behavior DPARAM parameter is when we change the thickness of the sleeve. In this case, we carried out 15 variants with altered thickness calculation sleeve in the range 5-12 mm in increments of 0.5 mm. The basic variant is a variant with a thickness of 15 mm and graph of the dependence is shown in Fig. 12. From this figure we can see that DPARAM values are zero values for the sleeve thickness less than 8.5 mm. The largest value DPARAM is for thickness 12 mm and is 0.569.

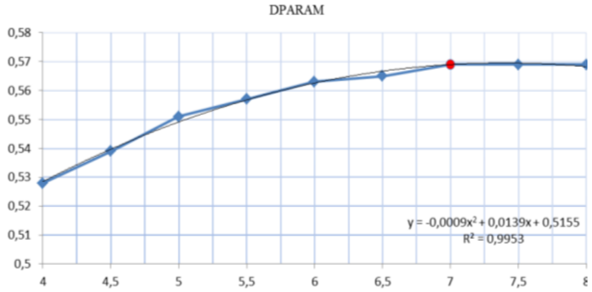

Fig. 11. Graph DPARAM vs. polymer thickness
Rys.11. Graf zależności DPARAM od grubości warstwy polimerowej

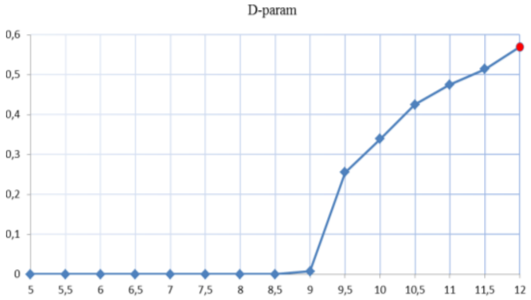

Fig. 12. Graph DPARAM vs. sleeve thickness
Rys. 12. Graf zależności DPARAM od grubości obejmy

6. CONCLUSION

On the basis of the mentioned results we can state that repairing of anomalous weld by means of the cold sleeve with modified polymer PROTEGOL is safe with respect to tearing polymer. Regard to the limit state, the piping as well as the sleeves are loaded in an elastic domain under the yield strength of the used steels. Since the problem has been solved as a nonlinear problem with elastic-plastic behavior of materials, the results of the numerical simulation proved that plastic strains of the piping nor the sleeve are not reached.

The research work is partially supported by the Project of the Structural Funds of the EU, Operational Program Research and Development, Measure 2.2 Transfer of knowledge and technology from research and development into practice:
Title of the project: Development of optimal technology for the analysis of the limit states of structural elements in contact, ITMS code: 26220220118.
We are support research activities in Slovakia / Project is cofounded from sources of ES.

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