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INVESTIGATION OF COMPOSITE REPAIR OF PIPELINES WITH VOLUMETRIC SURFACE DEFECT

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Abstract: *The paper describes equivalent stress change of pipe with longitudinal volumetric form defect on pipe surface – approximated as half of ellipsoid. The optimal experiment design created to analyse that defect increase. For every size of modelled volumetric surface defect created different thickness of applied bandage. The equivalent stress for working pressure is numerically calculated using ANSYS software in pipe without defect, with defect and after composite repair with varying thickness of the bandage for different sizes of defect. All results are approximated and analysed.*

Key words: volumetric defect, composite repair, modelling

1. INTRODUCTION

There are different kinds of pipe defects resulting metal loss – such as scars, corrosions, pitting, abrasion, grinding off, rupture, puncture or leak etc. When areas of corrosion or other damage on operating pipelines are identified, there are significant economic and environmental incentives for performing repair without removing the pipeline from service. There are a variety of repair strategies available to pipeline operators for a given repair situation [1]. An application of composite materials for the repair of damaged pipelines considerably improved situation in the last time [2]. The goal of this paper is investigation of composite repair of pipelines modelling volumetric surface defect before and after advanced composite repair and the development of optimization methodology for advanced composite repair of pipelines with volumetric surface defects, which consists from several tasks.

2. PIPE DEFECT DESCRIPTION

2.1. Parameters of defect

There are different kind of pipe defects resulting metal loss – such as scars, corrosions, pitting, abrasion, grinding off, rupture, puncture or leak [3] etc. The paper describes defect, which has volumetric longitudinal form – approximately half of ellipsoid.

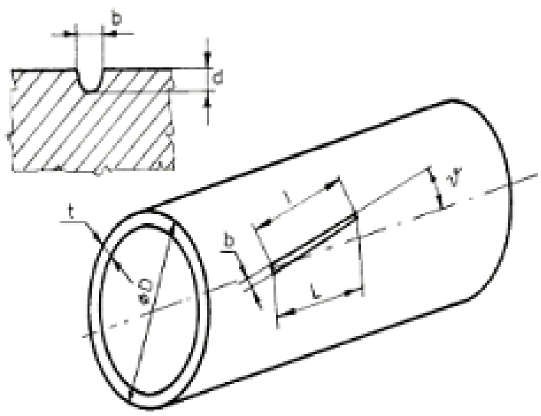

Fig. 1. Measures of longitudinal volumetric defect

The definition of pipe metal loss defect: groove like defect, which is nearly parallel with the centre line of the pipe having greater projected axial length than the triple of the nominal wall thickness and having a width, which is larger than the 30% of the nominal wall thickness [3]. Maximal depth of defect is close to 80% of pipe wall thickness.

Measures of longitudinal volumetric defect, see Fig.1.

- angle between the defect and the centre line of the pipe, υ[°];
- length, l [mm];
- projected axial length, L [mm];
- maximal width, b [mm];
- maximal or effective depth, d [mm],[2]

The constraints describing longitudinal volumetric defect is identified below (1, 2, 3, 4):

$$3t<L<10t \quad (1)$$
$$0.3t<b<3t \quad (2)$$
$$0.1t<d<0.8t \quad (3)$$
$$\upsilon = 0°, \quad (4)$$

where *t* is wall thickness of pipe, mm.

The geometrical and physical parameters of pipe and advanced composite repair materials are constant, except the thickness of bandage – *h, mm*. Thickness of bandage have to change in dependence of defect metal loss volume and it have to be less than pipe wall thickness.

The thickness of bandage defined as variable parameter – less is better, because of saving materials.

2.2. Description of VSD

For creation of optimal experiment design is used the model, which describes increase of longitudinal volumetric surface defect (VSD). Three parameters characterise increase of longitudinal volumetric surface defect (VSD) by mathematical linear expressions given below (5, 6, 7):

$$L_{n+1} = L_1 + 14n, \text{ where } L_1 = 3t \quad (5)$$
$$b_{n+1} = b_1 + 5.4n, \text{ where } b_1 = 0.3t \quad (6)$$
$$d_{n+1} = d_1 + 1.4n, \text{ where } d_1 = 0.1t \quad (7)$$
$$\text{and } n \epsilon (0,8)$$

The metal loss volume of longitudinal volumetric surface defect of pipe approximately is shown as a half of ellipsoid (8) by formula (9) [4]:

$$V = \frac{4}{3}\pi abc \quad (8)$$

$$V_n = \frac{1}{2} \times \frac{4}{3}\pi \frac{b_n}{2} d_n \frac{l_n}{2} = \frac{\pi b_n d_n l_n}{6} \quad (9)$$

Model of volumetric defect increase is given below, see Fig.2. That increase can consists of many different configurations of three parameters like axial length, maximal width and maximal depth, but in this research, they are given by expressions (5), (6) and (7).

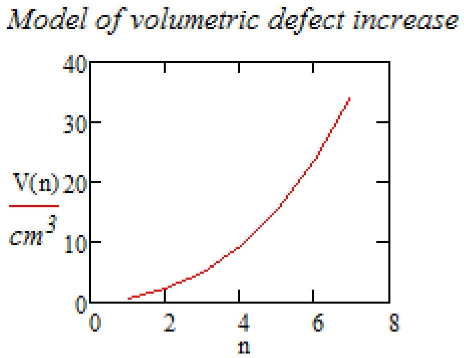

Fig.2. Model of volumetric surface defect increase for pipe with outside diameter is 1020 mm and wall thickness – 14 mm

3. EXPERIMENT DESIGN

3.1. Statement of the problem

Statement of the problem in this research is shown at Fig.3. Objective of optimization is to find a minimal stress *σ (MPa)* on the pipe surfaces after repair applying different thickness *h (mm)* of bandage on different size of chosen volumetric defect *V(L, b, d) (mm³)*[5].

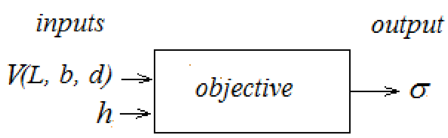

Fig. 3. Statement of the problem

$$\sigma = f\,(V(L, b, d), h) \quad (10)$$

As the result of experiment design is creating the output - σ functional dependence (10) of inputs – *V(L, b, d)* and *h,* which is necessary for optimization activities.

3.2. Experiment design

The experiment design [6] elaborated in the Table 1. Input data include:

- geometrical parameters of selected pipe; model of the defect defined by three increasing parameters – in this case (5), (6), (7);
- variable thickness of bandage;
- equivalent stress of the selected pipe without damage;
- equivalent stress of selected pipe with different size of defect (n=8 is number of different sizes of damage);
- equivalent stress of composite repaired pipe with different thickness of bandage.

Number of experiments	Outside diameter	Wall thickness	Axial length of defect:	Max width of defect:	Max depth of defect:	Equivalent stress	Equivalent stress with different bandage thickness (mm), Mpa							
#	D, mm	t, mm	l, mm	b, mm	d, mm	σ, MPa								
			$3t<l<10t$	$0.3t<b<3t$	$0.1t<d<0.8t$		1mm	3mm	5mm	7mm	9mm	11mm	13mm	15mm

Table 1. Experiment design

4. CREATION OF FEM MODELS

4.1. Constructive characteristics

According to elaborated experiment design plan FEM calculations were done. For calculations have been used parameters given below:

Pipe:

Geometry data:

outer radius R = 0.51m, wall thickness h_1 = 0.014m, half of length for calculations l_1 = 0.2m

Mechanical properties: E_1 = 200 GPa, υ_1 = 0.3, ρ_1 = 7850 kg/m^3

Filler:

Geometry data varies depending from size of VSD taken according to plan

Mechanical properties: E_2 = 20 GPa, υ_2 = 0.4, ρ_2 = 1250 kg/m^3

Bandage

Geometry data: inner radius equals pipes outer $R_3 = R_1$ = 0.51m, wall thickness h_2 = 0.014m, half of length for calculations l_2 = 0.1m

Mechanical properties: E_3 = 142 GPa, υ_3 = 0.3, ρ_3 = 1600 kg/m^3

For simplification glassfibre bandage considered as isotropic material.

Working pressure in the pipe 5.9 MPa.

As FEM element type is used Solid 95 and all three materials are connected with command *glue* (Ansys) and symmetry boundary conditions were applied.

At first, equivalent stress for pipe without any damage is founded. This numerical data is necessary for analysis of repaired system. From numerical calculations obtained, that in case for tube described above, the stress in undamaged pipe is very

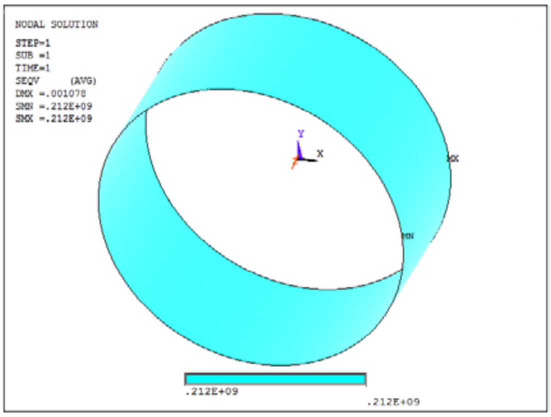

Fig.3. Equivalent stress in pipe without damage is 212 MPa

near to 200 MPa (see Fig.3) and it is more than half from Yield strength of material, factor of safety in statical loading case is more than 1, in this case is near or more than 2 (differs between used material properties). Stress 200 – 212 MPa will be used for comparison with obtained stress in repaired pipe, for which in each VSD case will be changed thickness of glassfibre bandage, which will be wrapped around pipe and filler in damaged place.

4.2. Description of defect model

Second task is to create FEM models for growing volumetric surface defect (VSD). Metal loss in pipes outer surface is modelled by using ellipsoids and sizes are taken according to three parameters characterise increase of longitudinal VSD by mathematical linear expressions (5, 6, 7). Damage is created in ellipsoidal coordinate system in *Ansys*, relationship between dimensions of damage are used (it is determined by radius ratios, see Fig. 4) for curvature determination.

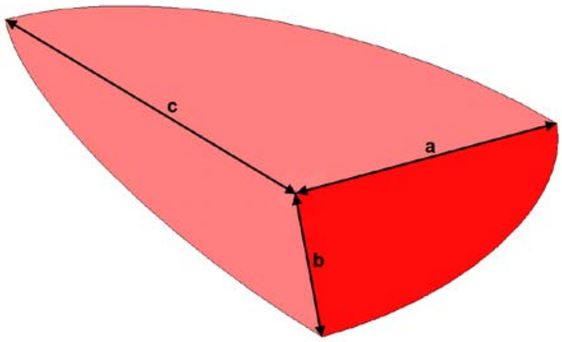

Fig. 4. ¼ of metal loss ellipsoid volume, letters correspond to dimensions

Totally is made eight different sizes of ellipsoidal volumetric surface defect using FEM, one model without defect with equivalent stress shown in Fig.3. A view of VSD is shown in Fig.5.

Figure 5 shows the VSD one model with wall thickness loss equivalent to 60% from pipe wall thickness.

Meshing is created so the smallest elements are in damage zone and farther elements grow by ratio (see in Fig. 6.), so it was possible to economy computing time, and for the same reason for modelling is

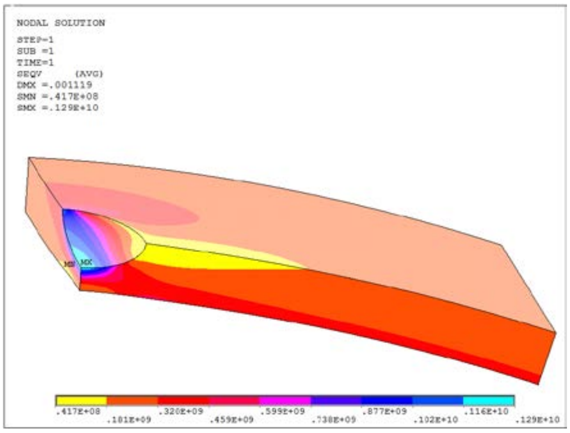

Fig. 5. Equivalent stress condition in case of one VSD size according to experiment plan

used only a sector of pipe with partial damage and for this symmetry boundary conditions were applied.

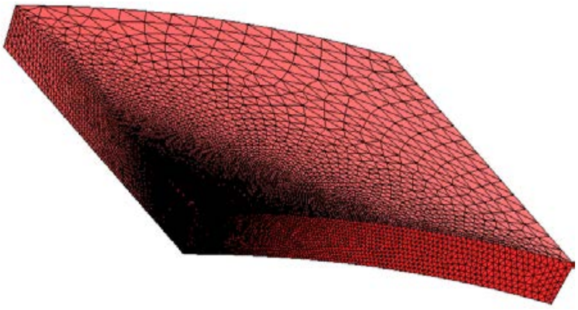

Fig. 6. Element map for pipe with damage

4.3. FEM models

In Fig. 7 and Fig. 8 is presented view on case 5 – 3 (number 5 means VSD size according to experiment design

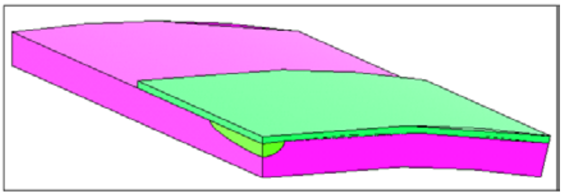

Fig.7. Model of sector of tube and bandage and filler in VSD cavern

expressions (5), (6), (7) and number 3 means thickness on bandage applied to pipe (3 mm)). Fig. 7 shows one sample without loading and in Fig. 8 is shown equivalent stress condition.

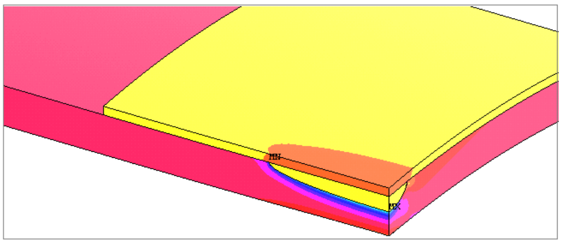

Fig.8. Equivalent stress condition for case 5 – 3

For several sizes of VSD is applied variable thickness of bandage, according to experiment design, for example, Fig.9.

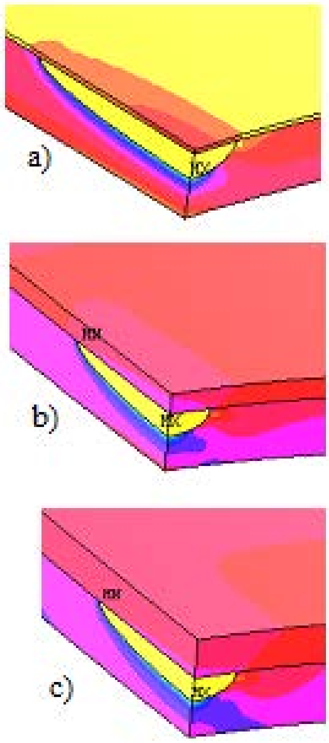

Fig. 9. Visualisation of increase of thickness of bandage layer for the one of VSD size, bandage thicknesses: a) 1 mm, b) 5 mm and c) 9 mm

Calculation results are collected. It shows that applying thicker layer of bandage, stress in damaged zone decreases. All results are useful for further research.

5. TREATMENT OF RESULTS

5.1. Equivalent stress

The results from Fig. 10 show how is changing the equivalent stress by applying composite repair materials for different size of volumetric defect if working pressure is constant. Different coloured lines characterize different size of modelled volumetric defect (VSD). The smallest VSD is defect Nr.1 and the largest – Nr. 9. The grey line shows the largest volumetric defect of the pipe being repaired, and blue line – the smallest volumetric defect of pipe being repaired. Coloured points shows numerically calculated Equivalent stress in pipe before and after composite repair depended on thickness of bandage

The horizontal axis is the thickness of bandage. The pipes with two smallest modelled volumetric damages according to expressions (5), (6), (7) and experiment design (Table 1) are crossing yield strength line when thickness of bandage of composite repair is less than 1mm, and the pipe with largest damage is crossing yield strength line when thickness of bandage of composite repair is more than 5 mm.

5.2. Equivalent stress approximation

For the analysis and optimization, the approximation curve was used. Fig. 10 shows approximated equivalent stress curve. The approximation with a logarithmic function gives very accurate approximations. The approximation with a logarithmic function used in the form:

$$\sigma(h) = \sigma_1 - C \cdot \ln(h) \qquad (11)$$

where $\sigma_1 = \sigma(h_1)$ is the equivalent stress of composite repaired pipe with a thickness of bandage of 1mm; *C* – is the constant, which depends on composite material properties and parameters of VSD. The constant for each sample is inside diapason (65; 83) in modelled configurations; *h* is the thickness of bandage.

Fig. 10 shows that the initial condition of equivalent stress of pipe after composite repair achieved in first two smallest modelled VSD. The largest modelled repaired VSD is Nr. 9 crossing yield stress with composite bandage thickness 5 mm. An impact of composite repair geometrical parameters and properties of its constituent materials on stress state in VSD taken into consideration.

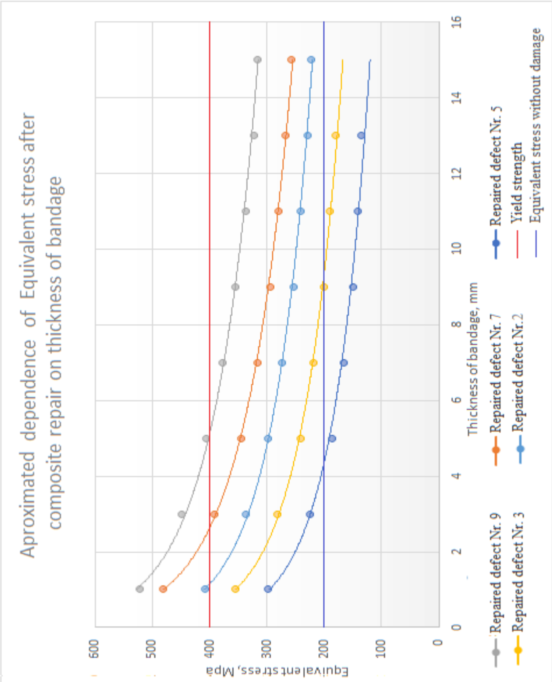

Fig. 10. Approximated Equivalent stress curves in pipe after composite repair depended on thickness of bandage

CONCLUSIONS

The optimal thickness of bandage for numerically modelled VSD depends on reserve ratio for working pipe, the total cost of applied composite materials and other external conditions, which shows the efficiency of repairing solution. Developed optimization methodology for the advanced composite repairs helps to engineer to make a decision about possibility of repair or not, and helps to find the necessary thickness of bandage for modelled VSD in this study. Approximated equivalent stress curves on Fig. 11 shows the impact of bandage thickness on repaired pipe.

The further model to analyse may include an angle between the defect and the centre line of the pipe.

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