EXPEDIENT REPAIR OF HYDRO-PNEUMATIC PIPES WITH ADHESIVES

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Abstract

The paper presents research on expedient repairs, including battle damage repair methods of hydro-pneumatic pipes with adhesives. According to analyzed publications concerning battle damage of military equipment, various pipes and lines, which are used in military vehicles and aircrafts, are one of the most often damaged parts during combat operations. During experimental tests, the efficiency of damaged pipes repair was researched. Various methods of repair depending on pressure in the pipe and sort of damage were considerate. To conduct experimental tests of repair two kind of adhesive were used. It was composite adhesive Belzona 1111, which is used by many armies of NATO, and epoxy adhesive Epidian 57 hardened with Z-1. The conducted experiments proofed that both low pressure and even high pressure hydro-pneumatic pipes can be repaired in the field conditions with considered adhesives. Presented methods of repairs can be very useful especially during combat operations when the access to spare parts and disposal time is limited. Using to repair the manufacturer's composite adhesive without any strengthening should be limited to low pressure pipes. The specific properties of epoxy adhesives must be considered before applying to repair, especially change of mechanical and utilitarian features at higher temperature.

Keywords: *military logistics, maintenance, expedient repairs, strength of pipes, composite adhesives*

1.Introduction

Contemporary technical objects include series of various hydraulic and pneumatic installations, which consist of numerous pipes. The planes includes for example the pipes, which entire length is even a few thousands meters. In the pipes, there is complex status of loads, which cause that they are one of the most unreliable elements of hydro-pneumatic installations. [1, 2]. The mentioned pipes are especially exposed to damage during combat operations while both intensive utilization and enemy life fire are conducted. According to references, hydro-pneumatic pipes are because of their replacement in planes, the most often damaged parts next to elements of aircraft structure [3]. The damaged fragments of pipes cause leak and interfere with right work of hydro-pneumatic systems. This phenomenon is very undesirable in the main installations, which are responsible for safe maintenance of military equipment, particularly aircrafts, such us fuel and oil systems, control power systems, systems of undercarriage. Even small damage of pipes like abrasions, incision and corrosion, can lead to their crack and finally to leak of installation as a result of:

- exceeding of acceptable tear stress cause by inside pressure – cracks arise usually along axle of pipe;
- exceeding of acceptable bend stress cause by fatigue bending (for instance from vibrations) – cracks arise perpendicularly to axle of pipe.

Using military equipment, especially during combat operations when time and spare parts are limited, expedient repairs of damaged section of pipes [4]. Repair can be conducted in two ways depending on pressure in the pipe. In the low pressure pipes, repair is executed by moving damaged section of pipe, fitting new section and joining it by flexible element of pipe using clamp – Fig. 1 [5].

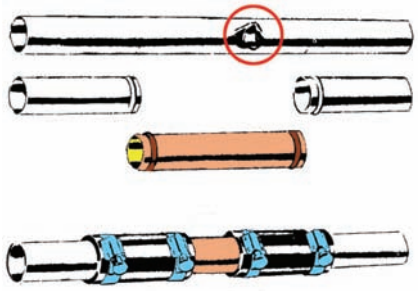


Fig. 1. Stages of low pressure pipe repair [5]

In the high pressure pipe the change of damage section is more laborious and consists in fitting new section of pipe by making additional joints between damaged and new fitted pipe (Fig. 2).

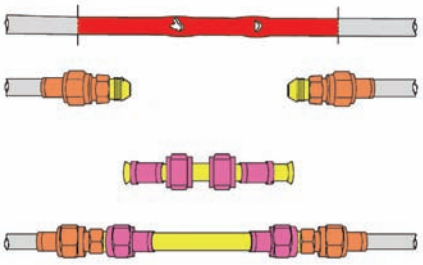


Fig. 2. Stages of high pressure pipe repair [5]

In the presented experiments, repair possibilities were researched with using epoxy adhesives and composites. The suggested way of repair allow efficiently shortening repair time and facilitate to conduct it in hard reach places (even without dismantling of damaged elements).

2.Methodology

During experimental tests the efficiency of damaged pipes repair was researched. The values of pressure, which destroy pipe, were compared in intact pipes to damaged and repaired pipes. The tested value was register at the moment when repaired pipe start likeness or was completely damaged. The tested sections of pipe were made with aluminum alloy PA2 and were 18 mm in exterior diameter, 2 mm thick and 220 mm length. The specimens were prepared by blanking off at the one end and connecting the second end to the research station (Fig. 3). The tested pipes were blanked off with glued corks made with steel St3, which were 15.8 mm in diameter and 30 mm length and with glued plug made with steel St3, which were 18.2 mm in interior diameter and 24 mm in exterior diameter and 40 mm length.

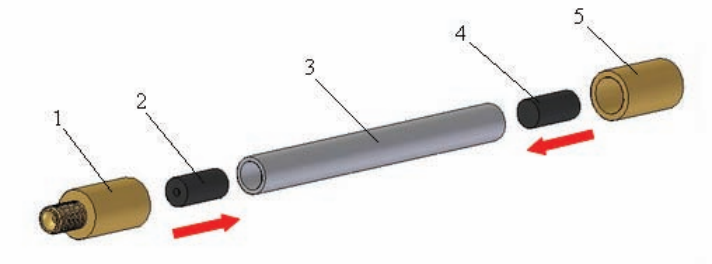


Fig. 3. Shape and elements of specimens used to test efficiency of repair: 1 – link, 2 – cork with hole, 3 – section of pipe, 4 – cork, 5 – plug

During experimental tests the research station was used, which had been prepared to load specimens by pressure of range 0÷100 MPa. High pressure was obtained by using multiplier of pressure (Fig. 4).

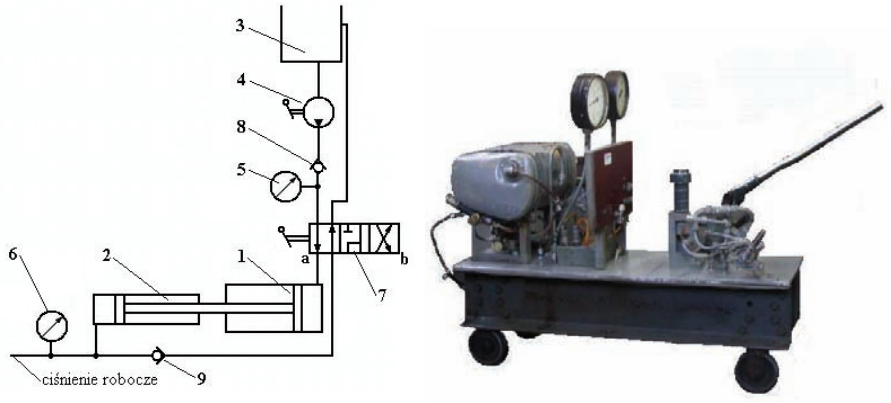


Fig. 4. Functional diagram and view of research station used to test efficiency of pipes repair , 1, 2 – pressure multiplier elements, 3 – hydraulic oil tank, 4 – hand piston pomp, 5, 6 – manometers, 7 – distributor , 8,9 – turning cocks

There was researched undamaged and also damaged and repaired section of pipes. The following methods of repair were considered:

- applying the coat of adhesive composite Belzona 1111, which was 2 mm thick and 80 mm wide (this kind of adhesive is dedicated to fast and expedient repair conducted in field conditions and it is used in numerous armies of NATO [6, 7]);
- bonding on the outside of pipe with 0.2 mm coat of adhesive composite Belzona 1111 strengthening strap. The strengthening strap took the form of pipe section cut along generating line, which was 1,5 mm thick, 80 mm length and different peripheral length (for conducted tests the straps were performed with a length equal to 50%, 90% and 100% of the repaired pipe perimeter);
- bonding on the outside of pipe the glass cloth permeated with epoxy adhesive Epidian 57 (hardened with Z-1). The glass cloth (weight 160g/cm^2) was wound around the pipe to form a composite bandage around the damage, which consist of 4 layers of glass cloth.

Preparing the damaged pipe to repair, the ends of cracks were drilled to prevent further propagation of crack. The surfaces of pipe near the damage and the interior surfaces of straps were prepared to repair by sandblasting and purifie

d petroleum ether (Fig. 5).

The straps length equal to 80 mm were based on recommendations given in the literature [8, 9], where is said that the repairs using adhesives composite should be carried out over a length of 20-30 mm form the edge of crack (crack length range from 26 to 29 mm). The same conditions of epoxy adhesives hardening were assumed, i.e. at temperature 60°C, hardening time – 1.5h. The pressures during bonding the straps were conducted using clamps (Fig. 6).

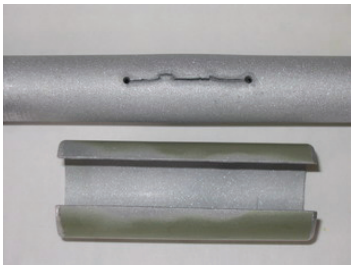


Fig. 5. The view of items prepared to bonding

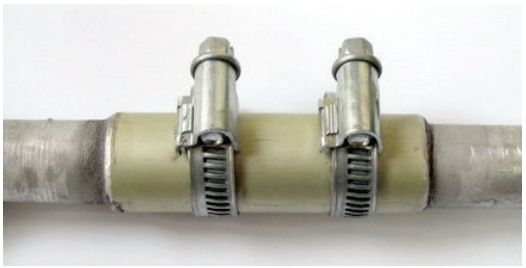


Fig. 6. The method of achieving pressure during bonding

3.Experimental tests

The repair of damaged pipes was conducted by following methodology:

1) Removing of fluid from damaged pipe;
2) Drilling the ends of cracks in order to prevent its further propagation;
3) Regenerating the geometry of damaged pipe
4) Pre-cleaning and degreasing of the surface with petroleum ether;
5) Preparing the surface to bonding;
6) Thorough cleaning and degreasing of the bonded surface;
7) Preparation of strap and composite adhesive according to the manufacturer's guidelines;
8) Applying of adhesive composition to the damaged area;
9) Bonding the strap and clamp;
10) Removing excess of adhesive composition;
11) Providing adequate hardening conditions (temperature and time).

The average value of pressure, which destroy undamaged pipe, amount was 65,0 ± 2,3 MPa (the calculations were made on the basis of 5 specimens for a confidence level $1-\alpha = 0.95$ – Fig. 7). The value of the mentioned pressure was benchmark in evaluating the conducted repairs.

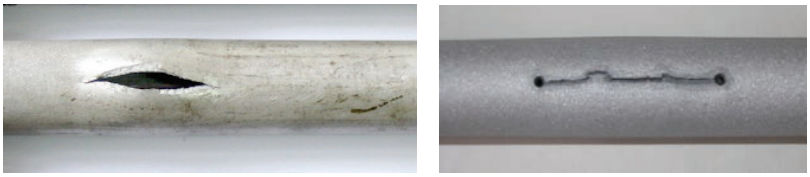
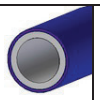
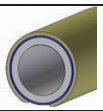
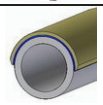
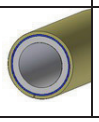
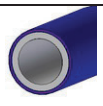


Fig. 7. The crack in a pipe and the pipe prepared to repair

The values of pressures, which cause renew damage of pipe, for various methods of repair are presented in Table 1.

Tab. 1. Maximum value of pressure, which cause damage of pipe for various methods of repair

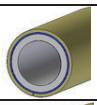
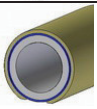
Method of repair		Max pressure [MPa]	Method of repair		Max pressure [MPa]
	Undamaged pipe	65		Adhesive composite Belzona 1111 + strap 90%	45
	The layer of adhesive composite Belzona 1111	3		Adhesive composite Belzona 1111 + strap 50%	28
	Adhesive composite Belzona 1111 + strap 100%	30		Epoxy adhesive Epidian 57 + glass cloth	18

The determined values of maximum pressure shows that the most efficient method of repair is applying of the strengthening strap, which length was equal to 90% of the repaired pipe perimeter. Applying the strap, which length was equal to 100% of the repaired pipe perimeter was less effective. It seems to be, that it is connected with insufficient pressure, which can be executed for such strap. Insufficient pressure on the strap caused that the layer of adhesive joint was too thick, what lead to penetration of adhesive layer by fluid and caused leak in repaired pipe. Additionally, this method of repair caused problems with instalment of strengthening strap. According to research, applying on the damaged pipe the coat of adhesive composite Belzona 1111 was the less effective method of repair, despite this method of repair is recommended by manufacturers of adhesive composite [10]. In the mentioned method, the repaired pipe was damaged again by

cracking of adhesive layer at the pressure of 3 MPa. It seems to be that using a glass cloth in this case, should improve the efficiency of repair. This fact is confirmed by results obtained for epoxy adhesive Epidian 57/Z1, which was reinforced with glass cloth (glass - epoxy composite) - maximum pressure for this method was 6 time higher.

Considering time of execution repair, the use of glass - epoxy composite seems to be very interesting method of removing damage. There was noticed during tests that renew damage of pipe was caused with fluid that penetrated consecutive layer of composite through aperture. It was assumed that blocking this aperture should increase efficiency of repair by increasing pressure, which lead to leak. Therefore, the tests were conducted whether adding corundum (grain F 500) to epoxy adhesive Epidian 57/Z1 will improve the efficiency of repair (the epoxy adhesive was modified by adding fillers in the mass ratio 1:1). The tests were carried out for 3 specimens and results (average value of pressure destroying repaired pipe) were compared to other methods of repair – Tab. 2. The proposed method improved significantly the efficiency of repair as the maximum pressure value has doubled.

Tab. 2. The repairs conducted with epoxy adhesive Epidian 57/Z1

Method of repair		Max pressure [MPa]	Method of repair		Max pressure [MPa]
	Undamaged pipe	65		Epoxy adhesive Epidian 57 + glass cloth + corundum filler	37.5
	Epoxy adhesive Epidian 57 + glass cloth	18		Epoxy adhesive Epidain 57 + strap 90%	45

The possibilities of conducting repair were asset considering the situation that a whole section of pipe was damaged (broken). This type of damage can be caused by fatigue bending of pipe, what often take place during current use of technical object or as a result of life fire. For this type of damage the repair was performed with using two sleeves: inner (with a length of 30 mm, external diameter of 14 mm and wall thickness of 0,35 mm) and the outer sleeves (with a length of 60 mm, external diameter of 22 mm and wall thickness of 1,85 mm). Both sleeves were made with aluminum alloy PA2. To providing bond adhesive composite Belzona 1111 was used. The method of repair is presented on the Figure 8. The inner sleeve was used to prevent the escape of adhesive composite to the inside of a repaired pipe, while thin wall of this sleeve (0.35 mm) did not result in a significant reduction in cross section area. The leak of fluid was noticed at a pressure of 37 MPa and total damage of joint took place at a pressure of 62 MPa.

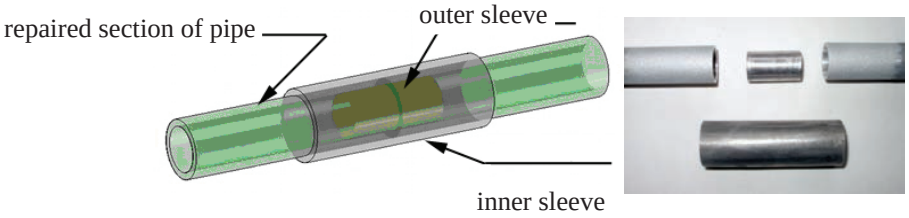


Fig. 8. Method of bonding two sections of pipe and components ready for repair

Similar results were obtained during experimental tests conducted for hydro-pneumatic pipes, which had the same dimensions [11]. During the mentioned tests, the values of pressure were determined using the research station (Fig. 4). Three methods of broken pipe repair were considered:

1. Bonding two section of pipe with adhesive composite Belzona 111 and applying the coat of adhesive composite Belzona 1111 strengthen with 4 layers of manufacturer's elastic fabric. The reinforced layer (composite adhesive and elastic fabric) was 4 mm thick and 52 mm wide.

2.Bonding two section of pipe with adhesive composite Belzona 111 and bonding on the outside of pipe with 0.5 mm layer of adhesive composite Belzona 1111 strengthening strap. The strengthening strap took the form of pipe section cut along generating line, which was 2 mm thick, 52 mm length and peripheral length equal to 100% of the repaired pipe perimeter).

3.Bonding two section of pipe with adhesive composite Belzona 111 and bonding on the outside of pipe with 0.5 mm layer of adhesive composite Belzona 1111 two strengthening straps. The strengthening straps took the form of pipe section cut along generating line, which were 2 mm thick, 52 mm length and peripheral length equal to 50% of the repaired pipe perimeter).

The mentioned methods of repair enabled to obtain following values of pressure in repaired pipe: 7.4 MPa for first method, 30 MPa for second repair and 22 MPa for third method.

4.Conclusions

The considered methods of repair damaged pipe with use of the epoxy adhesive seem to be effective and can be successfully applied to the repair of low and high pressure pipe (maximum pressure occurring in the hydro-pneumatic systems of military equipment do not exceed 30 MPa), which are partially damaged (scratches, cracks) or completely damaged (broken).

The main advantage of presented approach is short time of repair, the possibility of implementing an effective repair in field conditions and easy way of modelling the area of repair by using proper epoxy adhesive and layers number of glass cloth. The mentioned factors become significant during repairs of military equipment taking part in combat operations (particularly in areas remote from repair facilities and shops).

According to research it seems to be that the glass cloths of low weight (about 100 g/m^2) and densely woven should be used to forming composite materials for hydro-pneumatic pipes repair. Effective method of composite modification may be also adding ceramic fillers to its (for instance corundum), but micro grains of corundum should have size below 50 microns. Using to repair the manufacturer's composite adhesive without any strengthening (glass cloth or strap) should be limited to low pressure pipes (to 3 MPa).

The specific properties of epoxy adhesives must be considered before applying to repair, especially change of mechanical and utilitarian features at higher temperature (over 100^{o}C).

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