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Research Article

A Novel Method to Perform the Burst Pressure Test on the Repaired Drinking Water Pipelines

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ABSTRACT

This article investigates the repair process of damaged steel pipes of drinking water transmission lines by polyester resin or putty and a composite patch, as well as the internal pressure capacity of the repaired specimens during burst pressure tests carried out by the experimental method. The main aim is to introduce a completely practical method for repairing the pipelines in out-of-town areas without using electrical or other advanced equipment. In addition, an innovative novelty is employed in the burst pressure tests. Experiments demonstrate that the repaired pipes by the molded polyester putty and a composite patch of 100×100 mm^2 dimension with 3 or 5 layers can approximately sustain the maximum internal pressures up to 44 or 55 bar, respectively; while the repaired pipes by the molded polyester resin and the corresponding composite patch with 3 or 5 layers can withstand the maximum pressures up to 28 or 40 bar, respectively. Repairing the pipes by the presented methods helps achieve the main purpose of the present research, with an admissible safety factor.

1. Introduction

Engineers are faced with the ongoing task of rehabilitating pipelines due to damages caused by many environmental and load factors. In manufacturing and installation processes during loading, shipping, unloading, or storage, various defects may occur and cause damage to pipes. Additionally, various site conditions such as fluctuating groundwater and low soil resistivity accelerate the corrosion of pipes and create cracks in their wall [1].

Several methods have been introduced for repairing the cracked pipes. The first method is cutting out the damaged section of the pipe and adding an additional joint, which requires much time and labor. The second method is replacing the damaged pipe, which requires expensive materials. Moreover, there are some alternative methods to reduce or eliminate the use of labor, time, and materials, in order to quickly re-activate pipelines [2], such as using adhesives and galvanized steel patches or composite patches. Citil et al. [2] repaired cracked steel pipes by using an adhesive, and investigated mechanical behaviors of the repaired pipes [2].

Elchalakani et al. [3] performed some three-point bending and direct indentation experiments on two series

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of Carbon fiber-reinforced polymer (CFRP) of strengthened and rehabilitated pipes and investigated corrosion penetration in wall thickness, its extent along the pipe, and type and number of the CFRP sheets, as three main parameters. Goertzen and Kessler [4] evaluated the viscoelastic behavior of a carbon fiber/epoxy matrix composite material system used for pipeline repair through dynamic mechanical analysis. Duell et al. [5] developed an experimental method to stop external corrosion and structurally reinforce steel pipes by external wrapping of damaged sections using fiber reinforced polymer materials; while an axisymmetric or 6×6 in^2 patch defect with a depth of 50% wall thickness of the pipe was machined into the pipe wall.

Yu et al. [6] used natural fibers for trenchless rehabilitation of underground pipes and measured permeability and strength of natural fiber-reinforced composites. Mattos et al. [7] analyzed epoxy repair systems for metallic pipelines undergoing deformations with localized corrosion damage that impair serviceability. Lukacs et al. [8] investigated the role of external reinforcing (carbon fiber polymer matrix composite) on the structural integrity of transporting steel pipelines by performing fatigue and burst tests. Shouman and Taheri [9] investigated repaired pipelines and their applicability in reference to strain-based design; by producing a defect with a depth of 80% of pipe wall thickness. Lam et al. [10] numerically studied the reduction of stress intensity factor of cracked steel tubes repaired with fiber-reinforced polymer (FRP) patching.

Mattos et al. [11] carried out an analysis of special hydrostatic tests performed on metallic pipelines used to convey produced water in offshore oil and gas platforms. Their goal was to evaluate the strength of a pipeline with through-thickness corrosion damage (circular hole with 10 mm diameter) when repaired with special epoxy systems. Mally et al. [12] investigated the performance of a composite repair system that has been installed and cured while submerged. Full-scale testing on three pipe geometries (straight, elbow, and tee) with through-wall defects were performed to determine influences of water contact on repair efficacy [12].

Shamsuddoha et al. [13] provided a comprehensive review on the use of fiber-reinforced polymer composites for in-air, underground, and underwater pipeline repair. Saeed et al. [14] used a probabilistic method to investigate the reliability of steel pipelines rehabilitated with FRP wraps. Benziane et al. [15] numerically compared the performance of repaired longitudinal cracks in API X65 pipelines under two different conditions: with patches (single and double patches) and without patches. Kara et al. [16] applied low-velocity impacts of different energy levels on some pressurized fiber-reinforced composite tubes to damage them, and then the damaged areas of the affected tubes were repaired with a multi-layer laminate of glass/epoxy fabrics. Then, the repaired tubes failed catastrophically under monotonic internal burst tests [16].

Djukic et al. [17] presented two different composite clamp designs to repair fluid transportation pipelines, along with test results. Rohem et al. [18] manufactured two defect types (non-through wall and through wall) into pristine pipe specimens to evaluate the performance of the repaired pipe through hydrostatic tests. Das and Baishya [19] carried out a three-dimensional stress analysis along with fracture analysis of bonded socket joints with laminated FRP composite pipes. Woo et al. [20] investigated circumferentially cracked pipes repaired by boron-epoxy and graphite-epoxy patching under axial tension.

Fakoor et al. [21] modeled some 3D longitudinal and transverse semi-elliptical cracks without and with utilizing Graphite or Glass/Epoxy composite coatings in the internal and external lining. Elchalakani [22] experimented on a series of rehabilitated corroded steel circular tubes by Carbon FRP under 3-point bending and direct indentation. Witek [23] investigated a simple analytical method of burst pressure calculation for a straight gas transmission pipeline repaired with a composite sleeve. Recently, some researchers [24-29] have investigated the failure of metal pipes repaired by composite patches under internal pressure or fatigue

loading. Rafiee et al. [30] predicted load bearing capacity of composite tubes subjected to internal hydrostatic pressure using progressive damage modeling [30].

Reviewing the above-published works demonstrates that over long service periods, pipelines are subjected to deterioration and damage, which can reduce their strength and structural integrity. Repair mechanisms have been developed to restore the loading capacity of damaged pipelines. In this context, composite repair systems have become popular over the past few years [31]. In the present article, repairing the steel pipes of the drinking water transmission lines by a polyester resin or putty and a composite patch is carried out as a completely practical method for repairing the drinking water pipelines in out-of-town areas without using electrical or advanced equipment. Then, their capacity during the burst pressure tests is investigated by the experimental method. Finally, an innovative method for performing the burst pressure tests is introduced.

2. Experiments

Burst pressure test is performed to investigate the strength of pipes and vessels under internal pressure. To perform the test, firstly, the damaged area of the pipe is repaired and then, the repaired specimen is connected to a pre-designed hydraulic circuit. During the test, the pressure of the used fluid in the hydraulic circuit increases slowly. The gradual increment of internal pressure continues until the pipe breaks (bursts) from the repaired site or from other parts.

2.1. Preparing the specimens

From a branch of a commercial steel pipe with a nominal diameter of 2 in, 110 mm long pieces were cut by a rotary saw. Then, by the welding process, two 2-inch caps with 2 mm thickness were connected to the ends of the pipe; and a hole of 16 mm diameter was machined in the center of one of the caps. Following this, a ½ inch high-pressure female threaded coupling was welded to the perforated cap, coaxially. In the next step, a geometrical discontinuity (through-wall defects) was machined in the middle of the pipe length as the artificial defect. Fig. 1 illustrates the geometrical dimensions of the longitudinal defect. Defect dimensions of all the specimens are the same and equal to $L = 50\ mm$ and $W = 10\ mm$. Finally, the prepared specimens were repaired as the following. The general shape of the defect was selected based on the reported experiences in the previously published works [2, 18].

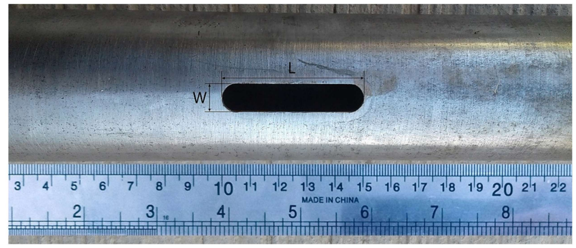

Fig. 1. A pipe with a geometrical discontinuity (through-wall defects) and the geometrical parameters of the defect.

2.2. Repair process

Four types of repair processes were used to prepare four types of the experimental specimens as the following:

1. Repaired pipes by polyester resin
2. Repaired pipes by polyester putty
3. Repaired pipes by polyester resin and composite patch
4. Repaired pipes by polyester putty and composite patch

In this article, an unsaturated polyester resin, based on Terephthalic Acid and standard Glycols, as a product of FARAPOL company with T505 trade code were used. To prepare the external surface of the tube and for better bonding between the composite patch and the tube surface, a sandpaper and a wire brush were used in the defect zone.

In the first type of repair, the defect was filled with polyester resin. For this purpose, a molded resin piece was produced, firstly. For this aim, a certain weight ratio of the unsaturated polyester resin, methyl ethyl ketone peroxide hardener, and cobalt octoate catalyst was mixed, based on the determined weight ratio by the manufacturer. The mixture of these three primary components was gently stirred to prevent air bubbles creation inside the resin. Some molds were produced by

machining a steel block, and the liquid resin was then poured into the molds, which were in the form of artificial defects of the pipe. The molded resin pieces were produced after curing the resin at room temperature. Next, according to Fig. 2, the molded resin was manually inserted into the specimen defect, and a similar liquid resin was used as adhesive to bond the lateral surfaces of the molded resin to the inner surfaces of the defect. After curing the adhesive, the repaired pipe by the polyester resin is prepared.

The preparation process of the second type of the specimens is similar to the corresponding process of the previous (the first type) specimen, except that in the second type sample, Talcum powder with a certain weight ratio is added to the mixture of polyester resin T505 to produce the molded putty. Later on, the molded putty was manually inserted into the specimen defect, and similar liquid putty was used as the adhesive to bond the molded resin to the inner surfaces of the defect. When the adhesive is cured, the repaired pipe by the polyester putty is prepared.

In the third type specimens, a molded polyester resin and a composite patch were used to repair the samples. In the specimens, firstly, the pipe defect was repaired by the molded polyester resin, similar to the preparation trend of the first type specimens. In the following, a composite patch was created on the external surface of the defected zone of the pipe. For this purpose, the square composite patches of woven E-glass fibers and polyester resin with two different dimensions of 150×150 mm^2 and 100×100 mm^2 were used to cover the external surface of the defected zone of the pipes by using the hand layup method. The composite patches of the different third type specimens were produced with several different layer numbers (1, 3, and 5 layer numbers) to investigate the influences of the number of layers on the burst pressure performance of the repaired pipes. Two types of glass fibers were used in the third type specimens, consisting of glass fiber chopped strand mat and woven glass fiber.

Fig. 2. Inserting a molded resin into the specimen defect, using the similar liquid resin as the adhesive.

In the fourth type specimens, a molded polyester putty and a composite patch were used to repair the samples. In these specimens, firstly, the pipe defect was repaired by the molded polyester putty, similar to the preparation trend of the second type specimens, and in the following, a composite patch was created on the external surface of the defected zone of the pipe. For this purpose, the square composite patches of woven E-glass fibers and polyester resin with 100×100 mm^2 dimension and with 1, 3, and 5 layer numbers were used to cover the defected zone of the pipes by the hand layup method. In the fourth type specimens, glass fiber chopped strand mat and polyester resin were used to produce the composite patch.

In total, 17 different specimens were produced, and in order to investigate the repeatability of the burst pressure test, two similar specimens of each condition were prepared. Therefore, 34 experimental specimens were produced and tested generally. Table 1 reports the characteristics of the specimens. In the table, the sample codes consist of two numerical and alphabetical parts. In the alphabetical part, BPT refers to the burst pressure test, and the letters R, P, and C indicate repaired pipe by resin, putty, and composite patch, respectively.

2.3. Test procedure

The prepared specimens were connected to a hydraulic circuit, including a ball valve, an analog pressure gauge, and an adjustable pressure relief valve which are connected in series. In most parts of Iran, the maximum pressure of the drinking water network is about 5 bar. Therefore, by considering the safety factor of 4, the allowable pressure of 20 bar is desirable for the

Table 1. Characteristics of the experimental specimens of the burst pressure test

Specimen code	Initial pressure (bar)	Repair type					
		Molded resin/putty		Composite patch			
		Resin	Putty	Number of layers	Number of chopped layers	Number of woven layers	Patch dimensions (mm×mm)
BPTR-01	4	✓	–	–	–	–	–
BPTR-02	4	✓	–	–	–	–	–
BPTC-03	10	✓	–	1	1	0	100×100
BPTC-04	10	✓	–	1	1	0	100×100
BPTC-05	10	✓	–	3	3	0	100×100
BPTC-06	10	✓	–	3	3	0	100×100
BPTC-07	10	✓	–	3	2	1	100×100
BPTC-08	10	✓	–	3	2	1	100×100
BPTC-09	10	✓	–	5	5	0	100×100
BPTC-10	10	✓	–	5	5	0	100×100
BPTC-11	10	✓	–	5	4	1	100×100
BPTC-12	10	✓	–	5	4	1	100×100
BPTC-13	10	✓	–	5	3	2	100×100
BPTC-14	10	✓	–	5	3	2	100×100
BPTC-15	10	✓	–	1	1	0	150×150
BPTC-16	10	✓	–	1	1	0	150×150
BPTC-17	10	✓	–	3	3	0	150×150
BPTC-18	10	✓	–	3	3	0	150×150
BPTC-19	10	✓	–	3	2	1	150×150
BPTC-20	10	✓	–	3	2	1	150×150
BPTC-21	10	✓	–	5	5	0	150×150
BPTC-22	10	✓	–	5	5	0	150×150
BPTC-23	10	✓	–	5	4	1	150×150
BPTC-24	10	✓	–	5	4	1	150×150
BPTC-25	10	✓	–	5	3	2	150×150
BPTC-26	10	✓	–	5	3	2	150×150
BPTP-27	4	–	✓	–	–	–	–
BPTP-28	4	–	✓	–	–	–	–
BPTC-29	10	–	✓	1	1	0	100×100
BPTC-30	10	–	✓	1	1	0	100×100
BPTC-31	10	–	✓	3	3	0	100×100
BPTC-32	10	–	✓	3	3	0	100×100
BPTC-33	10	–	✓	5	5	0	100×100
BPTC-34	10	–	✓	5	5	0	100×100

repaired pipes of the present research. However, in the tests, the pressure relief valve was adjusted to 60 bar. Consequently, during the burst pressure test, if the internal pressure of the pipe reaches 60 bar, the pressure relief valve will operate to prevent excessive pressure in the system. The analog pressure gauge was used to measure the internal pressure of the specimens during the tests. A hydraulic pump with manual excitation was installed before the inlet ball valve to complete the hydraulic circuit and provide the required initial pressure of the hydraulic circuit in various tests. At the next side of the hydraulic circuit, a high-pressure hose was installed to connect the prepared specimens to the hydraulic circuit. At the outlet of the hydraulic circuit,

another ball valve was installed to perform the bleeding process before each test. Fig. 3 illustrates a connected specimen to the hydraulic circuit.

As a primary stage of each test, the initial pressure of the connected specimens to the circuit reached 10 bar by the hydraulic pump with manual excitation. Then, the ball valve between the pump and the circuit was closed, and the pump was disconnected from the circuit and the specimen. In the following, the connected specimen to the circuit (without pump) was placed inside a universal testing machine, between a rigid flat plate and a rigid cylindrical punch, such that the cylindrical punch was far away from the repaired location of the pipe. Later on, the universal testing machine began and the rigid cylindrical punch moved with a constant displacement rate of 2 mm/min, so the punch applied the compressive force on the repaired pipe and due to lateral crushing and reduction of the internal volume of the pipe, the internal pressure of the pipe increased, gradually; without any plastic deformations in the repaired zone of the pipe. This test continued until the first leakage was observed at the repaired location of the pipe. A DMG universal testing machine, Model 7166, was used to perform the burst pressure test. Fig. 4 illustrates a specimen in the DMG universal testing machine during the burst pressure test. Fig. 5 shows some of the specimens after the test.

Fig. 3. A connected specimen to the hydraulic circuit.

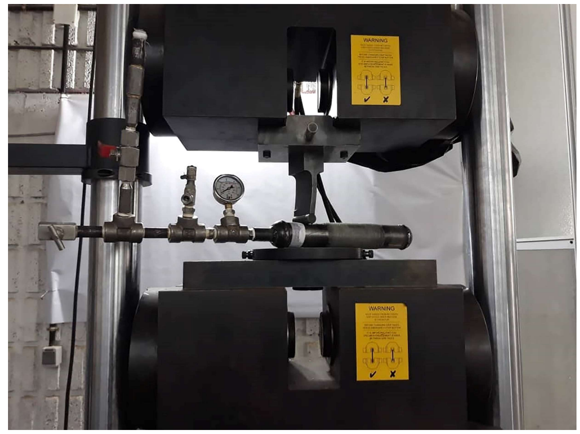

Fig. 4. A specimen in the DMG universal testing machine during the burst pressure test.

Fig. 5. Some of the specimens after the test.

The above-mentioned process introduces an alternative method for performing the burst pressure test on the repaired pipelines. In the mentioned process, the initial pressure (10 bar) was applied by a simple hydraulic pump with manual excitation to reduce the time of performing the burst pressure test in the universal testing machine (UTM). In other words, the mentioned burst pressure test can be carried out just by a universal testing machine without having to use the hydraulic pump and initial pressure. Furthermore, in this case, the burst pressure test takes time 2-3 more minutes. UTM is one of the common and most usual testing machines in most research laboratories, and the above-mentioned process introduces a new trend to perform the burst pressure test in the research laboratories without preparing the extra instruments.

The minimum required space between the rigid

cylindrical punch and the tube repaired zone was obtained experimentally. For this purpose, firstly, some similar specimens were prepared and tested with various spaces between the punch and tube repaired zone to determine the minimum required space without any effect on the test results. In the following, the mentioned space was used in the designed experiments, and it is justified based on the Saint-Venant principle.

3. Results and Discussion

Two similar specimens BPTR-01 and BPTR-02, were repaired with the molded polyester resin. In addition, two similar specimens BPTP-27 and BPTP-28, were repaired using the molded polyester putty. Fig. 6 shows their maximum pressure during the burst pressure test. The figure demonstrates that in two similar samples repaired by molded resin, the maximum pressures are 6 and 8 bar, and in two similar samples repaired by molded putty, their maximum pressures were equal to 5 and 9 bar. As mentioned before, the allowable internal pressure of the drinking water pipes is equal to 20 bar; therefore, repairing the damaged pipes just by the molded polyester resin or putty is not a suitable method for the drinking water applications.

Fig. 7 shows the maximum pressure of the 2-inch steel specimens repaired by the molded resin and composite patch with dimensions of 100×100 mm^2. The reported results in the figure demonstrate that repairing the steel pipes using a single layer chopped strand mat can sustain the internal pressures up to 19.5 bar, and if the number of layers of the glass fiber chopped strand mat

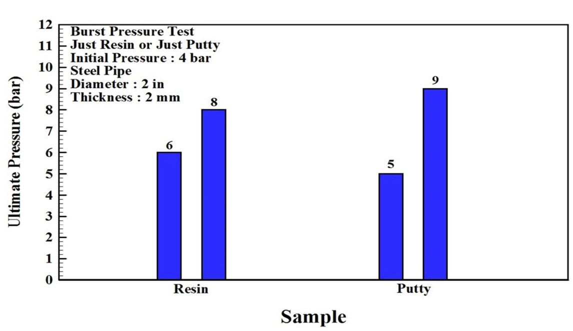

Fig. 6. Rupture pressure of the repaired specimens by the molded polyester resin or putty.

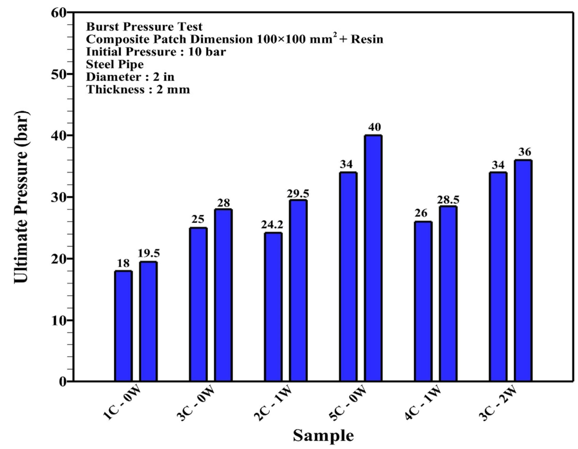

Fig. 7. Rupture pressure of the repaired specimens by the molded resin and a composite patch with dimensions of 100×100 mm^2.

is selected up to 3 or 5, the repaired pipes can sustain the internal pressures up to 28 and 40 bar, respectively. On the other hand, in the studied domain, by increasing the number of chopped strand mats, the maximum sustainable pressure by the repaired pipes increases, as well. Additionally, a comparison between the experimental results of the repaired specimens by 3-layers laminate with two different configurations of 3 chopped layers- zero woven layer, and 2 chopped layers-1 woven layer illustrates that replacing a layer of chopped fibers with a layer of woven fibers, does not change the internal pressure capacity of the pipes, considerably. Therefore, due to the economic considerations, using chopped fibers is recommended for the mentioned application. In the repair process by the molded polyester resin and 5-layers laminates, the rupture (maximum) pressure of the repaired specimens by 5-layers of chopped fibers is in the range of 34-40 bar, the rupture pressure of the repaired specimens with 4 chopped layers- 1 woven layer is in the range of 26-28.5 bar and the rupture pressure of the repaired pipes by 3 chopped layers- 2 woven layers were determined in the range of 34-36 bars. Hence, similar to the 3-layers laminates, in the repair process of the drinking water pipes by the 5-layers composite laminates, using the chopped fibers rather than the woven fibers are recommended. In sum, in the repair process of the steel pipes with the 100×100 mm^2 composite patch, the

repaired tubes can withstand the internal pressures between 18 and 40 bar, depending on the layer number of the composite patch, its configuration, and the skill of the trained worker. Therefore, in the damaged pipes, to achieve the internal pressure capacity of 20 bar and more, it is recommended to repair the pipes by a 100×100 mm^2 composite patch with 3 or 5 layers of chopped strand mat.

Fig. 8 illustrates the maximum pressure of the repaired steel specimens by the molded resin and composite patch with the dimensions of 150×150 mm^2. The results show that the pipes repaired with a single-layer of the chopped fibers can withstand the internal pressure up to 14 bar, and by increasing the layer numbers of the chopped fibers to 3 or 5, the maximum internal pressure of the repaired specimens reaches higher than 20 bar, which is desirable for this application. Moreover, a comparison of the results of the performed tests on two types of repaired samples with 3-layers laminate shows that the maximum internal pressures of two specimens with 3 chopped layers- zero woven fiber, and 2 chopped layers- 1 woven fiber are, approximately, the same. Hence, similar to the previous discussion and based on the economic considerations, using the chopped fibers is recommended. In addition, in different repair types with 5-layer laminate, including 5 chopped layers- zero woven layer, 4 chopped layers- 1 woven layer, and 3 chopped layers- 2 woven layers, the rupture pressures were measured in the range of 22-51 bar. Therefore, repairing the 2-inch steel pipes by the composite patch of 150×150 mm^2 dimension is a suitable method to achieve sustainable pressure capacities of higher than 20 bar, depending on the layer number of the composite patch and skill of the person who performs the hand layup repair process.

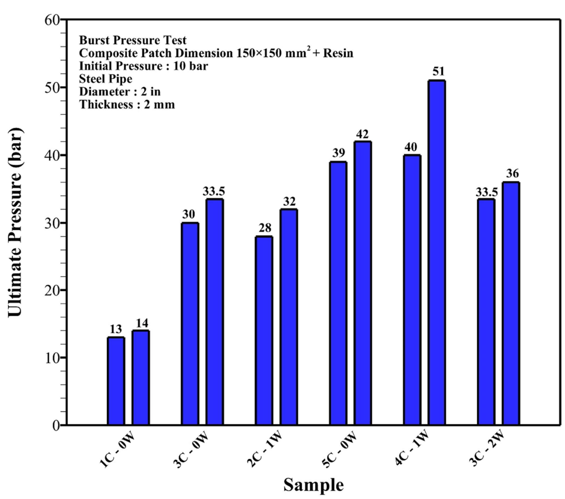

Fig. 8. Rupture pressure of the repaired specimens by the molded resin and a composite patch with dimensions of 150×150 mm^2.

However, comparing the reported results in Fig. 7 and Fig. 8 demonstrates that in some cases, the increment of layer numbers or composite patch dimensions does not enhance the maximum internal pressure of the repaired pipes. It may be due to a longer required time for performing the hand layup process of a larger composite patch on the pipe wall; and so, sooner curing the resin during the mentioned time and consequently, reduction of the quality of the produced composite patch, which may be eliminated by increasing the number of workers who perform the hand layup repair process. It is important to note that according to the instructions of the employer of this research project, the purpose of this study is to provide a completely practical method for repairing the drinking water transmission lines in out-of-town areas without using electrical or advanced equipment; therefore, in the repair process of the laboratory specimens, the mentioned trend was considered.

Fig. 9 shows the maximum internal pressure of 2-inch steel specimens, repaired by the molded putty and a composite patch of 100×100 mm^2 dimension. In the preparation process of the polyester putty, resin and talcum powder were used, based on a certain weight ratio of 70-30. The specimens of this group were prepared in 3 different types, including 1, 3, and 5 chopped layers and without any woven layers. The reported results in the recent figure show that the repaired steel pipes by the molded putty and a composite patch of a single chopped layer can sustain the internal pressures up to 16 bar, and when the layer number of the composite patch is selected equal to 3 or 5, the repaired pipes withstand the internal pressure of up to 44 and 56 bar, respectively.

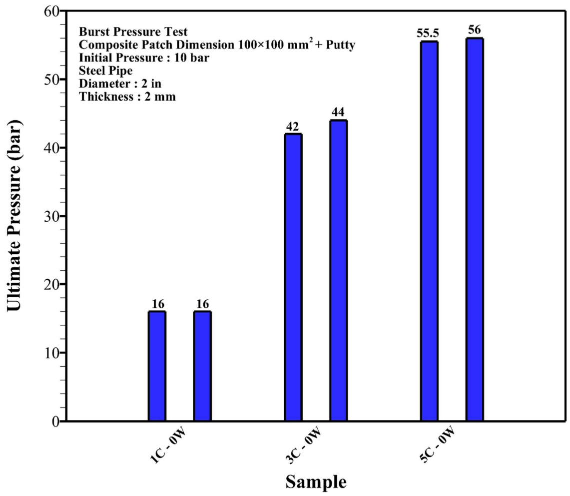

Fig. 9. Rupture pressure of the repaired specimens by the molded putty and a composite patch with dimensions of 100×100 mm^2.

In Fig. 9 and Fig. 7, the comparison of the corresponding results with the same layer numbers and layer configurations of the composite patch and with the different molded parts of putty and resin demonstrates that in most configurations, the rupture pressure of the repaired specimens by using the putty is higher than the corresponding repaired specimen by using the molded resin. As numeric investigations indicate, the results demonstrate that in the repaired specimens by the composite patch of 3 chopped layers- zero woven layer, the maximum rupture pressure of the repaired specimen containing the molded putty is 57% higher than the maximum rupture pressure of the corresponding specimen containing the molded resin. In the repaired specimens by the composite patch of 5 chopped layers- zero woven layer, the maximum rupture pressure of the repaired specimen containing the molded putty is 1.4 times the corresponding value of the corresponding specimen containing the molded resin.

In addition, obtaining almost similar values for the rupture pressure of each pair of the completely similar specimens repaired by the molded putty and the composite patch demonstrates the high accuracy of the performed repair process by the molded putty and the advantage of using the molded putty, in comparison with the molded resin, based on the high quality of the repair process of the similar pipes.

Previously, some Brazilian researchers, Rohem et al. [18], investigated the effectiveness of a polymeric matrix/glass fibers composite laminate in repairing some API-5L X56 steel pipes; and for this purpose, firstly, mechanical and thermal properties of the developed composite laminate were determined; and then, two defect types (non-through wall and through-wall) were manufactured into the pristine pipe specimen to evaluate the performance of the repaired pipe through hydrostatic tests. They [18] drilled a through-wall defect in the form of a circular hole through the wall thickness of the pipes with various hole diameters of 10, 15, and 20 mm (defect B); and then tested the prepared specimens by increasing the internal pressure, at a certain temperature. They measured the maximum internal pressures of the defected steel tubes with through-wall circular holes of 10, 15, and 25 mm diameters that were repaired by a composite laminate, experimentally; until the occurrence of delamination between the composite laminate layers and the substrate [18]. The reported results in reference [18] demonstrate that the maximum internal pressure of the repaired steel tubes with through-wall hole defect of 25 mm diameter is near 52 bar, while in the present research work, the repaired steel tubes with the illustrated through-wall defect in Fig. 1 can sustain the maximum internal pressure of up to 55 bar, approximately. Due to some differences between the performed test conditions in reference [18] and the present article, it is concluded that the obtained results in the present work are acceptable and applicable in repairing the Iranian drinking water pipelines.

4. Conclusion

In the present research work, repairing the steel pipes of the drinking water transmission lines by the polyester resin and putty and also, a composite patch is investigated, experimentally, to achieve a completely practical method for repairing the drinking water transmission pipelines in out-of-town areas without using electrical or advanced equipment.

The measured results of the performed tests demonstrate that:

- Repairing the pipes with the molded polyester resin or putty and without any composite patch can only sustain the maximum internal pressures in the range of 5-9 bar and is not able to achieve the desirable goal of at least 20 bar.
- Repairing the pipes with the molded polyester resin and a composite patch of 100×100 mm^2 dimension can approximately withstand the maximum internal pressures up to 30 bar when a 3-layers laminate is used; and can sustain the maximum internal pressures up to 40 bar, when a 5-layers laminate is produced. The mentioned repair conditions satisfy the main goal of the present research work, with an acceptable safety factor.
- Repairing the pipes with the molded polyester putty and a composite patch of 100×100 mm^2 dimension can approximately sustain the maximum internal pressures up to 44 bar when a 3-layers laminate is used; and can sustain the maximum internal pressures up to 55 bar, when a 5-layers laminate is produced. Repairing the pipes by the mentioned conditions helps achieve the main purpose of the present research, with a high safety factor.
- Experimental observations demonstrate that almost in all the cases, the failure mode of the repaired pipes is the separation between the composite patch and the external surface of the pipes; and no composite patch was broken or cracked. This means that by reinforcing the bond between the composite patch and the external surface of the pipe, higher rupture pressures may be achieved.
- In some cases, increment of the layer numbers may improve the quality of the bond.

Overall, the present research suggests the repair process of the drinking water transmission pipelines with the molded putty and a composite patch of 5 layers of the glass fiber chopped strand mat through the hand layup method.

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