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Original Paper

The anti – Temperature-vibration properties of viscoelastic anticorrosive tape

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ABSTRACT

Viscoelastic anticorrosive tape is extensively used for repairing anticorrosive layers on compressor outlet pipelines in the oil and gas industry. However, there is no relevant research on the coupling effect of temperature and vibration on the performance of viscoelastic anticorrosive tape. In this paper, acceleration tests of temperature and vibration coupling conditions were conducted to investigate the performance of viscoelastic anticorrosive tape. After temperature and vibration treatment, the specimens showed wide variance in thickness, and the adhesion and chemical soaking resistance of the tape was reduced. However, the viscoelastic anticorrosive tape still showed high adhesion. According to theoretical calculations, the tested viscoelastic body can repair pipes with a maximum diameter of 903 mm. Therefore, this viscoelastic anticorrosive tape is suitable for the compressor outlets of buried pipelines with diameters smaller than 903 mm. The research in this paper provides a method and basis for the selection of repairing materials for the anticorrosion coatings of compressor outlet pipelines.

1. Introduction

Currently, viscoelastic anticorrosive tape and polypropylene adhesive tape are extensively used to repair the anticorrosive layer of buried pipelines and other associated antiseptic equipment, such as flanges, valves, and pumps (Liang et al., 2018; Xu, 2021). Viscoelastic anticorrosive tape is a cold-wound adhesive tape that consists of a non-curing viscoelastic polymer composited on a polyethylene film (Zeng et al., 2020; Velsor et al., 2007). Due to its convenience, viscoelastic anticorrosive tape has been used in China since 2008 to repair or patch large defects during the external inspection of pipelines. The anticorrosive effect of viscoelastic anticorrosive tape depends on the adhesive performance of the viscoelastic body to the base material. Viscoelastic adhesive tape, which was specifically designed for buried pipeline applications, consists of a solidified viscoelastic polymer that has unique cold flow characteristics and exhibits self-repair functionality during the anticorrosion and repair process. The use of viscoelastic adhesive tape has many advantages. For instance, there is no need to use a primer layer, the tape does not easily peel off the base material, and it does not easily crack or harden. Moreover, viscoelastic adhesive tape exhibits strong adhesive force, good chemical resistance, no cathodic protection peeling phenomena, good moisture barrier properties, and antimicrobial corrosion properties. Thus, this tape demonstrates uniquely good long-term performance (Zhao, 2020; Sharma N and Sharma S 2020; Bedi et al., 2021).

The fabrication of viscoelastic adhesive tape is simple and convenient, and the requirements for surface treatment are not low. Manual derusting to grade ST2 meets the requirements for using viscoelastic adhesive tape. Viscoelastic adhesive tape is a modern anticorrosion and environmental protection material, and it is the ideal product for anticorrosion protection. Oil and gas pipeline anticorrosion layer repair, 3 PE anticorrosion layer damage repair, and the anticorrosion protection of flanges, valves, pumps, and other specialized equipment are some of the applications in which viscoelastic adhesive tape is widely used (Rogers et al., 2014; Melentiev et al., 2021; Maksaeva et al., 2019).

The fabrication of a viscoelastic adhesive tape anticorrosion layer is simple and mainly consists of four steps (Xu, 2021; Zhang et al., 2013). The first step involves cleaning the antiseptic areas

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of the equipment to be protected. The surface of the antiseptic parts of the equipment are heated to remove surface moisture, dirt is removed with a rag or a hair dryer, and oily residues are removed with solvent. The second step is surface derusting. Once the surface is dry and clean, it is derusted until a surface quality of ST2 is achieved. After rust removal, the dust on the surface is immediately removed (Suleiman et al., 2020; Zhao et al., 2019). The third step is the installation of viscoelastic adhesive tape. The viscoelastic adhesive tape is cut to an appropriate length based on the size and shape of the equipment, and then adhered to the clean equipment surface. Prior to adhesion of the tape, viscoelastic adhesive plaster can be used to fill the corners or holes of the equipment surface that are difficult to reach with the tape. After wrapping is completed, a roller wheel or other tools are used to fully bond the viscoelastic body to the surface of the equipment. The fourth step is the installation of cold tape. After the third step is completed, cold tape is wrapped around the surface of the viscoelastic adhesive tape. Finally, the cold tape is fully bonded to the surface of the adhesive tape by a roller wheel or other tools (Liu and Wang, 2014; Okafor et al., 2009; Riaz et al., 2014).

Pipeline compressor outlets exist in a state of high-frequency vibration, and the temperature of these pipelines can reach up to 70 °C (Montemor, 2014; Brylee and Rigoberto, 2015; Zvirko et al., 2021; Saliba et al., 2015). At present, there is no relevant research on the coupling effect of temperature and vibration on the performance of viscoelastic anticorrosive tape. Thus, an investigation of the service reliability of viscoelastic anticorrosive tape under practical conditions is urgently required.

Some test results (Fata and Possart, 2006; Li et al., 2015) show that the structure of viscoelastic anticorrosive tape has good bonding and covering performance as well as good aging resistance to drying, moisture, and heat. At present, various relevant standards exist for the inspection of viscoelastic anticorrosive tapes during construction. The most widely used standards are two Canadian standards (CSA-Z245.21 2002; CSA-Z245.20 2002). The corresponding Chinese industry standards are SY/T0414-2017 and SY/T0315-2013. However, no relevant research or standards have been reported on the damage mechanism of buried pipeline anticorrosion coatings under the coupling effect of temperature and vibration. A self-made accelerated erosion test device was developed (Zeng et al., 2020), and a prediction model for the viscoelastic anticorrosive coating of steel structures under sand flow was proposed. However, the research is not aimed at the service condition of station anticorrosion coatings.

In this paper, the service reliability of viscoelastic anticorrosive tape was tested under coupled temperature and vibration conditions. At the same time, according to the type of test stipulated in the standard (SY/T0414 2017; SY/T0315 2013), the performance of the anticorrosive products and processes used in the repair of a compressor's anticorrosion layer in a station yard was verified under the coupled temperature and vibration conditions. This research provides an experimental basis for the selection of an anticorrosive layer for compressor outlet pipelines.

2. Specimen

Viscoelastic anticorrosive tape and polypropylene adhesive tape are extensively used as an anticorrosive material for the repair of anticorrosive layers. The anticorrosive effect of viscoelastic anticorrosive tape depends on the adhesive performance of the tape to the base material. Viscoelastic tape produced by STOPAQ (the Netherlands) is an internationally recognized product of reliable quality that is widely used in oil and gas pipeline anticorrosion applications. Its product quality is universal and extensive (Liang et al., 2018). Therefore, this paper takes the viscoelastic tape produced by STOPAQ as the research object. The specimens were coated on prefabricated steel sheets using the same process and products (produced by STOPAQ, the Netherlands) as those of on-site locations to ensure that the experimental anticorrosion effect was completely consistent with real-world conditions (see Fig. 1).

3. Experimental process

3.1. Vibration spectrum test

3.1.1. The test pipeline

To simulate the vibration characteristics of the coating failure section of a pipeline, a vibration spectrum test was conducted in Kongquehe compressor station. The test pipeline section is shown in Fig. 2. The original anticorrosive layer of the test pipe was a fusion-bonded epoxy powder coating (FBE), and excavation detection was used to determine that a large area of local anticorrosive layer was detached from the pipe, leading to serious corrosion of the pipe wall. The pipeline operator intended to repair the damaged pipeline anticorrosion coating using a viscoelastic body. The purpose of this paper was to verify the bearing capacity of the viscoelastic anticorrosion coating with regard to the temperature and vibration conditions of the compressor outlet pipeline. The pipeline vibration spectra were thus measured during compressor commissioning.

3.1.2. Test equipment and process

The signal acquisition hardware was composed of a vibration sensor, a low pass filter, a data acquisition card, and a computer. The vibration acceleration sensor model number was M601A01. The 16-channel UA300 series data acquisition card was developed and produced by Beijing Youmining Company, and it had a maximum sampling frequency of 250 kHz. During the data collection process in this work, the sampling frequency was 8192 Hz and the sampling duration was 5 s.

During testing, sensors were installed on the pipeline through electromagnetic suction, and the spectrum test was carried out at the 3 points with the most significant anticorrosion coating damage, as shown in Fig. 3. Measurement point 1 was located at 12 o'clock, measurement point 2 was located at 9 o'clock, and measurement point 3 was located at 6 o'clock. After the compressor was started, the pipeline vibration test was performed and data were collected.

3.1.3. Pipeline vibration test results

The pipeline vibration spectrum test results for the three measurement points are shown in Fig. 4. The main frequency components in all three directions were 313.6 Hz, 1281 Hz, 1695 Hz, 2558 Hz, 3070 Hz, and 3842 Hz. Thus, it was preliminarily concluded that the main vibration frequency of the output pipeline during this trial operation included these frequency components. Among these frequency components, 1281 Hz, 2558 Hz, and 3842 Hz exhibited an obvious frequency doubling relationship. It was therefore inferred that these three frequency components were the vibrations caused by excitation of the compressor frequency. As shown in Fig. 4, the acceleration at the point with the highest amplitude was about 0.37 g and the frequency at this point was 1281 Hz. A greater frequency and amplitude mean greater structural vibration damage. Therefore, 1281 Hz and 0.37 g were selected as the rate and amplitude for the laboratory simulation test.

3.2. Acceleration test of coupled temperature and vibration action

We have experimentally studied the service performance of a 3 PE anticorrosive coating under the coupled conditions of

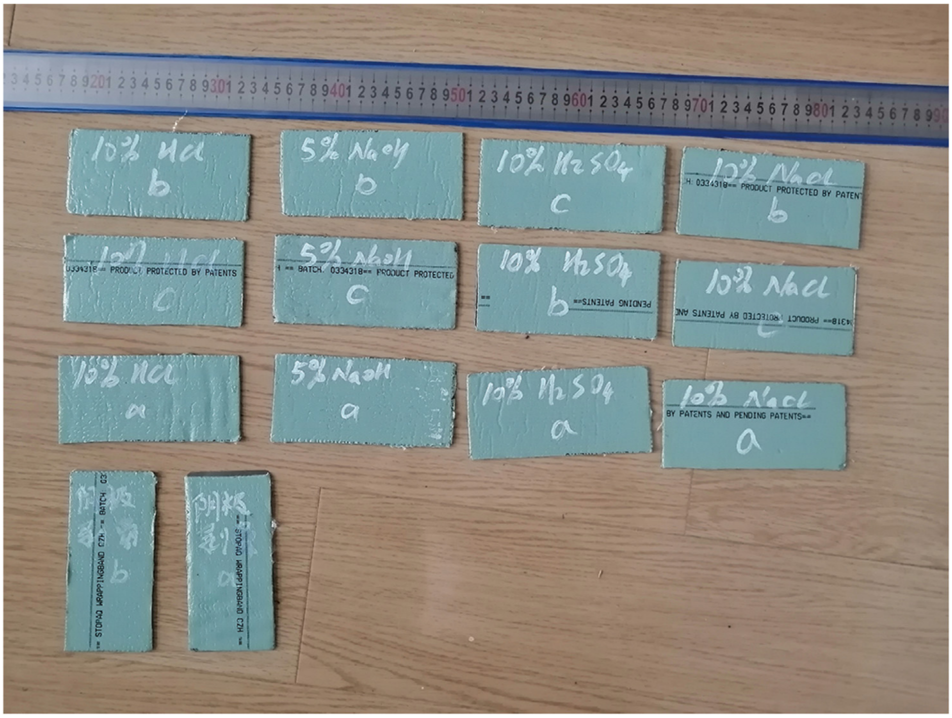

Fig. 1. Preparation of anticorrosive layer specimens.

Fig. 2. Field condition of tested pipe section.

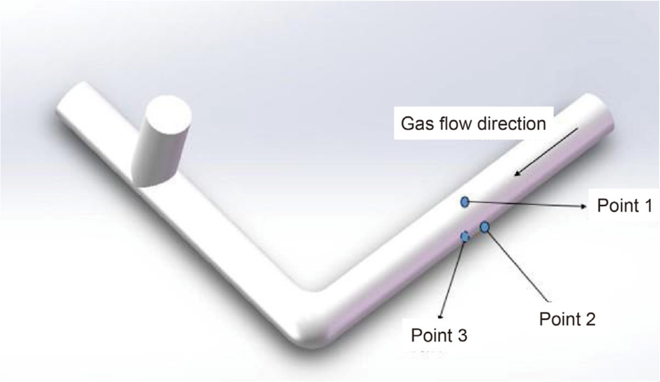

Fig. 3. Schematic diagram of sensors layout.

temperature and vibration at a compressor outlet by experimental means (Nie et al., 2021). We obtained relatively reliable research results from this study. Thus, this work adopted the same method to test the viscoelastic antiadhesive tape. In order to ensure that the anticorrosion coating specimens bore the specified vibration load at a constant test temperature, an accelerated temperature and vibration coupling test was conducted to simulate the operational condition of the anticorrosion layer at the compressor outlet in the Kongquehe compressor station. The temperature and vibration platform was independently developed by the project team, and this platform met the requirements of a 24-h uninterrupted coupled loading of temperature and vibration. The maximum heating temperature of this platform was 200 °C, and the vibration frequency range was 5–2700 Hz. A camera was used for real-time monitoring to ensure that the test was continuous and uninterrupted.

In this experiment, the vibration parameters were the main frequency (1218 Hz) and acceleration (0.37 g) obtained from the field tests, and the maximum temperature of the compressor outlet pipe was 70 °C (according to the compressor outlet pipeline temperature monitoring data of pipeline operators). To ensure consistency between the indoor simulation experiments and the field environment, the researchers extracted approximately 5 kg of soil from the Kongquehe compressor station to use in the indoor simulation experiments. The specimens were buried in a sealed container containing the soil and water from the site. The buried specimens were then treated with the coupled high temperature and vibration conditions for 30 days, as shown in Fig. 5.

After the temperature and vibration coupling test, the tested specimens were subjected to the tests specified in the relevant standards. A conventional untreated specimen was subjected to the same tests for comparison. The test results of the treated and

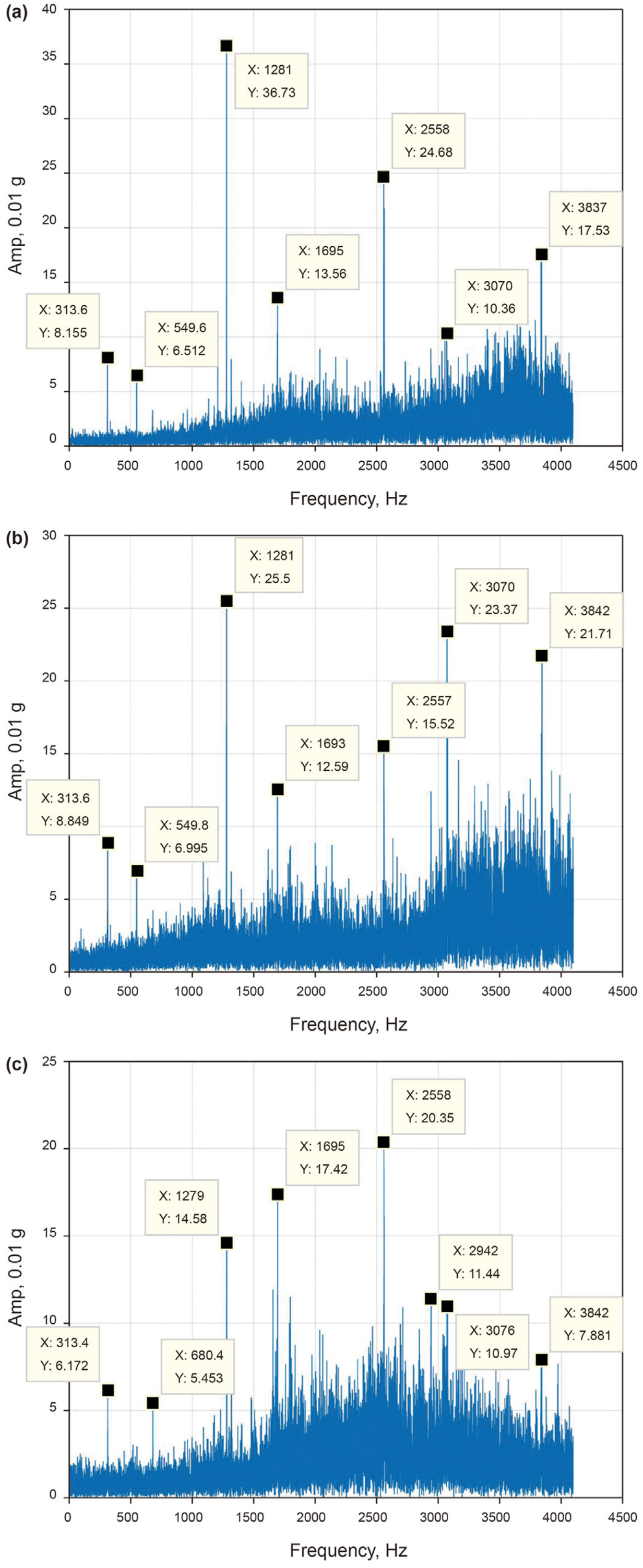

Fig. 4. Vibration measurement results during compressor commissioning: (**a**) measurement point 1, (**b**) measurement point 2, (**c**) measurement point 3.

conventional specimens were compared to determine the property degradation behavior of the viscoelastic anticorrosive tape under the coupled temperature and vibration conditions.

In accordance with the standard SY/T 5918-2017 “Specification for external coating and insulation rehabilitation of buried steel pipeline”, the thickness, chemical immersion resistance, and adhesion of the conventional and treated viscoelastic anticorrosive tape specimens were tested.

Three solutions were used for the chemical immersion: 5% NaOH, 10% HCl, and 10% NaCl. In each test, a specimen was soaked in chemical solution for 7 days. The surface of the anticorrosive layer of each specimen was observed to identify changes such as discoloration, bulking, softening, and debonding.

A qualitative test method was adopted to test the adhesive force of the specimens. After the reagent on the surface of the anticorrosive layer was removed, two intersecting straight lines were carved on the surface of the anticorrosive layer along the two diagonal directions of the specimen with a knife tip to form an X-shaped pattern. Each cut line was scratched through the coating. The knife tip was then inserted under the coating at one of the X-shaped pattern corners and lifted vertically upward until the anticorrosion coating at the X-shaped corner was pried away. Finally, the peeling state of the anticorrosive layer was observed and assessed.

4. Experimental results and discussion

4.1. Thickness measurement

The thickness measurement results of the conventional specimens and the specimens treated by temperature and vibration are shown in Table 1. After temperature and vibration treatment, the anticorrosion layer became thicker during water absorption, and the surface thickness also displayed a relatively wide range of values. However, the viscoelastic anticorrosive layer still exhibited complete coverage of the surface of the base metal, and no base metal was exposed. Thus, the viscoelastic body still demonstrated a good anticorrosion effect after coupled temperature and vibration treatment.

4.2. Chemical immersion resistance

The specimens were soaked in chemical solution for 7 days, and the chemical soaking resistance results are shown in Fig. 6 and Table 2. The chemical soaking resistance of the conventional specimen was relatively high, and its anticorrosive layer was almost entirely unchanged.

After the coupled action of temperature and vibration, the viscoelastic anticorrosive layer was discolored, bulging, softened, and significantly distorted. However, this anticorrosive layer was still closely attached to the surface of the base metal, and no bare matrix was visible. Therefore, after chemical soaking, the viscoelastic anticorrosive tape still retained good anticorrosion properties.

4.3. Adhesion

The adhesive force of the viscoelastic body was qualitatively tested, and the test results are shown in Fig. 7. The conventional viscoelastic anticorrosive tape layer was more viscoelastic and not easily stripped. The base metal of the conventional specimen was still covered by viscoelastic anticorrosive tape after being partially stripped.

In contrast, the treated specimen obtained by temperature-vibration action was easily stripped and the base metal was locally exposed in the test area. The base metal was then re-covered by the viscoelastic anticorrosive tape under springback action. Although the surface tension and adhesion of the viscoelastic

Fig. 5. Coupled temperature and vibration loading experiment process.

Table 1
Viscoelastic anticorrosive tape thickness test results.

Specimen	Thickness, μm					
	Conventional specimen			Specimen after temperature-vibration treatment		
	Point 1	Point 2	Point 3	Point 1	Point 2	Point 3
a	1867	1854	1849	2040	2170	2100
b	1857	1864	1868	2067	2105	2164
c	1852	1866	1859	2101	2180	2207
Average thickness	1859.56			2126.00		
Average variance	6.62			53.20		

anticorrosive tape decreased after the coupled effect of temperature and vibration, it still displayed better anticorrosion performance.

In conclusion, the anticorrosion properties of the viscoelastic anticorrosive tape were negatively impacted due to the lower thickness and reduced chemical soaking resistance after the coupled action of temperature and vibration. However, the tape still demonstrated a good anticorrosion effect, with a performance still suitable for the anticorrosion layer of compressor outlet pipelines.

4.4. Discussion of maximum pipe diameter suitable for viscoelastic body

The viscoelastic material has a certain fluidity, and the viscoelastic tape also has a certain thickness and weight. Numerous engineering cases exist in which adhesive tape produces a droplet phenomenon at the 6 o'clock position due to its own weight (Gilbert et al., 1991). Thus, investigating the critical conditions that result in this droplet phenomenon will have guiding significance for the practical engineering application of viscoelastic anticorrosive tape. The maximum pipe diameter suitable for the viscoelastic body tape was therefore determined by theoretical calculation.

The viscoelastic weight at the bottom of the pipe acts on the side of the outer pipe wall (at 3:00 and 9:00° 'clock) to generate shear force τ:

$$\tau = \frac{1}{4}\pi D g \rho \times 2h$$

The pipe diameter $D_{\max}$ is the maximum pipe diameter suitable for the viscoelastic body:

$$D_{\max} = \frac{4\tau_s}{2\pi g \rho h}$$

where D is the pipe diameter, $D_{\max}$ is the maximum pipe diameter applicable to the viscoelastic body, ρ is the density of the adhesive tape, h is the thickness of the adhesive tape, and τ_s is the shear strength of viscoelastic tape on steel. Thus, the maximum diameter is obtained when $\tau = \tau_s$.

According to the performance parameters of the viscoelastic body (Zeng et al., 2020), in this work, the maximum applicable pipe diameter of the viscoelastic anticorrosive tape is 903 mm. Therefore, this viscoelastic anticorrosive tape is not suitable for the anticorrosion layer of pipes with diameters larger than 903 mm.

5. Conclusion

In this study, the performance of specimens coated with viscoelastic anticorrosive tape was investigated. The specimens were treated with a self-developed coupled temperature and vibration process, and soil obtained near the buried pipeline of a compressor outlet was used to ensure that the indoor acceleration tests replicated the conditions of the real-world compressor outlet buried pipeline. A comparative analysis of various performance indices of the anticorrosive specimens was used to determine the following conclusions: The fluidity of the viscoelastic anticorrosive tape increases under the action of temperature and vibration, resulting in significant variance in surface thickness, reduced adhesion, and reduced chemical soaking resistance. However, the viscoelastic anticorrosive tape is still highly effective as an anticorrosion layer. Finally, theoretical calculations were used to determine that the maximum pipe diameter that can be repaired by this viscoelastic body is 903 mm. Therefore, the viscoelastic anticorrosive tape studied in this work is suitable for compressor outlet buried

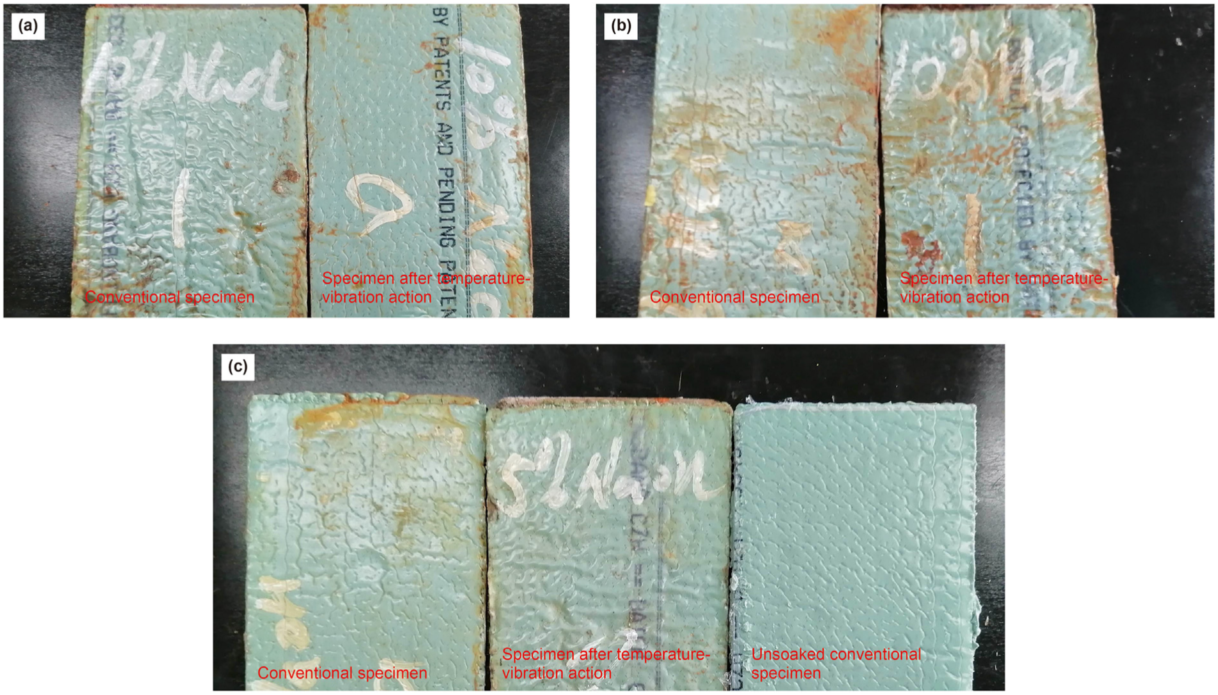

Fig. 6. Surface condition of specimens after soaking for 7 days in: (**a**) 10% NaCl, (**b**) 10% HCl, (**c**) 5% NaOH.

Table 2
Chemical soaking resistance experimental results.

Specimen	5% NaOH	10% HCl	10% NaCl
Treated specimen	Discoloration	Discoloration, softening, bulging	Discoloration
Conventional specimen	No change	No change	No change

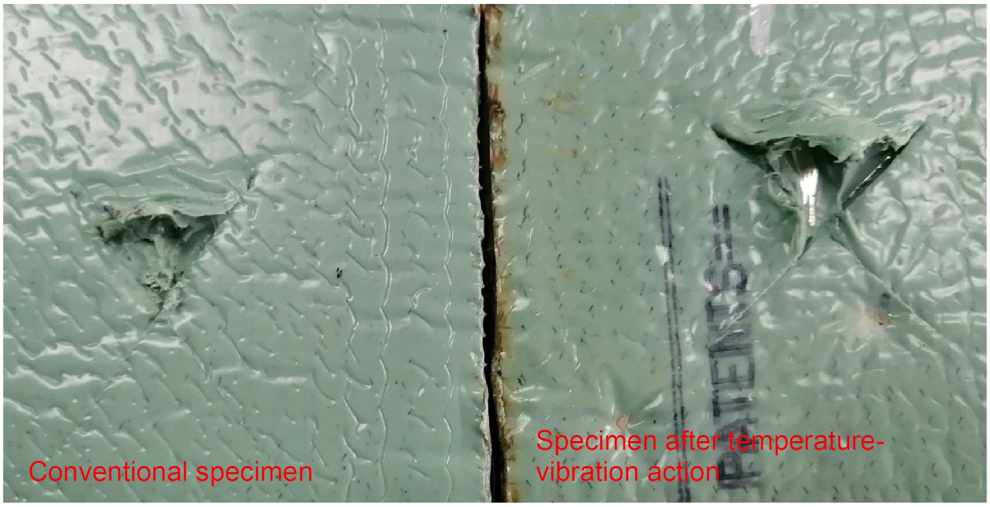

Fig. 7. The bonding strength of viscoelastic anticorrosive tape anticorrosion layer.

pipelines with diameters smaller than 903 mm. The research in this paper provides a method and basis for the selection of repairing materials for the anticorrosion coatings of compressor outlet pipelines.

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