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THE INFLUENCE OF TEMPERATURE ON PROPERTIES OF THE POLYMER FLEXIBLE JOINT USED FOR STRENGTHENING HISTORICAL MASONRIES

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ABSTRACT

A new method of repairing damaged structures by filling the cracks with a specially prepared elastomeric polymer mass has been recently proposed. This new and innovative technique, known as the Flexible Joint Method (FJM), is mainly dedicated to masonries and historical objects, where minimum intervention is permitted. The flexible joint bonds the disrupted elements and ensures further safe exploitation of a damaged structure. The aim of the present paper is to show the results of the experimental study focused on determining the properties of the polymer composite used for the injections. The polymeric specimens were subjected to static tension and compression tests. The DMA tests were performed to measure the glass transition temperature of an analyzed material and also to determine the elastic modulus (storage modulus), viscous modulus (loss modulus) and damping properties as a function of temperature.

Keywords: *Polymer flexible joint, Elastomeric polymer composite, DMA tests, Temperature effects*

1. INTRODUCTION

1.1. Repair of cracked masonries using stiff and flexible bonding materials

Repair of historical masonry structures using materials of high strength and stiffens as FRP laminates and epoxy bonding adhesives is very popular. Unfortunately, possible advantages of these materials are not utilized in full range because of low tensile and shear surface strength of adherents [1-3]. The main problem is the debonding effect, especially in cases of masonry walls subjected to cyclic or dynamic loads. Usually, laminates are fixed to the surface of the masonry walls by stiff epoxy glues or mortars, but in many cases, especially referring to buildings made with a weak lime mortars, this method is not so good and adequate [4]. Similar problems are observed if stiff and brittle grouts are used as injection [6]. It is highly preferred to select properly innovative materials to make them work together with the existing materials with better "compatibility" from the mechanical point of view. This is to reduce as much as possible high stress concentrations, which occurs using high strength/high stiffness modern bonding materials [4]. Introduction of flexible adhesives [5] and flexible bonding joints gives advantages in the case of historical masonry structures subjected to cyclic or dynamic (seismic) loads. Application of flexible materials, like modified polymers, reduces stress concentrations and introduces higher ductility and energy dissipation capacity [6, 7]. It is important especially in the case of heritage masonries.

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1.2. Durability aspect of the masonry strengthening using various bonding materials

Building materials are very often exposed to natural weathering (solar radiation, impact of oxygen, rain, hail, variable temperature etc.) or/and to some chemicals that reduce their strength properties [8]. Problem of weathering of structural materials has been investigated with reference to stone [9] and façade sealants [10]. Compatibility of component materials working in strengthening systems is especially important in the case of the changing temperature influence [11]. It is observed in regions where the masonry wall is exposed to the sun (the surface temperature can easily reach 70°C) and is rapidly cooled at night (even to 0°C). Such big temperature gradient influences the bond stress when bonding materials are of different thermal elongation coefficients.

2. TEMPERATURE ASPECT IN STRENGTHENING MASONRIES

2.1. Thermal elongation coefficient differences at the boundary of joined materials

Thermal research presented in [11] indicated that masonry porous units of low strength (appearing also in historical masonries) strengthened using CFRP strip bonded on stiff epoxy adhesive, are sensitive to cyclic thermal ageing (Fig. 1). The CFRP strengthening detachment occurred at the boundary of original brick material and stiff epoxy resin. This is because joined materials substantially differ in the thermal elongation coefficients (brick $\varepsilon^{th} = 0.5 \cdot 10^{-5}$ [1/°C] and epoxy resin $\varepsilon^{th} = 6 \div 21 \cdot 10^{-5}$ [1/°C]). The stiff epoxy adhesive (elastic modulus of about 3 000 MPa) generated to high shear stress in the brick during thermal expansion, which overcame the brick strength. Applying flexible polymer adhesive, of the thermal elongation coefficients similar to the epoxy resin epoxy resin (for e.g. polymer PM $\varepsilon^{th} = 15 \div 18 \cdot 10^{-5}$ [1/°C]) but of the lower elastic modulus (for e.g. the polymer PM [12] elastic modulus is of about 4 MPa), reduces the shear stress in the brick (own research – not published jet), protecting it against failure.

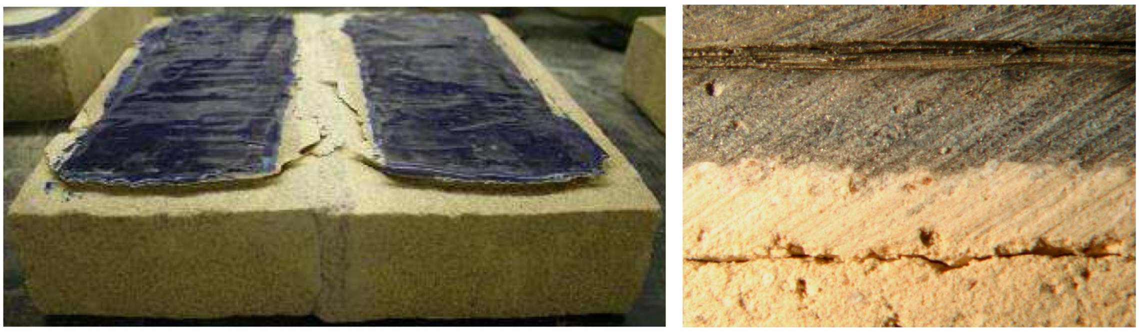

Fig. 1 Detachment of the CFRP strip after thermal cycling (left) and failure at the contact zone between the original brick and the brick saturated by stiff epoxy resin (right) – after [11]

2.2. Properties change with temperature of the polymer flexible adhesive

Effectiveness of polymer flexible joints in cases of static and dynamic loads was presented in publications, basing on laboratory and field tests [6, 7]. Polymer PM (assumed for application as an adhesive in strengthening of damaged masonry) is visco-elastic polyurethane mass of the non-linear characteristic. Such material has good anty-vibration properties [13] and is able to dissipate higher amount of deformation energy (ductile behaviour) than stiff epoxy resins, thus it is worth to use it in seismic areas. Anyway, visco-elastic materials are also sensitive to temperature changes, therefore determination of the stiffness and damping properties changing with temperature is necessary, especially if such material is applied in seismic areas where extreme temperatures can influence the work of strengthening systems significantly. The research described in this paper has been dedicated to finding of static and dynamic properties of the polymer PM at various temperatures, to check if this kind of material is stable and can be recommended for application in strengthening of historical masonries.

3. STATIC COMPRESSION TESTS

The basic mechanical properties of the elastomeric polymer used in the Flexible Joint Method were determined during static compression and tension tests. The compression experiment was performed using Zwick 1456 universal testing machine. For the purpose of the investigation, a number of cylindrical specimens (46 mm in diameter and 46mm high) were firstly prepared. The measurements were carried out at room temperature at three different strain rates (10^{-1}, 10^{0}, 10^{1} 1/min). Six cylindrical specimens (Fig. 2) were gradually loaded up to the ultimate force 20 kN at each strain rate. The experimental results (average curves from six specimens for each tested strain rate) presented in the form of stress-strain curves (Fig. 3) exhibit non-linear and visco-elastic behaviour of the analyzed material.

The tension experiment was also conducted using Zwick 1456 universal testing machine with a Long-Way-Extensometer (Fig. 2). For the purpose of the investigation, a number of dumbbell specimens (150 mm × 10 mm × 2.75 mm – according to ISO 527-1 [14]) were firstly prepared. The measurements were carried out at room temperature at five different strain rates (10^{-3}, 10^{-2}, 10^{-1}, 10^{0}, 10^{1} 1/min). Six elastomeric specimens were gradually loaded up to total failure at each strain rate. The results of the experiment presented in the form of average stress-strain curves (Fig. 3) exhibit also highly non-linear and visco-elastic behaviour of the analyzed material.

Fig. 2 Compressive (left) and tensile (right) setup with the tested specimens of the polymer PM

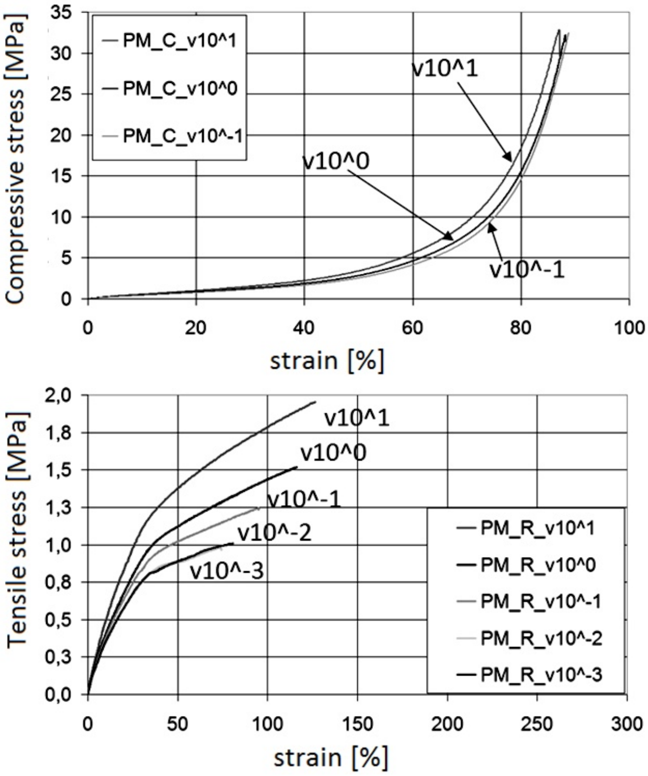

Fig. 3 Compressive (top) and tensile (bottom) stress-strain curves for different strain rates

4. DYNAMIC MECHANICAL ANALYSIS

The visco-elastic properties of the polymer PM indicate that this kind of material has damping properties and is able also to dissipate deformation energy by non-linear characteristic, withstanding locally large deformation caused by differences in thermal elongation coefficients of used materials. The polymer PM, as the material of elastomeric behaviour, works stable over the glass transition temperature in the environmental temperature range (from -25°C to 70°C). It is in opposite to epoxy resins which work under the glass transition temperature in the mentioned above environmental temperature range. There are reported problems of epoxy resin melting (instable work) close to the temperature of 60-70°C [15] influencing strength of adhesive joints. Many important characteristics of a material according to temperature and dynamic behaviour can be found using the Dynamic Mechanical Analysis (DMA).

The DMA tests were later on performed to measure the glass transition temperature of an analyzed polymer PM and also to determine as a function of temperature: the elastic modulus (storage modulus E' – stiffness of a visco-elastic material, proportional to the energy stored during a loading cycle), viscous modulus (loss modulus E'' – proportional to the energy dissipated during one loading cycle) and damping ratio (given by Tan Delta = tan(δ)) as $\xi = \tan(\delta)/2 = \tan(E''/E')/2$ [16]. The analysis was conducted according to EN ISO 6721 (2011) using the DMA Q800 analyzer of TA Instruments. For the purpose of the investigation a number of beam specimens (60 mm × 10 mm × 4 mm) were prepared. The specimens were fastened in a single-cantilever clamp (Fig. 4).

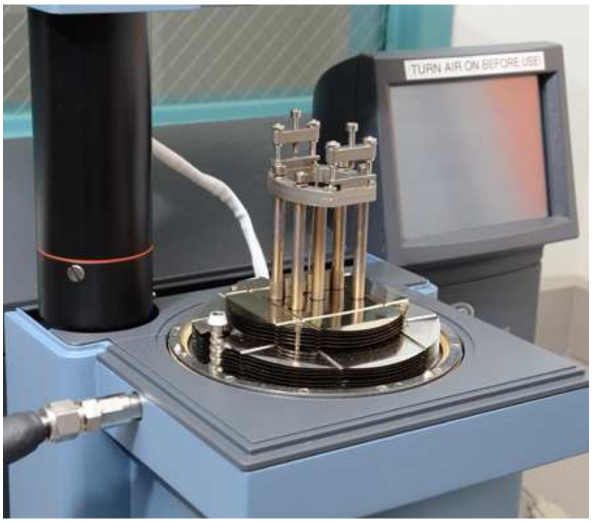

Fig. 4 Single cantilever clamp mounted on the DMA Q800 analyser

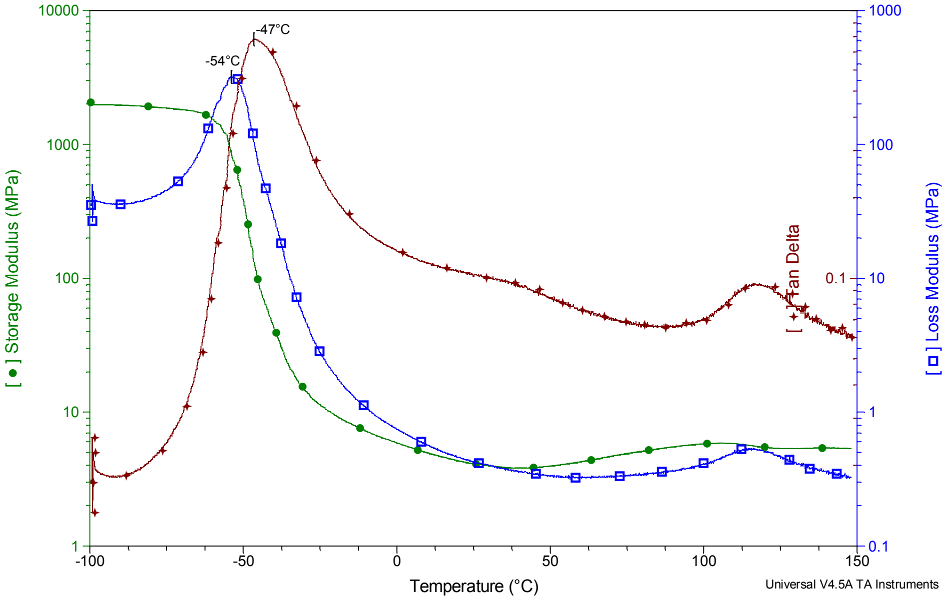

Fig. 5 DMA results at excitation frequency of 1Hz

The temperature range of the investigation was set to -100÷150°C and the corresponding heating rate to 3°C/min. Tests in the above-mentioned configuration were performed for two excitation frequencies (1Hz, 10Hz). The investigations were performed under constant excitation amplitude of 20 µm. Acquired characteristic material parameters have been applied for determination of the glass-transition temperatures (T_g based on the peak value of Tan Delta or loss modulus). Selected results of conducted DMA measurements are presented in Figure 5, 6 and 7.

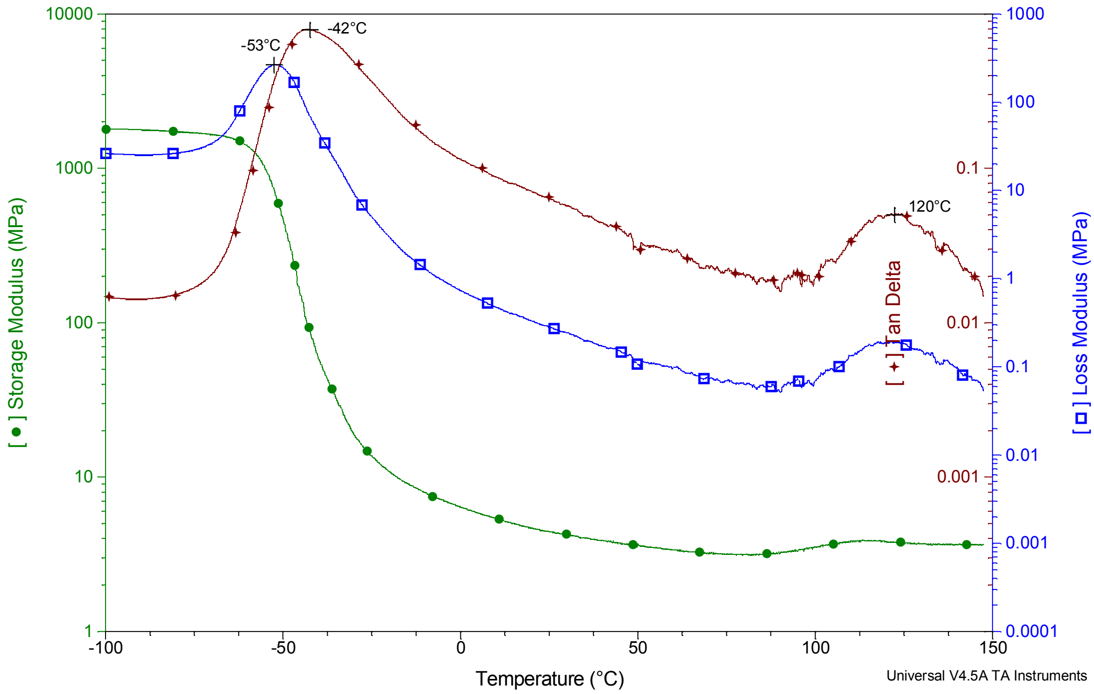

Fig. 6 DMA results at excitation frequency of 10Hz

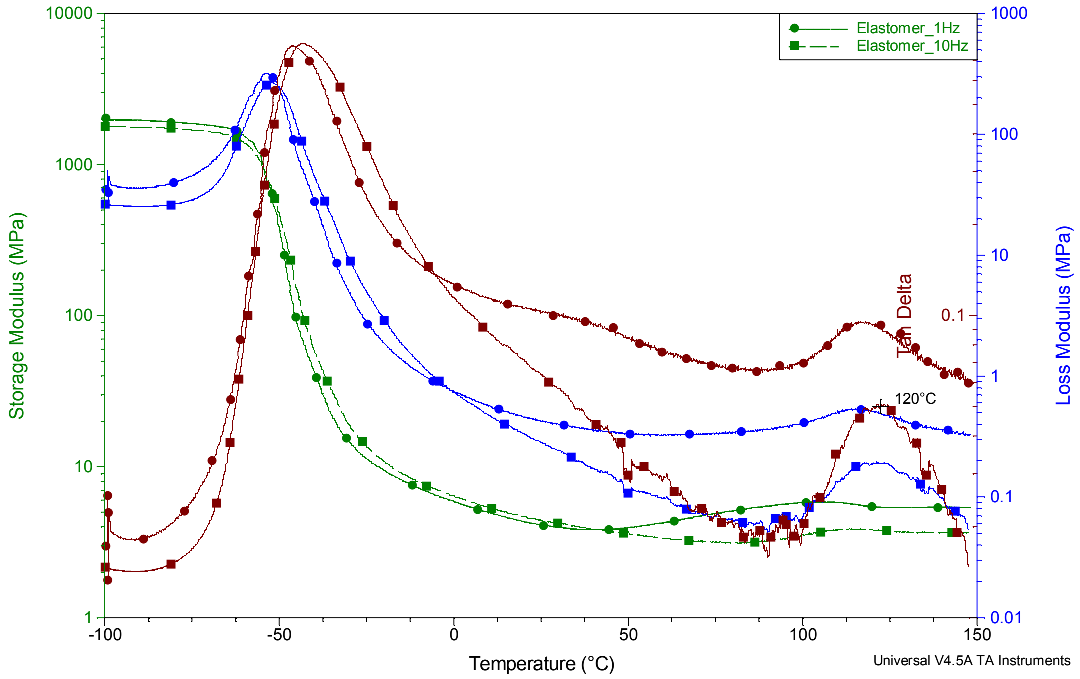

Fig. 7 Comparison of DMA results at two different excitation frequencies

As it can be seen in Fig. 5, with the increase in temperature, Tan Delta initially increases (the peak value is obtained for t = -47°C which is the glass-transition temperature of the polymer PM for the frequency of 1Hz) and then exhibits the decrease trend. Similar trends have also been observed for the loss modulus. On the other hand, the higher the temperature, the lower the observed value of storage modulus is. Similar behavior of the analyzed material was observed for the frequency of 10Hz (see

Fig. 6 and 7), but the damping ability decreases more quickly than in the case of the frequency of 1 Hz. Taking into consideration the possible exploitation range of temperatures (-20÷70°C), there is very low change of the storage modulus E' (from 10 MPa to 5 MPa) and it is independent of the frequency. Comparing damping properties in the same temperature range, the damping ratio ξ for the frequency 1 Hz and 10 Hz changes differently: from 0.14 to 0.04 and from 0.17 to 0.01, respectively. The same comparison for the room temperature of 23°C gives 0.06 and 0.04, respectively.

5. CONCLUSIONS

The experimental investigation on the polymer PM used in the Flexible Joint Method for the injections and flexible bonding of FRP composites has been presented in this paper. The results obtained from the described experiments (static tension and compression tests) exhibit highly non-linear behaviour of the analyzed material. On the other hand, relatively high values of Tan Delta obtained from the DMA tests, in the exploitation temperature range (-20÷70°C) and in the typical seismic frequency range (1÷10 Hz), confirms its potential to dissipate the energy during the vibrations induced by dynamic loads and to prevent against further structural damage. Moreover the storage modulus E' practically does not change in these ranges.

The results obtained from the preliminary investigation on the polymeric specimens are very promising. They indicates that applied polyurethane mass do not change significantly its mechanical properties in high temperatures and can be used for strengthening of masonries in seismic areas, where high exploitation temperature occurs. Nevertheless, further research is required in order to fully verify the properties of the polymer PM and other ones used in the Flexible Joint Method.

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