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Original article

Experimental modal analysis of brick masonry arches strengthened prepreg composites

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ABSTRACT

Polymer composites have been significantly used for strengthening of masonry structures in order to improve their structural behavior. In this study, the modal parameters and dynamic responses of the brick masonry arches, strengthened with prepreg polymer composites, have been experimentally assessed using experimental and numerical tests. The study was carried out in four major steps. Firstly, prepreg composites and traditional Horasan mortar were produced in the laboratory. In the second step, compression and tensile tests on the materials were conducted to determine the mechanical properties. In the third step, semicircular arches were built with masonry units and the prepreg composites were applied to four different strengthening configurations on the extrados and intrados surface of the arches. Finally, modal parameters of all arches were determined through experimental modal analysis method (EMA). After that, the results of the experimental analysis were compared with the numerical analysis. The results of the analyses show that the prepreg composites play an important role in the strengthening of the brick masonry arches and the prepreg composites enhance the frequencies and damping ratios of the brick masonry arches.

1. Research aims

The cultural heritage in the world and their preservation for the next generation is crucial. Many historical structures continue to offer services and historical values; and as such, it is important to understand their structural behavior and collapse mechanism when developing a plan for their preservation and retrofit. New restoration and retrofitting methods should be preferred where traditional methods are insufficient. New technologies that can be appealing to historical structures are emerging with current advancements in materials and construction techniques.

The main objectives of this research are:

- to show the importance of the prepreg composites and to prove a reliable approach for strengthening and retrofit of historical structures;
- to evaluate the effectiveness of the prepreg composites for brick masonry arches in terms of dynamic loads;
- to examine and prove the benefits of using the prepreg composites in strengthening brick masonry arches.

2. Introduction

The use of engineering materials has depended on their local availability, so far. However, the diversity of engineering materials has completely changed thanks to the innovations in material technology. Modern technologies have greatly improved the efficiency of materials and workmanship. Especially, polymeric materials have been of significant importance to the engineering community for many years, and they have been broadly used in many different areas.

Today, polymer materials are used as a strengthening material for existing and new structures because of their excellent engineering properties. They are significantly used for strengthening of masonry structures in order to increase their ultimate capacity. Many masonry structures have been built in earthquake prone zones and large portions of them are seismically unsafe. Thus, they have to be strengthened with convenient restoration materials. Over the years, engineers have strengthened masonry structures to withstand static and dynamic loads. In general, and to most extent, engineers have relied on several traditional strengthening materials that could be applied for masonry structures. However,

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traditional retrofitting materials have been inadequate to improve structural behavior and seismic resistance of these structures. Polymer technologies that can be appealing to masonry structures are emerging with current advancements in materials and construction techniques. In the last few decades, the polymer technology has been significantly expanded because of its proven effectiveness as an attractive solution for the structural and seismic retrofitting. For these reasons, applications of polymeric composites have increased gradually for masonry structures. One of the most important products of polymer technology is prepreg composite. Prepreg, which is known as preimpregnated reinforcement fabrics, is a product obtained with polymer technology in the past decade [1]. Prepreg composites have been used as an industrial material in different areas such as aerospace, automotive, and civil engineering.

In previous studies, many researchers focused on the dynamic parameters and behavior of masonry structures using modal analysis methods [2–7]. However, in almost all of the previous studies, operational modal analysis was carried out in order to determine the dynamic parameters [8–10]. In addition, several experimental studies were carried out in order to monitor the dynamic behavior of masonry structures [11–14]. Unlike operational modal analysis and monitoring technique, experimental modal analysis has been rarely performed on masonry structures [15,16]. Moreover, the dynamic parameters of composites strengthened masonry arches are not completely clarified and investigated. Therefore, this study mainly focuses on unidirectional prepreg composites and their effects on dynamic behavior of masonry brick arches.

3. Materials and methods

3.1. Preparation of prepreg composites

Prepreg composites are multi-component materials, such as matrix and filler materials, and they consist of a continuous sheet of oriented fibers, which have been completely impregnated with a polymer. In this study, the matrix material was preferred as a polymer matrix, and it was two-part epoxy system manufactured by Huntsman. This system consisted of Araldite® LY 1564 SP epoxy resin and Aradur® XB 3486 hardener, and they were weightily mixed in the ratio of 100:34, respectively. Furthermore, in the production of the prepreg material, carbon fibers were used as the filler materials. The carbon fibers were obtained from DowAksa Advanced Composites Holdings BV and 12 K A-42 code fibers were used in the production of the prepregs. The prepregs were manufactured by means of a specialized prepreg machine. In the production

Fig. 1. The production of the prepreg composite.

of the prepregs, in the first step, the carbon fibers were completely applied through the epoxy mixture. In the second step, the resinous fibers were wound onto the wax paper covered wheeler drum, and finally, the wound fiber sheet was properly cut and allowed to dry [15]. In this method, the carbon fibers were successively impregnated by polymer, and they were evenly spreading a metered volume of the resin and storage. After prepreg preparation, the laminate was treated by being heated at 80 °C for 30 minutes with a pressure of 0.5 MPa [17,18] (Fig. 1). All of the prepregs were produced at the laboratories of Department of Mechanical Engineering at Ege University, Izmir, Turkey.

3.2. Preparation of masonry arches

A series of semicircular arches, which have the same geometrical properties, were built from masonry hollow bricks. The arches were built on timber shutters, and they were removed two days after the construction of the arch. Traditional mortar mixture was preferred as a connection material between masonry bricks. For this purpose, traditional Horasan mortar, which was used in many historical structures in Anatolia [19,20], was chosen in this study. During preparation of the mortar, Alberia® bonding material (obtained from BASF Chemical Company), fine sand, lime paste, stone powder, and brick powder were mixed in equal ratios in weight.

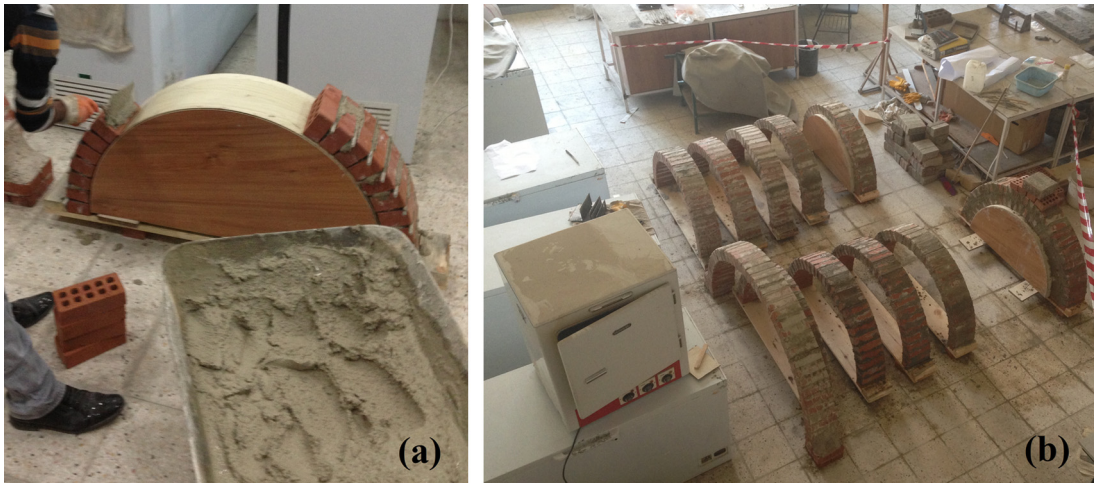

Fig. 2. a: the preparation of brick masonry arches; b: the stacking of masonry arches to take the cure.