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Compressive and lap shear tests on traditional putty and polymer sealants

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ABSTRACT

In the 19th century, iron-and-glass roofs were built using linseed oil based putty as sealant to fix the glass plates in the iron glazing bars. Since then, two evolutions influenced the construction details of roofs drastically. First, new sealants with better mechanical properties and higher durability displaced the use of traditional putty. Second, as the insights in the properties and behaviour of glass improved, glass plates can today play a structural role in the global stability of an iron-and-glass structure.

This article examines the mechanical properties of the traditional linseed oil based putty to assess the structural integrity of existing iron-and-glass roofs. Single-lap shear and compressive tests are carried out on a traditional linseed oil putty sealant. Next, to determine the impact of a renovation campaign, a modern MS polymer sealant with comparable viscosity and texture but higher durability, is subjected to single-lap shear experiments.

The experiments demonstrate that the linseed oil putty can have significant compressive stiffness. However, the shear strength is negligible. The modern polymer sealant has higher shear stiffness and strength as well as a cohesive failure in shear.

1. Introduction

When renovating 19th-century iron-and-glass roofs, the question rises how we can preserve this built heritage while fulfilling the modern standards on safety and structural integrity. The goal of a structural recalculation is to assess the safety level of the structure. At the same time, the heritage value of the roof and its components define the boundary conditions in which restoration proposals are presented. The structural role glass plays in modern constructions e.g. [1–3], poses the question how this could be applied in 19th-century iron-and-glass roofs. Incorporating the glass cladding into the structural model might limit new interventions necessary to fulfil the modern requirements for structural integrity.

If the glass plates and the iron frame must structurally work together, both parts have to be bonded in such a way that loads can be transferred. In 19th-century joints, the glass plates were mostly sealed to the iron T-shaped glazing bar (Fig. 1) by using linseed oil putty [4,5]. To evaluate the force transfer between iron and glass, the mechanical properties of the joining material must be known.

Modern adhesive technology is able to connect glass and metal structurally e.g. [6]. For application on 19th-century iron-and-glass roofs, we face the problem that the mechanical properties of the 19th-century linseed oil based putty are not known. Traditional materials however can have considerable value e.g. [7,8]. Consequently, this paper will go into the experimental work that is carried out to determine the mechanical properties of linseed oil putty and to compare properties with a modern replacement sealant. These experiments will lead to a first insight in the mechanical possibilities of traditional putty materials to determine whether or not further experimental work would be useful.

2. Materials and experiment design

Taking into account the common joints used in current adhesive bonding, the structural behaviour of a typical 19th-century iron-glass connection (Fig. 1) can be categorised as a butt strap joint (Fig. 2): a combination of a single-lap shear joint (working in

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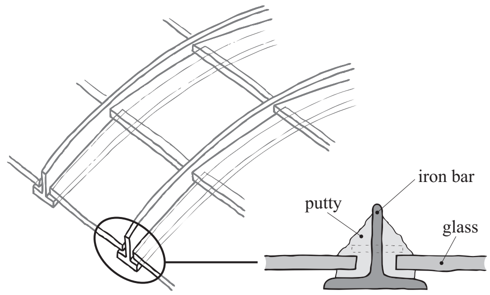

Fig. 1. Section of a typical 19th-century construction detail: the single glass plate is connected to the iron section with putty.

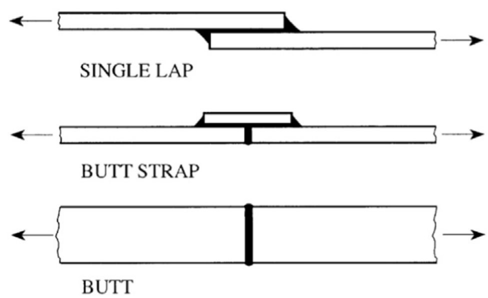

Fig. 2. : Common engineering adhesive joints [10].

shear) and a butt joint (working in tension or compression). When the glass is loaded in-plane, the single-lap shear part is located at the flange of the T-section and the butt joint at the web.

When a tensile force is applied parallel to the glass surface, the butt joint is loaded in tension. For this load situation, Adams [9] indicates that the lap shear part will resist the majority of the forces. Thus, to gather information about the structural behaviour of the connection, a single-lap shear test can be performed on the sealant.

However, when a compressive force is applied parallel to the glass plate, the contribution of the butt joint could be important if the ratio between the compressive strength and the shear strength of the sealant is high. The latter is the case for traditional linseed oil putty. Determining the compressive strength of the sealant via a compressive test is then appropriate. Both lap shear and compressive tests are performed on two sealant materials and will be discussed in the following paragraphs.

2.1. Putty and polymer sealants

Originally, glass claddings were sealed to the iron glazing bars with putty [5]. Linseed oil mostly served as the basis for the putty throughout the 19th century and continued to be used in traditional putty manufacture by glazing craftsmen. The other ingredients vary per recipe. The general principle was to make a paste by mixing linseed oil with a drying agent. This drying agent could be chalk or ceruse (white lead). In addition, if desired, a pigment was added to it.

Both the drying oil and the filler pigment were decisive for the quality of the putty: equilibrium had to be found between flexibility for handling during construction and hardening on the longer term [11]. Glaziers often made their own linseed oil putty on-site or in their workshop, adjusting the composition based on experience. Glaziers today still use these traditional recipes to make their own putty for restoring historic glazing (both plane and stained glass).

Adhesive manufacturers also compose products based on the traditional recipes. In this experimental research, Soudal putty (*Stopverf* or *Mastic vitrier*) is tested. This glazier's putty is made of synthetic resin modified linseed oil. It can be painted. The technical data sheet states a maximum allowable strain of 5% [12]. It will be referred to as "putty sealant" in the proceeding text.

According to literature, traditional putty has to be repainted regularly after which it has a life expectancy of three to five years [13]. Therefore, adhesive manufacturers search for replacement products with increased life span. Modern polymers are developed to obtain a product with similar workability, viscosity, etc. as linseed oil putty. The main goal is to create a product that stays elastic to ensure the water-tightness of a joint over a longer period of time.

Soudaseal Tradition is a MS (modified silane) polymer that was developed as a replacement product for traditional linseed oil putty. The maximum allowable strain is around 20% [14], illustrating the higher elasticity compared to the Soudal putty. This product will be referred to as "polymer sealant" in the proceeding text.

2.2. Metal substrates

The material of the substrates for the putty compressive tests is not critical. Firstly, the expected stiffness of the putty sealant is much lower than the stiffness of a metal substrate, thus the geometry of the samples will be invariable. Secondly, when acting in compression, the influence of the adhesion to the substrate surface is negligible, therefore the compressive strength is independent from the substrate material. The substrates for the putty compressive samples were thus manufactured out of aluminium (AlMgSi0,5).

The substrate materials for the single-lap shear test samples are chosen based on practical considerations. The selected polymer sealant was tested in a broad research project on glass–metal adhesive bonds [15–17] where the adhesion to both aluminium and glass was tested. To complement these two substrate materials, steel substrates are chosen for the experiments reported in this paper. The putty shear samples are manufactured with the same steel substrate material to allow comparison of the results. Therefore, two lap shear sample sets are made of construction steel (S235 with a yield stress of 235 MPa and a Young's modulus of 210 GPa).

2.3. Test sample matrix

The putty sealant is tested in compression. Traditional putty is known for drying out and thus hardening during its curing time. Therefore, two sample series out of aluminium were manufactured to test the putty sealant at different curing times. The tests were performed after 1 and after 3 months of curing (choice of these curing times will be explained in Section 3.1). Additionally, the putty sealant as well as the polymer sealant are tested in shear after 1 month curing time. Two single-lap shear sample series are made out of construction steel to test both sealant materials.

An overview of all the test sample series is given in Table 1. In the proceeding text, the sample series are named with abbreviations relating to the test set-up (CO for compression, SH for single-lap shear).

3. Experiment execution

3.1. Compressive test samples

The compressive samples are made out of aluminium. The individual moulds are built up of a PVC holder and an aluminium spacer block (Fig. 4). The samples are constructed as a representation of a traditional 19th-century iron and glass connection: a