FACE DELAMINATIONS AND BLISTERING IN PIR-CORE SANDWICH PANELS: INFLUENCE OF TIME, TEMPERATURE AND PRODUCTION PARAMETERS

Annalena Schardt[1], Felicitas Rädel[2] and Jörg Lange[2]
[1]Department of Steel Construction, Technical University of Darmstadt, Germany. schardt@stahlbau.tu-darmstadt.de
[2] Department of Steel Construction, Technical University of Darmstadt, Germany. info@stahlbau.tu-darmstadt.de

1. INTRODUCTION

Sandwich panels used in the construction industry consist of two thin faces of steel and an intermediate core of rigid polyurethane foam or mineral wool. The panels are manufactured continuously in a double-belt process and are usually used as a cladding for walls and roofs. In their installed state, the components are subjected to considerable thermal loads, which can vary depending e.g. on the color of the outer face [1]. In this context, a damage pattern has been increasingly observed in practice in recent years in which localized delamination and blistering occurs on the outside of the panels in the assembled state. This damage pattern is well known for sandwich constructions, but has gained significant relevance in recent years, both in research and in practical applications. The increase in damage due to delamination and blistering is often associated with the implementation of polyisocyanurate foams (PIR) as a core material [2,3]. Various aspects of blistering have already been investigated in previous research work [2,4,5], but there are no holistic observations, and the underlying causes have not yet been fully unraveled. In the available literature, the influence of high temperature stress and existing weak points in the face-core bond are highlighted as influencing factors [4,5]. Another important aspect is the change in the material properties of the core material depending on time and temperature [6,7]. Changes in stiffness and strength can be observed, with differences between older and new foam systems [7]. The potential impact of this behavior on delamination and blister formation has not yet been investigated. However, it could be relevant, as the damage only occurs in the assembled state, during which the component is subjected to high thermal stresses and the material undergoes changes in its mechanical properties.

In this study, the time- and temperature-dependent behavior of sandwich wall panels with a PIR core is investigated experimentally. As part of the material tests according to EN 14509:2013 [8], tensile, shear, and full-scale tests were carried out and the results analysed with regard to blistering. For this purpose, the specimens were stored in a climate chamber at a temperature of 80°C for different periods of time, thus accelerating their ageing. In addition, material and production parameters were varied. The objective of this study is to identify possible factors influencing the formation of blisters and delaminations and to utilize these findings to draw conclusions regarding the underlying causes of this phenomenon.

2. EXPERIMENTAL TESTING

The analysed test specimens are sandwich wall panels with a PIR core and flat steel faces on both sides with a nominal thickness of 0.45 mm (outside) and 0.43 mm (inside), while the total thickness was 40 mm. During the production of the panels, both the raw density of the core material and the production temperature in the double-belt were varied. It should be noted that the 60°C is the usual temperature in the production process and 38 kg/m³ is a usual raw density for PIR in sandwich panels. A total of three different specimen types were used for the tests (Table 1).

Table 1: Overview and Configuration of tested specimens.

Type	Double-belt temperature	Raw density of core material
1	60°C	38 kg/m³
2	60°C	35 kg/m³
3	80°C	38 kg/m³

Before the tests, the specimens were conditioned at different temperatures and times. One part was stored in a climate chamber at 80°C for 14 and 42 days without special humidity, while the reference part remained at room temperature. Tensile and shear tests in accordance with EN 14509:2013 were carried out at room temperature. The Young´s Modulus and tensile strength of the core material were determined by tensile tests on 100x100x40 mm cubes, while shear modulus and strength were determined by shear tests on 800x100x40 mm beams. Additionally, 4000 mm long panels were tested after storage at 20°C and 80°C. For each series, 5 test specimens were tested for the small scale tests and 3 specimens for the full-scale tests.

3. RESULTS

The influence of raw density and double-belt temperature on the change in mechanical properties, obtained from the experimental results, is shown in Fig. 1. These are recognizable trends resulting from storage at 80°C for 14 and 42 days. Furthermore, the relative changes in mechanical values are shown exemplary using the average shear strength of all types for the storage periods and temperatures tested.

	E_{ct}	f_{ct}	G_c	f_{cv}
Type 1	↗	↗	↗	↘
Type 2	↗	↗	→	↘
Type 3	↗	↘	↘	↘

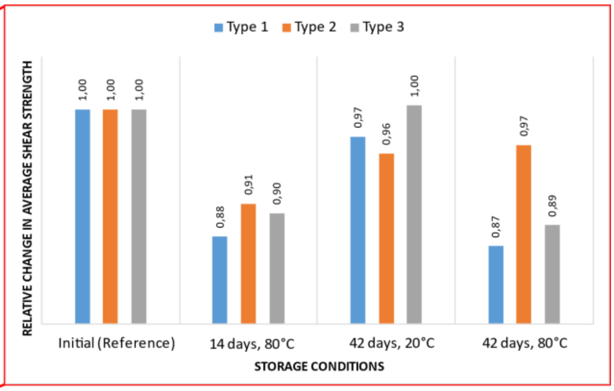

Fig. 1: Trends about the change in mechanical properties due to storage at 80°C with schematic of changes in shear strength.

The analysis shows that the change in mechanical properties is only partially dependent on the tested parameters. The Young´s Modulus increases as a result of storage for all panel types, although the degree of relative change varies between the types. The influence of the raw density is particularly apparent, as the relative change in the average Young´s Modulus is most pronounced for type 2. A comparison of the tensile strengths shows that these tend to increase for specimens that were produced at the usual double-belt temperature of 60°C. In contrast, the tensile strength decreases for specimens that were produced at a significantly higher temperature. Differences between the panel types can also been observed for the shear modulus, with the double-belt temperature being of central importance here. This is clearly evident from the results of type 1 and type 3, which exhibit contrasting behavior despite having the same raw density due to different double-belt temperatures. However, for type 2, which has a lower raw density than the other types, no significant change in the shear modulus was observed after conditioning at 80°C.

The shear strength decreases for all types stored at 80°C. However, Fig. 1 shows that the degree of relative change in average tensile strength varies. The results for types 1 and 3 are particularly remarkable, as the relative change is much more pronounced than for type 2. A comparison of the relative changes after 42 days at 20°C and 80°C further demonstrates that for types 1 and 3 it is not the duration of storage but the temperature that is decisive. Contrary to this, the influence of storage temperature is less significant for type 2, as the relative change is comparable at both 20°C and 80°C. The higher raw density, which type 1 and 3 have in common, appears to be a major influencing factor. The double-belt temperature on the other hand, has no decisive impact on the observed differences.

An overall comparison of the various types reveals a tendency for both tensile and shear strength to decrease for type 3, indicating a deviation from the behavior observed for the other types. The full-scale tests showed statistically insignificant change in load-bearing capacity for all types after conditioning at 80°C. As expected, the ultimate loads were lowest for the components with the lower raw density. An influence of the double-belt temperature on the load-bearing capacity of the panels was not observed. However, a relatively large area of blistering due to delamination was observed on the type 3 components after storage at 80°C (Fig. 2).

Fig. 2: Extensive delamination and blistering of type 3 components after storage at 80°C for 14 days.

4. CONCLUSIONS AND OUTLOOK

The findings of this study allowed for the derivation of trends concerning the variation in the core material and the production depending on raw density and double-belt temperature. Nevertheless, it should be noted that in practice the entire panel does not heat up completely when installed. The raw density primarily determines the grade of relative change in the mechanical properties. Additionally, it also has an influence on whether the time or temperature dependency has a greater impact on the material behavior. Based on the results obtained, it can be assumed that the susceptibility to delamination and blistering increases due to the changes in mechanical properties in relation to time and temperature. According to the sandwich theory, the flexibility of the core must be taken into account when determining the internal forces [1]. Consequently, an increase in the shear modulus leads to an increase in the stresses in statically indetermined systems. In multi-span systems, the constrained internal forces would also increase accordingly as a result of the load case "temperature", which would also have to be taken into account when designing sandwich panels and their fastenings. Regarding the adhesion in the contact surface between the face and the core, the double-belt temperature is particularly decisive in relation to the analysed specimens. The resulting damage pattern for type 3 components showed that a significant increase in this temperature reduces the adhesion strength between face and core and thus possibly favors the formation of blisters due to previous delamination. An indication of an increased risk of damage in this context could also be the simultaneous tendency towards a decrease in shear and tensile strength, as delamination may occur in the contact surface if these are exceeded. The relevance of the parameter "double-belt temperature" clearly highlights the influence of production parameters on damage patterns of sandwich panels. The influencing variables identified in this study must be verified in in future parameter studies. Further panel thicknesses and foam systems that differ from these specimens should be tested. Furthermore, sensitivity analyses should be carried out to assess the effects with regard to dimensioning.

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