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DAMAGES TO FACADE PANELS – THEORY AND EXPERIMENTAL VERIFICATION

ŠKODY NA FASÁDNÍCH DESKÁCH – TEORIE A EXPERIMENTÁLNÍ OVĚŘENÍ

Abstract

The facade of a multi-storey building was clad with Cembonit cladding sheets installed in the Autumn of 2003. In the Summer of 2004 the first destruction of these cladding sheets took place particularly on the southern face of the building, consisting in the origin of crack passing mostly through the rivet across the sheet corner. Further destructions took place in the Summer of 2005. The cause of damage was investigated and ascertained both theoretically and experimentally. Theoretical conclusions were in very good agreement with experimental results.

Abstrakt

Na fasádě vícepodlažní budovy byly použity cembonitové fasádní desky. Montáž byla provedena v průběhu podzimu 2003. V letních měsících 2004 došlo zejména na jižní straně budovy k prvním destrukcím desek spočívajícím ve vzniku trhlin procházejících převážně nýtem přes roh desky. K dalším destrukcím došlo v létě 2005. Příčina poškození fasádních desek byla vyšetřována a zjištěna teoreticky i experimentálně. Teoretické výsledky se velmi dobře shodovaly s experimenty.

1 INTRODUCTION

The facade of the building (Fig. 1) was clad with Cembonit FDA cladding sheets 8 mm thick, of dark grey colour, sized 1200 x 3050 mm (Fig. 2), installed in September to November 2003. Their first destructions took place in the Summer months, further in the Summer of 2005. In exceptional cases these destructions concerned also newly installed sheets replacing the damaged ones.

The expert assessment drafted at the request of the installation firm states that a major number of the sheets is damaged by cracks passing mostly through the rivet across the sheet corner, that the greatest occurrence of damaged sheets was ascertained on the southern face of the building, that the sheets were fastened to a frame of aluminium sections by explosion rivets, that these rivets were missing in some solitary places, that in the places of sheet corner separation the rivet shaft was deformed to a C and even S shape and that rivets of 5.5 to 6.4 mm diameter were found in the environs of the building. In conclusion the expert states that the damage is due most probably to volume changes and obvious sheet deformation after insolation and that in April 2005 the sheet supplier issued a change of specification which changed very significantly the installation conditions in the manner enabling sheet expansion on the framework and that it is obvious, consequently, that he (the supplier) had realized the unsuitability of instructions given in the technical manual for cladding sheet installation in force since April 2003.

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The instructions for the installation of Cembonit sheets dated April 2003 state that the explosion rivets are of aluminium and are available in two dimensions according to sheet thickness. The dimensions of rivets, however, are not specified anywhere in the instructions. The instructions provide that the sheets must be provided in advance with bored holes the diameter of which is at least 1.5 multiple of rivet shaft diameter (i.e. 7.5 mm) and at the most 9 mm. It follows that the rivet diameter is assumed to be max. 5.0 mm. The instructions for the installation of Cembonit sheets in force since 1 June 2005 specify dia. 4.8 x 16 mm rivets for the aluminium framework and sheets 6 mm thick and dia 4.8 x 18 mm rivets for the sheets 8 mm thick. Therefore, it is assumed that rivets of the same dimensions were used also prior to 1 June 2005.

In the course of inspection made by the workers of the Institute 6 used rivets were found. Their shaft diameter was within the limits of 6.2 and 6.4 mm in five cases and 5.6 mm in one case. This was in agreement with the data ascertained by the expert (5.5 – 6.4 mm) who drafted the assessment for the installation company. Consequently, it was proved beyond doubt that after sheet installation the dia. 7.5 – 9.0 mm holes contained rivets of 5.5 – 6.4 mm in diameter, i.e. of a substantially larger diameter than the theoretical 4.8 mm.

The sheet manufacturer offered the opinion that the fastening of the sheets to aluminium framework was too tight which prevented mutual movement. This was considered a great risk by the manufacturer who maintained that the sheet corners cracked because of climatic changes (heat, frost). The inspection by the workers of the Institute, however, ascertained that the manner of fastening of the sheets to the framework enabled mutual movements of the framework and the sheets. The sheet manufacturer further objected that numerous holes in the aluminium structure had not been bored so as to place the centre of the holes in the structure accurately below the centre of the hole in the sheet. Consequently, the manufacturer did not take at all into account that the expansion or shortening of the aluminium framework during temperature changes were significantly different from analogous changes of the cladding sheets. Therefore, this manufacturer’s objection that the joints of the individual parts of the aluminium framework had not coincided with the joints of individual sheets and that, consequently, the individual sheets had been fastened in some cases in a single line to two aluminium sections, was technically unacceptable and was in no causal relation to the cracks separating the sheet corners from their body.

Flexural and tensile tests have proved that the sheets complied with the requirements of the respective technical standard and confirmed the strength data specified by the manufacturer. On the basis of their results it was possible to exclude the lower strength of installed sheets than that declared by the manufacturer from the causes of their damage. Nevertheless, as the damage to the sheets did (even repeatedly) take place, it was necessary to ascertain its cause.

2 THEORETICAL APPROACH

The first step included theoretical calculations of stresses in the sheet in the proximity of rivets in sheet corners in several alternatives. These computations considered a change of the temperature of the sheet and of the aluminium sections at the rate of $\Delta t = 50^{o}C$. Such minimum temperature rise is entirely realistic, and if the sheets are installed at low outside temperatures, prevailing e.g. in the Autumn, which is the assessed case, even higher temperature changes (e.g. of some $60^{o}C$) can be expected.

Technical parameters of the sheets were considered as follows:

coefficient of thermal expansion	$\alpha = 10 \times 10^{-6}$
tensile strength (ascertained)	$R_m = 9.25$ MPa

Technical parameters of aluminium sections were considered as follows:

coefficient of thermal expansion	$\alpha = 23 \times 10^{-6}$
modulus of elasticity	$E = 71\,000$ MPa

For the sheet height of 3050 mm and the prescribed vertical hole distance from the sheet edge of 80 to 120 mm the vertical distance between the holes in the sheet corners is approximately 2 800 mm. When warming the sheet shrinks from the horizontal plane passing through its centre in the direction of vertical aluminium section which, on the other hand, elongate under the effect of heat.

Alternative 1

The diameter of the sheet hole is 7.5 mm, the diameter of the rivet in the hole is the actual 6.4 mm. The distance between the rivet situated middlemost in the hole and the cladding sheet is therefore 0,55 mm. Then $2 \times 0.55 = (0.000023 + 0.000010) \times \Delta t \times 2\,800 \Rightarrow \Delta t = 11.9^{o}C$

When the temperature increases by $11.9^{o}C$, the rivets touch the hole edges. Further temperature increase will make the rivets tear off the sheet corners. Further calculations have ascertained that the sheet corner must be torn off even if the sheet temperature increases by less than $50^{o}C$.

Alternative 2

The diameter of the sheet hole is 9 mm, the diameter of the rivet in the hole is the actual 6.4 mm. Also in this case the temperature increase of $50^{o}C$ will produce with very high probability the tearing-off of the sheet corner; it is necessary to take into account the stress concentrations on hole circumference and the initiation of the crack which further propagates towards the sheet edge.

In this particular case, however, it is necessary to cope with the possible objection, namely why only some sheet corners and not all corners of all sheets were broken off. The reason is that the diameter of numerous rivets built into the structure was smaller than the maximum ascertained value of 6.4 mm considered in this calculation.

Alternative 3

The diameter of the sheet hole is 7.5 mm, the diameter of the rivet in the hole is the theoretical 4.8 mm. Also in this purely theoretical case the sheet corner would be torn off, if the temperature increased by $50^{o}C$.

Alternative 4

The diameter of the sheet hole is 9 mm, the diameter of the rivet in the hole is the theoretical 4.8 mm. In this purely theoretical case the temperature rise of $50^{o}C$ would not generate the tear-off of the sheet corner.

Alternative 5

The diameter of the sheet hole is 10 mm, the diameter of the rivet in the hole is the actual 6.4 mm. In this case the temperature rise of $50^{o}C$ should not produce the sheet corner tear-off.

3 EXPERIMENTAL VERIFICATION

Apart from the afore mentioned theoretical calculation it was decided to verify their results on samples subjected to thermal loads rising to the very moment of crack appearance. For this purpose three samples 60 mm wide and 880 mm long were cut out of one of the dismantled cladding sheets and fastened to an aluminium bar with two screws so as the screws had no side play in the hole during aluminium bar elongation due to heating. The screws were spaced at 780 mm. The lengths of the samples and of the aluminium bar were so selected as to enable the assembly to be placed in the furnace. After every single sample had been placed in the furnace the temperature was increased successively until the failure of the sample. It was ascertained that the failure of the sample was sudden, without any warning, always at the temperature of $75^{o}C$, i.e. after the temperature increase by $55^{o}C$ from the room temperature of $20^{o}C$. After the temperature increase by $55^{o}C$ the bar length between the screw increased by $\Delta l = 0.000023 \times 55 \times 780 = 0.987$ mm.

According to **Alternative 1** of theoretical calculations, with dia. 7.5 mm of hole diameter and 6.4 mm diameter of the rivet in the hole, the clearance between the rivet and the sheet disappears at the temperature rise of 11.9^{o}C.

The crack appeared, when the bar elongation attained 0.987 mm. Such elongation corresponds with further temperature increase by 30.6^{o}C of the bar 1400 mm long and it holds that

$$0.987 = 0.000023 \text{ x } \Delta t \text{ x } 1400 \Rightarrow \Delta t = 0.987\ (0.000023 \text{ x } 1400) = 30.6$$

In this particular case the temperature increase by 11.9 + 30.6 = 42.5^{o}C is sufficient to produce crack origin.

In case of **Alternative 2** with 9 mm hole diameter and 6.4 mm diameter of the rivet in the hole the clearance between the hole and the rivet disappears at the temperature rise of 28.1^{o}C. In this case the temperature increase by 28.1 + 30.6 = 58.7^{o}C is sufficient to produce crack origin. In case of **Alternative 3** with 7.5 mm hole diameter and 4.8 mm theoretical rivet diameter in the hole the clearance between the sheet and the rivet disappears after temperature increase of 29.2^{o}C. In this particular case the temperature increase by 29.2 + 30.6 = 59.8^{o}C is sufficient to produce crack origin. In case of **Alternative 4** with 9 mm hole diameter and 4.8 mm theoretical rivet diameter in the hole the clearance between the sheet and the rivet disappears after temperature increase by 45.4^{o}C. In this particular case the temperature increase by 45.4 + 30.6 = 76^{o}C would be necessary to produce crack origin, which is not realistic. In case of **Alternative 5** with 10 mm hole diameter and 6.4 mm rivet diameter in the hole the clearance between the sheet and the rivet disappears after temperature increase by 39^{o}C. In this particular case the crack origin would necessitate a temperature increase by 39 + 30.6 = 69.6^{o}C. Unless the sheet installation takes place at extremely low temperatures, no corner tear-off should take place.

4 CONCLUSIONS

Experimental verification agreed with theoretical calculations. Therefore, it was possible to conclude that the initial installation instructions drafted by the sheet manufacturer and prescribing the hole diameter of merely 7.5 to 9.0 mm were in direct causal relation with the damage to the cladding sheets on the building. The author of the instructions obviously underestimated the approximately double thermal expansion of aluminium with reference to steel. Apart from that he underestimated the fact that the dia. 4.8 mm explosion rivets increase their diameter to 6.4 mm during their application. Consequently, the installation firm did not cause the destruction of the cladding sheets by its work. The installation according to new instructions prescribing dia. 10 mm holes should not cause the tearing-off of sheet corners, unless the installation is carried out at extremely low temperatures.

Fig. 1 View of the building facade

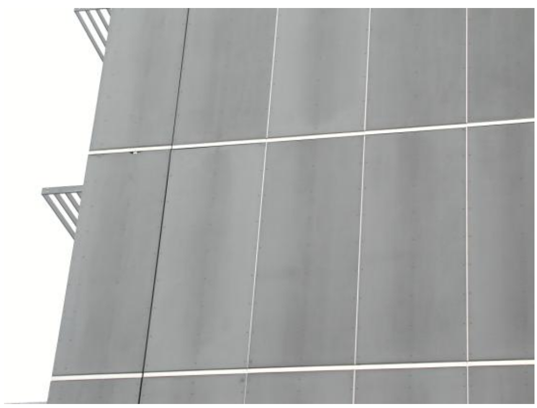

Fig. 2 Cembonit FDA cladding sheets

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