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Thermal and mechanical analysis of thermal break with end-plate for attached steel structures

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ABSTRACT

The thermal and mechanical performances of a simple thermal break are analysed. This thermal break can be used with external steel structures such as balconies and passageways attached on a concrete facade with external thermal insulation. The thermal barrier effect is obtained by a PVC and an acoustic insulation plates inserted between the end-plates of the attached steel beams and the support (floor slab, concrete wall). The thermal performances of the selected solutions were evaluated by numerical simulation. It shows that this simple solution reduces by up to 65% the thermal bridge at the attached steel beams connections. Besides, a parametric analysis showed that the reduction ratio depends on the configuration of thermal break (with or without additional thermal insulation around the steel beams at the connection), the thickness of PVC plate, the material of fastening systems (carbon steel or stainless steel) and the thickness of the facade thermal insulation. As deformable layers are used under the end-plates, the thermal break can be considered as unconventional steel connection with mechanical performances to be investigated. Thus, experimental program including static and cyclic tests is performed on various configurations of connections with thermal breaks to evaluate their mechanical behaviour considering the stiffness and the resistance. The results show that the solution of simple thermal break is efficient mainly for connections with extended end-plates.

1. Introduction

The construction of nearly zero-energy buildings (NZEB), which will be the standard in coming years [1], requires the improvement of the energy efficiency of buildings, and thus reducing heat losses from envelope including thermal bridging.

The importance of minimizing thermal bridging has indeed been exacerbated in recent years by the increase in insulation levels due to tighter national building regulations, which makes the relative contribution of thermal bridging to the overall heat loss through the building envelope more and more significant [2].

Thermal bridges are parts of the building envelope, where the otherwise uniform thermal resistance varies significantly. They can be categorized as linear or point thermal bridges. Linear thermal bridges occur at the junctions between building envelope elements and are characterized by a linear thermal transmittance (or Ψ-value in W/m.K). Point thermal bridges typically occur where an insulated wall is perforated (penetration) by an element with high thermal conductivity, or at three dimensional corners. They are characterized by a point thermal transmittance (or χ-value in W/K). It is possible to reliably determine the heat transfer through a thermal bridge via numerical methods using finite element or finite difference methods [3]. Numerical calculations of the steady state heat transfer are generally conducted in accordance with the methods specified in ISO 10211 [4].

The localised additional heat transfer through a thermal bridge leads to a lower temperature on the inner surface of the affected element within the area of thermal influence of the thermal bridge, which can lead to condensation and mould formation.

The implementation of external steel structures, such as balconies and passageways, on a façade with external thermal insulation, both in the construction of new buildings or the renovation of existing ones, reduces thermal bridges, compared to concrete structures, due to the point fixings on the support instead of continuous extension of the floor slab [5].

However, the thermal performance can be further improved by the use of thermal breaks between the external steel structure and

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Symbols

χ	point thermal transmittance (W/K)	PVC	polyvinyl chloride
Ψ	linear thermal transmittance (W/m.K)	ULS	Ultimate Limit State

the support which can be concrete floor or concrete wall (see Fig. 1). The thermal breaks can be either standard manufactured products proposed by industrial suppliers or simpler solutions implemented by companies. The present paper focuses on the thermal and mechanical performances of simple solutions to be used by common steel construction companies. These simple thermal breaks combining classical end-plate connections and insulation layers are easy to use. However, they need to be justified for structural stability requirements in normal conditions and in earthquake zones. In fact, the insulation layers introduce deformable materials under the steel end-plate, influencing the compression zone of the connection, and increases the additional moment on the fasteners due to the distance between the end-plate and the support.

Recent researches have been carried out on the mechanical behaviour of connections in steel structures using insulating intermediate layers as thermal breaks. Nasdala et al. [6] and Sulcova et al. [7] proposed to adapt the analytical approach, called component method, of Eurocode 3 in order to take into account the influence of deformable insulation plates. The results based on numerical model [6] showed that the thickness of insulation layer, the friction coefficient at the steel-insulation interface and the initial bolt preload have a great influence on the mechanical behaviour of these connections. Cleary et al. [8] conducted tests on steel connections using filler plates made of Fiber-Reinforced Resin as thermal barrier. Simple connections and moment connections tested under service loading showed that thermal filler plates increase the rotation of moment connections and the vertical displacement of simple connections. Peterman et al. [9] performed tests on connections insulated by Fiber-reinforced polymer fillers to characterize their long term behaviour and to evaluate the modification of the shear resistances of bolts in presence of fillers. They confirmed the influence of the additional bending moment on the fasteners due to the presence of fillers.

The proposed solution in the present study involves also non-traditional transfer of load in the connection of steel structures to concrete support. The actual European standards provide no design rules to check the transfer of a shear force and a bending moment from a steel end-plate to the concrete support in presence of insulation material between end-plate and concrete. Moreover, the elastomeric (acoustic insulation) and PVC intermediate layer clearly decrease the rotational stiffness of the connection that can affect the displacement of the attached steel structure particularly at the Serviceability Limit States. PVC and elastomeric material are also sensitive to long-term loading. To understand and evaluate the mechanical behaviour of end-plate connections with thermal insulation, an experimental program is done using various configurations of connections. Thus, static and cyclic tests were performed under a combination of shear and bending loads. The basic materials of the tested systems are also tested to obtain their real mechanical characteristics. The time effect is evaluated on specimens of insulation materials under compression. The long-term effect on the whole connections will be considered in the near future.

The present paper gives the results of the numerical analysis of thermal performance and those of the experimental study of mechanical behaviour of a thermal break to be used with external steel structures. The thermal break solution is described in Section 2 and its thermal performances in Section 3. The thermal performances are characterized by the point thermal bridge (χ) at the

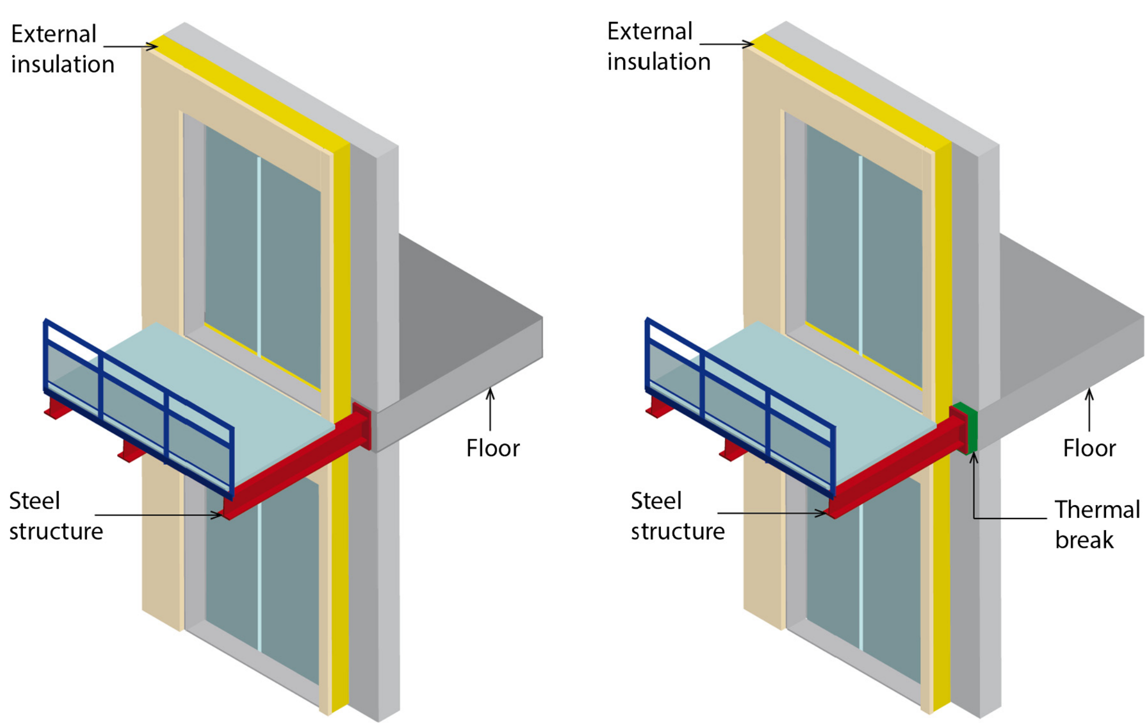

Fig. 1. Thermal break principles.

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