Cold Bendable, Laminated Glass – New Possibilities in Design

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Summary

A new product has recently become available: a cold bendable, laminated glass. This transparent material is bendable on site at ambient temperature. In glass panes, the positive qualities of warm bent, laminated glass and of plastics are united. They are as flexible as plastic and also lightweight. Their optical quality is much better than that of traditionally warm bent, laminated glass and their price is considerably lower, comparable with plastics. It pollutes less than plastics, does not scratch, does not age and therefore requires little maintenance. Moreover, it is of value from the point of view of sustainable building. It was applied for the first time in 1997 in the skylights of 's-Hertogenbosch station. An application for a huge roof for the bus station at Amsterdam Central station is currently under construction.

Introduction

In architecture there is a growing interest in transparent surfaces and curved shapes. Nevertheless, curved transparent shapes are being applied less than expected. Considering safety, curved transparent surfaces for public spaces should be constructed from laminated glass or fire resistant plastics. Both products, however, have disadvantages. Curved laminated glass, traditionally warm bent, is expensive, especially to replace due to breakage, and does not have very good optical properties. Plastics, although less expensive, have the disadvantage of degrading due to static charge, scratching easily (typically in cleaning) and of ageing in sunlight.

Recently, a new type of glass has been introduced, uniting the advantages of these existing products into cold bendable laminated glass. In view of its properties, this new type of glass is very interesting and opens new opportunities in architecture. This article describes this new patented product [1] and its application in two projects.

Material Properties

Cold bendable, laminated glass consists of a few tempered or toughened glass panes interconnected with one or more PVB layers. Such panes can be bent on site at ambient temperature over curved frames or a number of fixing points on curved surfaces and attached to them.

The thermal insulation value of such panes is comparable with that of single panes of the same thickness. To achieve better thermal insulation, it is possible to make traditional double or multiple glazing, i.e. two or more cold bendable, laminated panes each attached to their own curved window frame with a void in between.

The action of the glass can be explained as follows. As a result of the pre-stressing due to the tempering process it is possible to sufficiently bend tempered panes without obtaining tension stresses at the glass surface. The thinner a pane is, the smaller the achievable radius. This results in a lower resistance to external loading. To meet this problem, the load is distributed over more than one pane. In general, two panes will be sufficient to take up the load. These panes are easily bendable, each acting independently, as long as they can slip with respect to one another.

The PVB foil between the panes has the particular property that it permanently fixes the glass panes together, yet it allows displacement of the panes with respect to each other by slipping. This combination allows panes to be made flexible enough to be bent while being strong enough to withstand the applied load.

Behaviour

At short term loading the panes of the sandwich will work together. The sandwich will act approximately as a single layered pane of the thickness of the whole sandwich (Fig. 1a). The sandwich is thus very strong and stiff.

At long term loading the foil between the panes will yield and the panes will slip with respect to one another (Fig. 1b). For permanent loads, such as due to the load from bending itself, the panes of the sandwich act independently from one another as separate panes, yet they are connected, thus deflecting equally.

Fig. 1: Stress distribution at short (left) and long term behaviour (right) respectively.

Availability

The unit cost of this cold bendable, laminated glass depends on its dimensions, its loadings, the quantity, delivery time etc., however, it will be cheaper than warm bent laminated glass and it will be competitive with plastics. Currently, panes are typically fabricated in maximum sizes of approximately 4,50 m x 2,50 m, though larger dimensions are available. The minimum bending radius depends on the applied thickness and the composition of the sandwich, the dimensions of the pane, the attachment system of the pane and the load it has to withstand. For panes 2 m long and 1 m wide supported along four sides, a radius of 3 m can be reached.

Detailing

Due to the character of the material a pane of cold bendable laminated glass must be attached to a curved frame or to point supports on a curved surface. The panes are bent over curved window frames and secured with an attachment frame that is bolted or screwed to the window frame. A click frame can also be used, but the pane must then be kept in the bent shape by means of screw plates (Fig. 2).
The pane can be supported either on two sides or on four sides. When it is supported on two sides, the maximum distance of the window frames is restricted and the minimum bending radius is rather large. This is because half way between the window frames, the pane tends to stay straight, which makes the pane bend perpendicular to the actual bending direction. When supported on four sides, this effect is reduced. This makes possible for smaller bending radiiues, and larger frame distances. Additionally, the behaviour of a pane supported on four sides is much safer upon breakage and should be used.

Comparison with Other Materials

This new product withstands the comparison with other materials for similar applications. The following summary clearly shows the advantages.

Warm Bent, Laminated Glass

Cold bending causes a pre-stress in the glass pane that is favourable for carrying downward loads, allowing for a smaller glass thickness. Because of this and the method used in fabrication, cold bent, laminated glass has a substantial cost advantage compared to warm bendable, laminated glass; the cost of the latter being about twice as high. This allows for new glass applications to be more economically feasible. Also, the optical quality is better than warm bendable, laminated glass since the thickness is more constant. Finally, it is easier to transport flat glass than bent glass.

Plastics

Compared to plastics such as polycarbonate, cold bendable glass is less sensitive to static electrical loading and to scratching, and will therefore degrade less. In a railway environment, for instance, grinding dust due to braking and copper dust from the catenary system will penetrate the surface less. Thus, appearance is improved and maintenance budgets can be reduced. In addition, the cold bendable glass is less sensitive to ageing, stable under ultraviolet light, completely fireproof and much more rigid.

In spite of these better properties, the cost is in the same range. However, in train station areas, for instance, the contamination of plastics seriously limits their application. Thus, new applications of cold bendable glass can be made in these areas where the use of plastics is limited by the aforementioned properties.

Cold Bent, Tempered Single Layered Glass

A good alternative might be found in cold bendable, single layered glass. This is fitted on one side with a PVB foil that functions to keep the numerous small glass splinters together in case of breakage. However, cold bendable, laminated glass also has major advantages over cold bendable, tempered single layered glass. Its behaviour in case of overloading and breakage is more favourable, providing a safer construction. Moreover, the load bearing capacity for concentrated loads as required by regulations can be met more easily. Also, cold bendable, single layered glass has some of the same limiting properties as plastics, due to the foil being the surface of the pane. Thus, cold bendable, laminated glass with its better properties and cost in the same range is a more favourable product.

Sustainable Building

Cold bendable, laminated glass is also very interesting from the point of view of sustainable building. To start with, the material use is halved. In addition, cold bendable glass requires no post-manufacture heating, nor is a bending mould required to be produced, thus saving energy. Also, flat panes can be transported more easily and economically to the building site than prebent panes. Site assembly takes a similar amount of energy. Lastly, glass mainly consists of sand, which is abundantly available.

Applications

Canopy of 's-Hertogenbosch Station

Cold bent, laminated glass was first applied in 1997 in the canopy of the third platform of 's-Hertogenbosch station in the Netherlands [2], [3], [4], [5], [6]. This canopy has a total length of about 192 m, at a width of 10,80 m. As a test case, a part of the skylights were carried out in cold bent, laminated glass, while the remaining skylights consist of traditional, warm bent laminated glass. The panes of the skylights have dimensions of about 2 m by 1 m and a bending radius of 3 m. They are attached to frames consisting of hollow sections, curved profiles and angles (Fig. 3 and 4).

In the warm bent glass the skylights consist of two panes each 8 mm thick with 3 mm of resin between them. In the cold bent glass a composition of 9,5 mm laminated glass, was found to be sufficient. The cold bent panes withstand the concentrated load according to the standards better than doubly thick warm bent ones. The warm bent panes are attached with click frames, the cold bent ones were first tightened into a curved shape with screw plates.

What is most striking, is the clearness of the thinner, cold bent glass. Also the optical quality is better, due to its constant thickness and consequent absence of lens effects. A recent check showed...
that the glass remains in good condition, seven years after mounting and without any cleaning whatsoever. In spite of their position between railway tracks, the contamination has proven to be less than anticipated.

**IIse Bus Station Roof**

On the waterside behind Amsterdam Central station, the construction of a new bus station began in September 2003. This bus station will have a huge station roof, measuring 360 m in length, designed by Benthem and Vákár. It consists of steel arches every 12.5 m, spanning 65 m (Fig. 5). One side of these arches rests on the quayside, the other on short columns built into the bus platform. The arches are interconnected with purlins every 3 m. Most of the roof will be covered with cold bent, laminated glass panes, 3 m long and 1.1 m wide. The glass panes are supported on 15 m long, bent profiles (Fig. 6).

This cold bendable glass makes it possible to realise such a huge roof within a limited budget. This is not only due to the moderate price of the glass itself but also due to the allowance for thinner glass sheets resulting in a reduction in dead weight. Moreover, the steel structure can be constructed lighter, because in the case of deformations the glass surface will accommodate these deformations. Finally, if the glass would not have been bent and the roof surface had been faceted, it would have been necessary to make costly joints in the glass-carrying profiles.

**Conclusion**

Cold bendable, laminated glass is a new product that opens new and interesting opportunities in architecture. The creation of economic high standard, transparent, curved surfaces comes within reach of designers and clients at moderate prices.

**References**