Glued and preloaded bolted connections for laminated float glass

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Keywords

1=bolted connection 2=preload 3=glue 4=laminated glass

Abstract

Bolted connections are probably the most commonly used assembling devices for glass structures. It is general practice to use bolted connections only in combination with tempered glass, which shows a relatively good resistance to stress concentrations. Increased production time and costs are the major drawbacks caused by the use of tempered glass. Due to the high local stresses caused by common bolted connections, annealed float glass is usually not used.

In order to fill up this gap and to exclude the drawbacks mentioned above, a bolted connection for float glass was designed and tested. To reach a good strength transfer between the bolt and the laminated float glass, a preloaded bolt proved to be inevitable. To maintain the preload, the interlayer needed to be replaced locally by aluminium. To increase the failure load, the aluminium inserts were glued on the glass.

During the design process, the influence of different parameters (e.g. the cross-section of the aluminium inserts and the diameter of the drilled hole and the bolt) was tested experimentally. The test program showed that with a judicious choice of the design parameters, the failure load could be multiplied with a factor three compared to a fitting bolted connection.

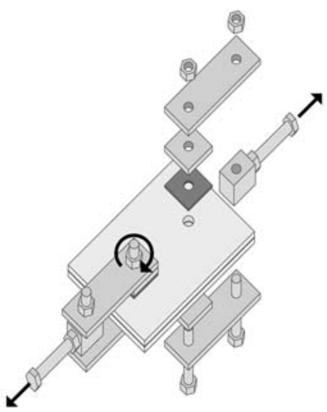


Figure 1

Assembly of the test specimens.

Introduction

Bolts are a simple and therefore a widely-used connection method in all kinds of constructive applications. It has the advantage that it can compose elements on the yard with only few resources. An additional advantage is the small size, which leads to a restricted visual impact on transparent structures, e.g. glazed curtain walls with point-fixings.

At this moment, the existing bolted connections are yet inadequate to use float glass in a safe way. Consequently, only prestressed glass is used. Because this preliminary treatment of the glass has a large influence on the total cost, the Laboratory for Research on Structural Models tried to develop a new bolted connection for annealed float glass. To reach this, a mainly experimental investigation was conducted.

Fitting versus preloaded

At steel structures, there is a basic distinction between fitting bolts and preloaded bolts. The main difference between these two is the way forces are transferred from the bolt to the element. With the fitting bolt, the forces are directly transmitted between the edge of the hole and the side of the bolt. To optimize the contact area, the diameter of the hole is the same as the diameter of the bolt. If this is not possible, the space between the bolt and the edge of the hole is filled with a stiff material. The Hanz Schmitz Haus is an example of a glass structure where this connection technique is used [1].

In a preloaded bolted connection, the forces are transferred by friction on the surface around the hole. The friction coefficient and the amount of preloading determine the force that can be transmitted. To avoid stress concentrations in the glass, originating from a direct contact with the bolt, the diameter of the hole was larger than the diameter of the bolt.

Method

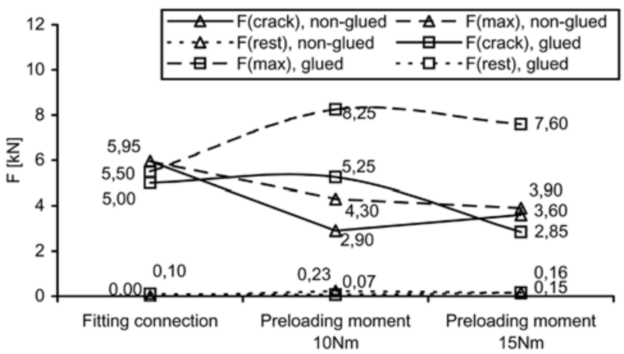
In order to investigate the possibilities of these two different connection types in combination with laminated, annealed float glass, small-scale tension tests were performed. The test specimens were recycled out of broken laminated glass beams. Due to this, the samples had two polished edges and two cut edges. However, this had no large impact on the results because all of the cracks initiated at the drilling hole and not at the edges. The influence of the parameters of the connection on the failure load, as shown in the next chapter, proved this belief.

The test pieces were composed and loaded as shown in figure 1. An Amsler tensile testing machine introduced the tensile force, while the force on the bolts of the preloaded connection was applied with a socket spanner with adjustable moment. For the fitting connection, the bolt was tightened by hand. With this type, also a small aluminium tube was inserted to avoid direct contact between the steel of the bolt and the glass. For the same reason, there was always an aluminium insert between the glass and the steel plates.

The results of the first test series show a better behaviour for the fitting bolt (Figure 2). The explanation for this can be found in the insufficient friction between the aluminium and the

Figure 2

Mean test results for a fitting- and a preloaded bolted connection.



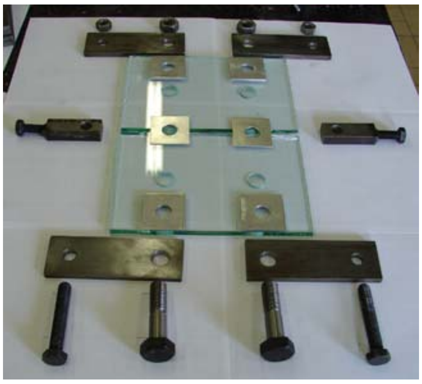


Figure 3

Assembly of the self-composed test specimens.

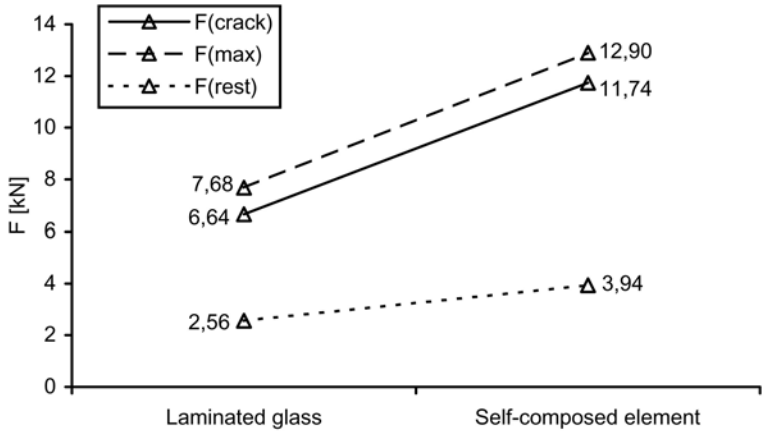


Figure 4

Mean test results for a bolted connection with a preloading moment of 20Nm for laminated glass and self-composed glass.

glass. Through this, the steel bolt slided against the side of the hole in the glass, causing brittle fraction. To avoid this, an identical test series was performed with only 1 difference: that the aluminium was glued on the glass. Hereby a much higher failure load occured for the preloaded bolts.

Unfortunately, the initial crack load was not proportional to the preloading moment. With a preloading moment of 15Nm, this value even reduced in accordance with both the non-glued version and the glued, preloaded bolt with a preloading moment of 10Nm. The fact that a higher preloading moment caused earlier glass fracture can be explained by the material properties of the PVB interlayer. Because of the small stiffness, the interlayer was locally compressed by the preloading of the bolt. Through this, the glass was locally bent and therefore subjected to additional stresses. To reduce this problem, a much stiffer interlayer was necessary at the bolts. At hereafter, the test specimens were composed differently (Figure 3). The samples were no longer laminated and only two 1mm thick aluminium plates were inserted between the glass sheets.

Another test series was performed to investigate the strength possibilities of this configuration. The results fulfilled the expectations largely as can be seen in figure 4 (also the tests with the laminated glass were re-executed, cause of some other small changes). The initial crack load for the self-composed test specimens increased with more than 50% according to the tests with the laminated glass. The ultimate load even grew with 68%.

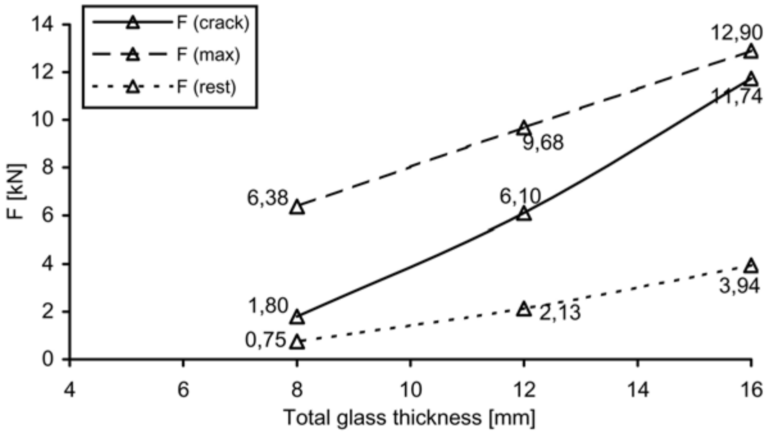


Figure 5

Mean test results in function of the glass thickness.

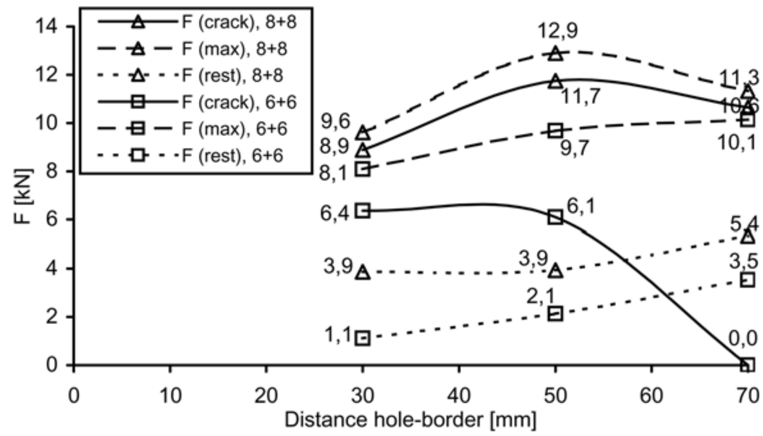


Figure 6

Mean test results in function of the distance between the hole and the glass edge.

Parameters

The previous tests demonstrated that a considerable load could be transferred to annealed float glass using a bolted connection. It is important, however, that much attention is given to all details of the connection. To investigate the influence of some details on the load transferring capacity of this new connection, additional test series were executed. In each of these test series, only one parameter was changed in comparison to a reference. For al the series, the reference test was the same, namely the self-composed assembly discussed above.

The first parameter investigated, was the glass thickness. In addition to the reference test with two glass sheets of 8mm, tests were performed with two plates of 6mm and two plates of 4mm. As expected, the loads increased for a larger thickness. However, it was noticed that the initial crack load raised faster than the ultimate load, which changed linearly in function of the glass thickness.

The next parameter which was changed, was the distance from the hole to the border of the glass. This value was reduced from 50mm to 30mm and increased to 70mm. Because of this, the stresses due to the preloading of the bolds were spread differently. With a distance of 30mm, the bolt was too close to the glass edge. With a distance of 70mm to the edge, the two bolts came too close to each other for this size of test specimens

(150mm x 230mm). This occured clearly in the initial crack load of 0,0kN at the self-composed test specimen of 6mm+6mm.

The thickness of the aluminium inserts between the glass and the steel plates was randomly chosen to 3mm. To know if this was sufficient, some more tests were done with other cross-sections. The results showed that 1mm was clearly insufficient to spread the stresses from the hard steel to the glass. There was no big difference anymore between 2mm and 3mm. This showed that 2mm was enough for this size of connection.

A parameter with a large impact on the load-bearing capacity of the preloaded connection was the size of the aluminium plates. By increasing the side of the square plates from 50mm to 60mm, the glued surface raised with about 50%. The test results showed that both the initial crack load as the ultimate load mainly followed this behaviour.

With the reduction of the side to 40mm, much lower loads were expected. The only explanation found for the high values, were the higher stresses due to the preloading, because the constant preloading force was distributed to a smaller surface.

In addition, the influence of the shape of the connection on its load-transferring capacity was investigated. For this reason tests were also performed with circular aluminium plates. The circular plates had a diameter of 56,4mm so the surface corresponds with the square plates. This showed a slightly better maximum load for the square plates, but a lower residual load.

The diameter of the hole was the next investigated parameter. With this to change, also the bolt diameter had to be adapted. It was opted to keep the diameter of the bolts always 2mm smaller than the diameter of the hole. The first test results showed an unexpected big improvement for the self-composed test specimen of 8mm+8mm glass with a drilled hole of 12mm. The explanation for this laid in the choice of a constant preloading moment. The preloaded force was opposite proportional to the diameter of the bolt. Therefore, the preloading force was involuntary increased by reducing the diameter of the hole.

For this reason, an extra test series was executed. Within this series, the preloading force was kept equal with two different bolt diameters. This was realised with a bolt with a diameter of 10mm and a preloading moment of 15Nm and a bolt with a diameter of 14mm and a preloading moment of 20Nm. To maintain the same glued surface, the drilled hole had a constant diameter of 16mm. There was thus no evident difference visible in the test results.

Only the initial crack load of 6,1kN for the self-composed element with

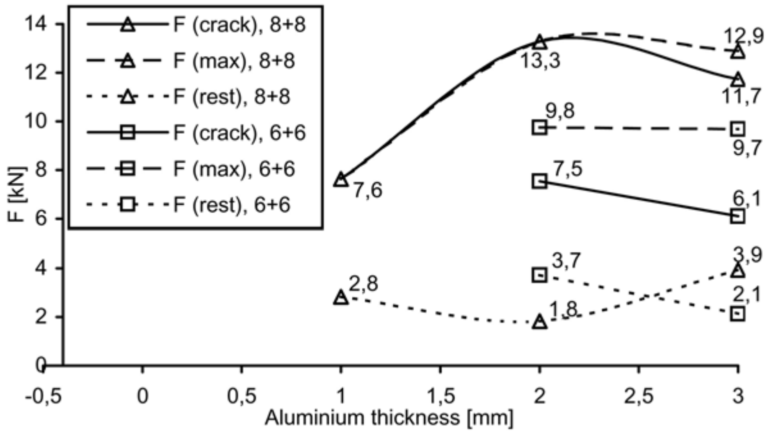


Figure 7

Mean test results in function of the thickness of the aluminium plates.

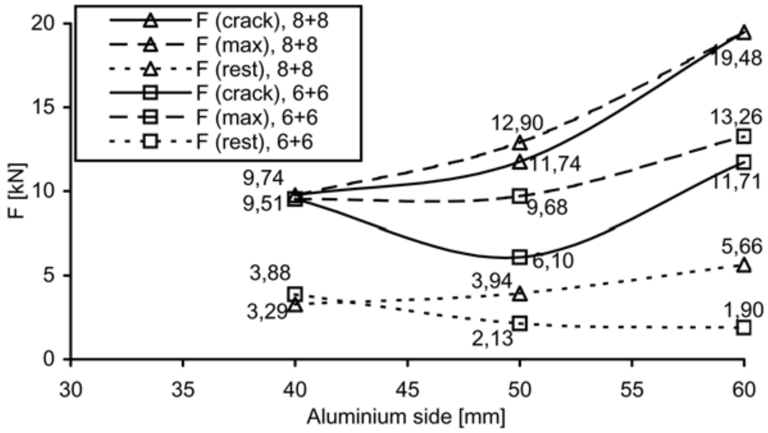


Figure 8

Mean test results in function of the size of the aluminium plates.

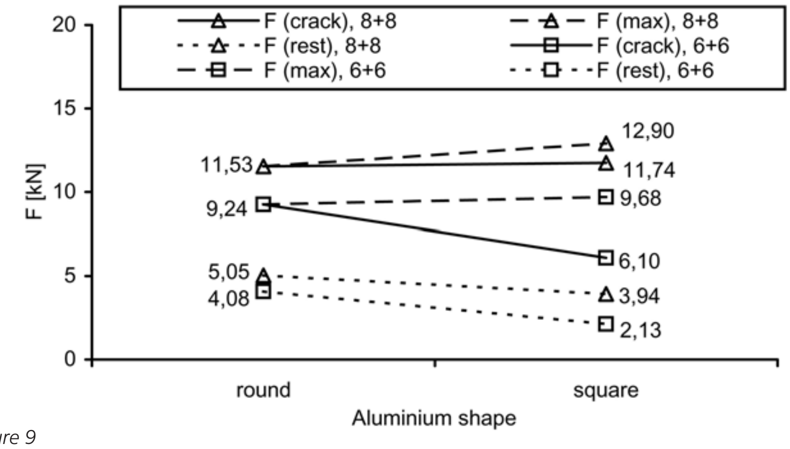


Figure 9

Mean test results in function of the shape of the aluminium plates.

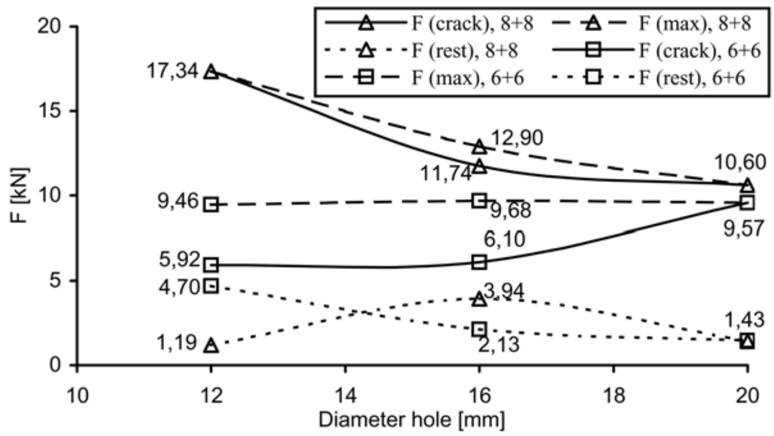


Figure 10

Mean test results in function of the diameter of the hole.

glass plies of 6mm proved to be too low. This was already noticeable in the previous graphs. The reason for this low value could be that all the test results were a mean value of only two tests.

The tests with a bolt of 10mm in a hole of 16mm with a preloading moment of 20Nm showed however that a higher preloading force could also reduce the load-transferring capacity of the bolted connection.

The last parameter that was changed was the thickness of the steel plates. In order to reduce the visual impact of the connection, the thickness of the steel plates was diminished to 3mm. By doing this, the initial crack load and the ultimate load decreased a little. Again became clear that the value of 6,1kN was too low.

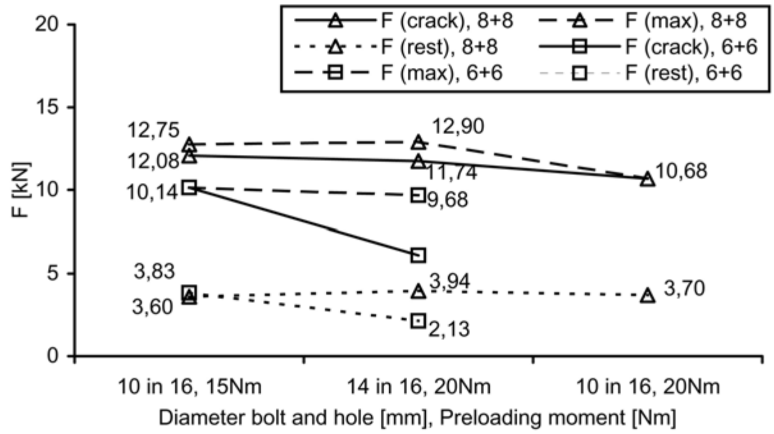


Figure 11

Mean test results in function of the diameter of the bolt and the preloading moment.

Summary and conclusions

In order to develop a new bolted connection that could be used with annealed float glass, an experimental research was performed at the Laboratory for Research on Structural Models of Ghent University. First, the difference between a fitting and a preloaded connection was clarified. After increasing the friction between the glass and the aluminium by gluing these together, the structural possibility of the preloaded bolted connection came to the surface.

To explore this possibility, extensive test series were executed. Through this, it was shown that some small changes could have a large impact on the load-transferring capacity of the connection. For example, an aluminium insert of insufficient thickness between the steel plates and the glass sheets could halve the initial crack load, while an increase of the side of the square aluminium plates could increase this load with about 50%. It must also been noticed that the change of multiple parameters at the same time might have an unexpected effect.

Furthermore, it must be emphasised that these test results were always the average of only two identical tests.

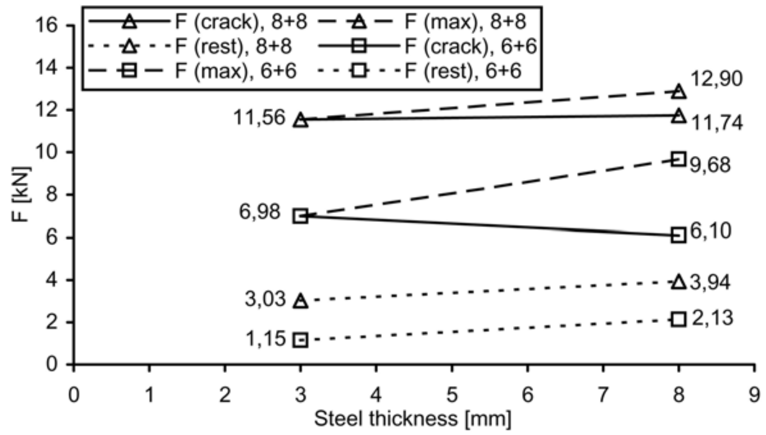


Figure 12

Mean test results in function of the thickness of the steel plates.

These tests were thus only carried out for control of the impact of certain parameters. The results can therefore not be used unthinkingly. Nevertheless, these tests proved that bolted connections in annealed float glass can be used to transfer considerable forces. This glued and preloaded bolted connection could transfer double load in accordance to the fitting connection tested at the beginning.

More details and test results of each test specimen separately can be found in [2].

References

[1] Wellershof, Frank and Sedlacek, Gerhard. "Glass Pavilion Rheinbach – Stability of Glass Columns". Proceedings of Glass Processing Days 2003. Tampere. 2003. p. 316 – 318.

[2] Callewaert, Dieter. "Bout- en lasverbindingen in floatglas: experimentele studie". Master Thesis, Ghent University. 2006, unpublished.