The Application of Adhesives to Connect Steel Members

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ABSTRACT

Adhesives are used in very different applications. Up to now the technique of structural adhesive bonding is not applied to steel constructions. This article shows adhesives to be efficient. The application of adhesives in steel constructions is possible and can be an alternative on its own to common techniques like bolts and welds as well as in combination with bolts.

STATE OF THE TECHNIQUE

Normally, steel members are connected with the help of bolts (in the past: rivets) or welds. In the 1960ies, some bridges were built with adhesive connections. There are, however, additional bolts for the sake of safety. Since there was no knowledge of calculation, the construction and design of these buildings were based on tests. Up to now, the bridges do not have any damages. This shows a sufficient long-lasting behaviour of adhesives [1]. Meanwhile the quality of adhesives has been very much improved. There are special adhesives for various possibilities of application. Above all, the car and airplane industries are using adhesives to connect aluminium or steel – so why not the steel manufacturers? Adhesive connections can be an alternative to common techniques like welds, bolts or rivets. Until now the adhesive connection is not used because of a lack of knowledge about the mechanism and design calculation, the long-time resistance as well as the working of the sticking surfaces. For applications, an adhesive with suitable strength and long-time resistance must used. The technique has to be handled easily during the manufacturing of the steel construction.

ADHESIVES AND ADHESIVE CONNECTIONS

Failure modes

The adhesive technique is a positive substance jointing. The additional material - the adhesive - is needed to connect two sections. The active cohesive and adhesive forces in an adhesive layer are responsible for the strength (Fig. 1).

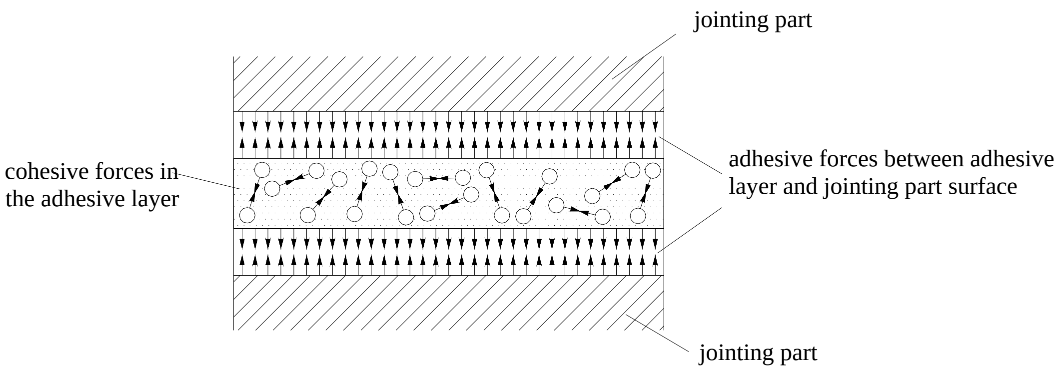


Fig. 1. Adhesive and cohesive forces in an adhesive sealing

If one of the both forces or both will be exceeded due to stress, the adhesive connection fails. If “internal forces” are exceeded, the fracture will occur in the adhesive layer. This is a cohesive crack. The adhesive forces are effective between the adhesive layer and the jointing part surface. An adhesive crack occurs when there is a separation between the both materials. Another possibility of failure mode is the occurrence of cohesive and adhesive cracks at the same time (Fig. 2).

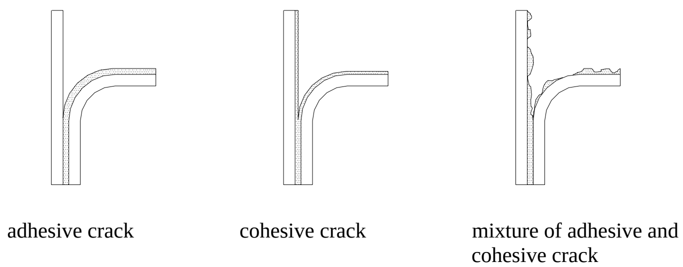


Fig. 2. Crack types

Advantages and Disadvantages

Compared with common technologies of connecting, like bolts, rivets and welds, the technique of adhesives has many advantages. There is a uniformly distributed transmission of forces causing at the same time a uniformly distribution of stress vertical to the loading plane. Fig. 3 shows different stress distributions. The stress distribution by welding depends on the quality of the weld (in particular on the thickness of the weld). There are stress peaks in connections with bolts or rivets due to the weakening of the material (e.g. boreholes).

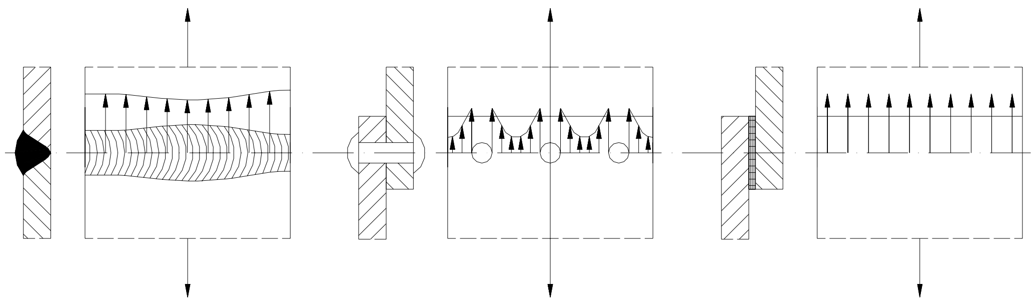


Fig. 3. Stress distributions of different jointings [2]

The production of the adhesive connection is a low-heat fitting process. There are no or only low negative effects to the material structure. During welding the major residual stresses are much higher. In comparison to other jointings like bolts or spot-welding additional adhesive sealings increase the strength. Due to cyclic loading the adhesive functions like a vibration damper because of the lower elastic modulus.

There are, however, disadvantages as well. It is necessary to prepare the jointing surfaces and a definite time is required for the curing of the adhesive in order to get a sufficient strength. A loss of strength is possible due to many influences. High temperatures (>200°C) are the main reason. The design of the steel construction has to be adapted to the adhesive technique. Adhesives have very different strengths in regard to loading. Adhesive connections should be designed in a way to prevent later peeling or split stress. There are negative stress peaks in the adhesive layer due to punctual or in-line stress.

Despite of many tests there are no universal calculation rules for the design of metal-adhesive sealings up to now. The reasons are the very different strength and deformation characteristics of the jointing parts and the adhesive sealing. The adhesive layer is affected by many factors. An adhesive joint consists of an adhesive with an elastic-plastic/viscous-elastic deformation behaviour and the jointing parts with linear-elastic behaviour. This is a composite system of the adhesive and jointing parts. The deformation of the adhesive sealing is influenced by the jointing parts.

ADHESIVE CONNECTION TESTS

Several tests of adhesive connections were carried out. In the first test series, different adhesives were used under various loads. The adhesives tested were not selected for special characteristics, but were free-samples. This test series is described shortly in the following.

The second test series contains combined connections, bolts and adhesives. In comparison with the first test series the second one has been much more informative.

Test series 1

The adhesives were one-component adhesives (e.g. Penloc ® GZ 107) and two-component adhesives (e.g. Sikadur 30). There were two different specimens – plates and t-stubs. The specimens were loaded by bending moments (t-stubs), shear forces (plates) and tension (t-stub). Table 1 shows a list of the tests. The assumption of a cohesive crack was validated in most of the tests. An adhesive crack or a mixture of both crack types was caused by an unsufficient preparation of the jointing surfaces.

Table 1
Test series 1

Plates (2 plates per specimen – figure 4)				
Adhesive	*Number*	*Load*	*Loading*	*Comment*
Strucalit 5800	2	shear	monotonic: 1 cyclic: 1	surface sandblasted
UHU Endfest plus 300	2	shear	monotonic: 1 cyclic: 1	surface sandblasted
Sikadur 30	6	shear	monotonic: 3 cyclic: 3	4 specimen surface sandblasted 2 specimen without prep. surf.
T-stubs (2 profiles per specimen – figure 6)				
Adhesive	*Number*	*Load*	*Loading*	*Comment*
Penloc®GZ 107	2	tension	monotonic: 1 cyclic: 1	surface sandblasted
Penloc®GTI	2	tension	monotonic: 1 cyclic: 1	surface sandblasted
Strucalit 5800	2	tension	monotonic: 1 cyclic: 1	surface sandblasted
UHU Endfest plus 300	2	tension	monotonic: 1 cyclic: 1	surface sandblasted
Sikadur 30	21	tension	monotonic: 8 cyclic: 8	12 specimen surface sandblasted 4 specimen without prep. surf.
		bending moment	monotonic: 5	surface sandblasted

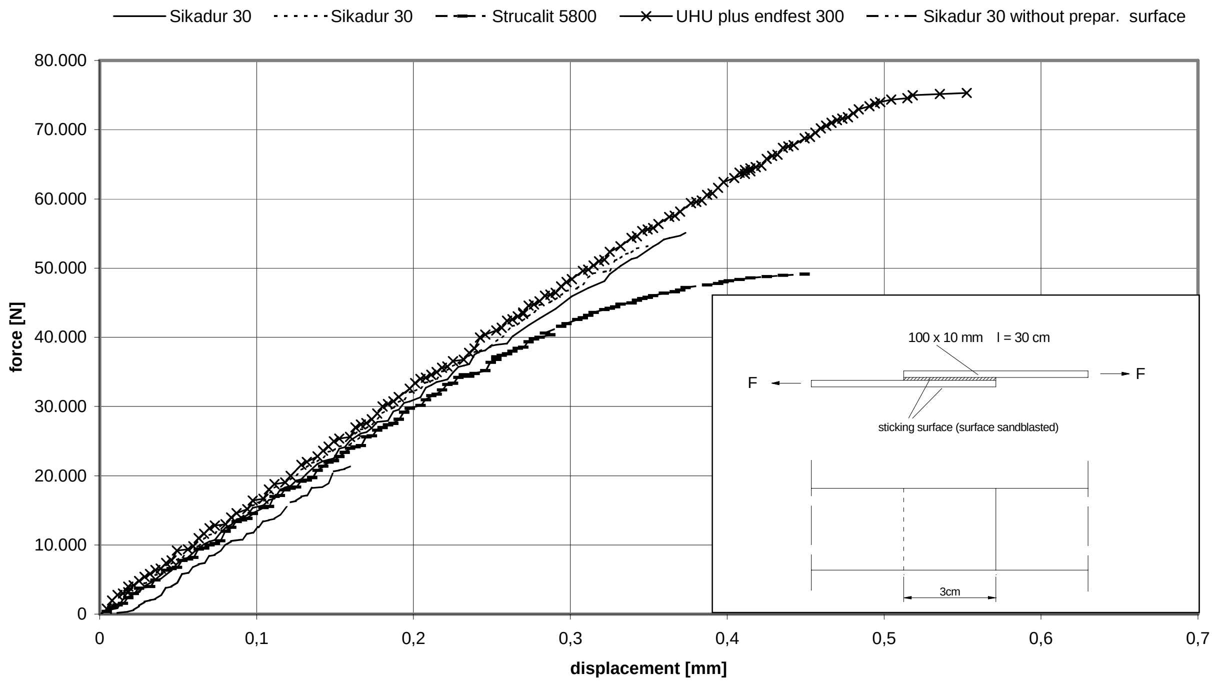


Fig. 4. Plates-connection – force-displacement relations

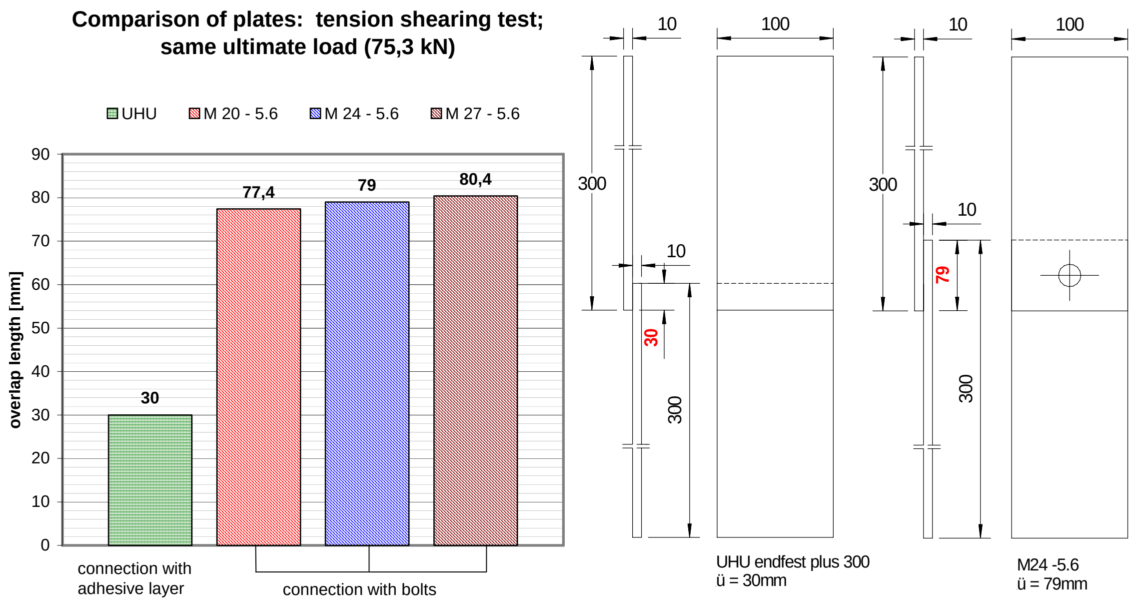


Fig. 5. Comparison of overlap-lengths – adhesive bonding and bolted connections

Fig. 4 compares different adhesives in regard to shear forces. In the test with UHU endfest plus 300, for example, a small sticking area of 30cm² carries of a force of 70kN. In fig. 5, the results were compared with bolted joints. This comparison at the same load level of 75.3kN led to the following result: the overlap-length of an adhesive bonding joint is much smaller than that of a bolted joint, namely 60%. The ultimate load for this bolted connections is determined by bolt bearing and, therefore, by the edge distance.

The first test series also included small t-stubs, which are made from t-profiles. This connection can only be realised as a bolted connection with M12 because of the edge distances. When using high strength bolts of the strength 10.9, the ultimate load is 74kN. Fig. 6 contains the t-stub under tension. The sticking area is 100cm². A t-stub connection with an adhesive named Penloc GZ has an ultimate load of 118kN. This means an increase of 60%.

Both diagrams (fig. 4 and fig. 6) show the requirement of preparing the jointing surfaces.

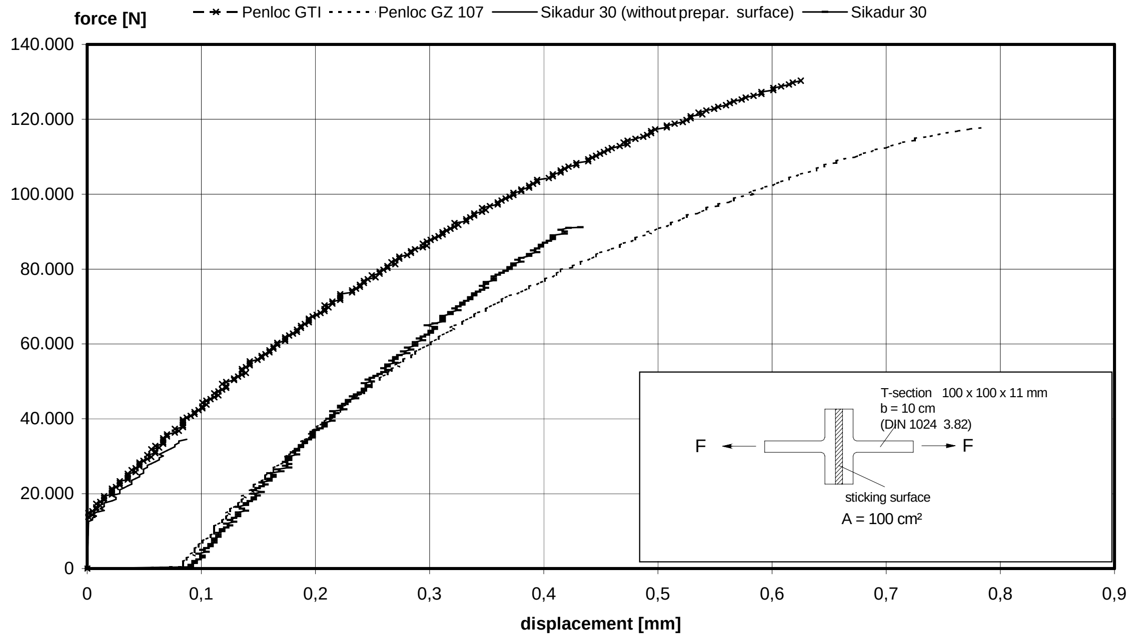


Fig. 6. T-stub – force-displacement graphs

Test series 2

This series includes 38 t-stubs (Fig. 7). There are combined connections with bolts and adhesives as well as specimens only connected by adhesives (Table 2). The high-strength bolts were additionally prestressed. Two-component adhesives were used because of their characteristics in all tests.

Table 2
Test series 2

Adhesive	Connection	preloading of the bolts
Sikadur 30	bolted and sticked: 11	no preloading: 3
		60% = 85Nm: 4
		80% = 113Nm: 4
	sticked only: 3	-
Strucalit 5800	bolted and sticked: 9	no preloading: 3
		60% = 85Nm: 3
		80% = 113Nm: 3
	sticked only: 3	-
Penloc®GTI	bolted and sticked: 9	no preloading: 3
		60% = 85Nm: 3
		80% = 113Nm: 3
	sticked only: 3	-

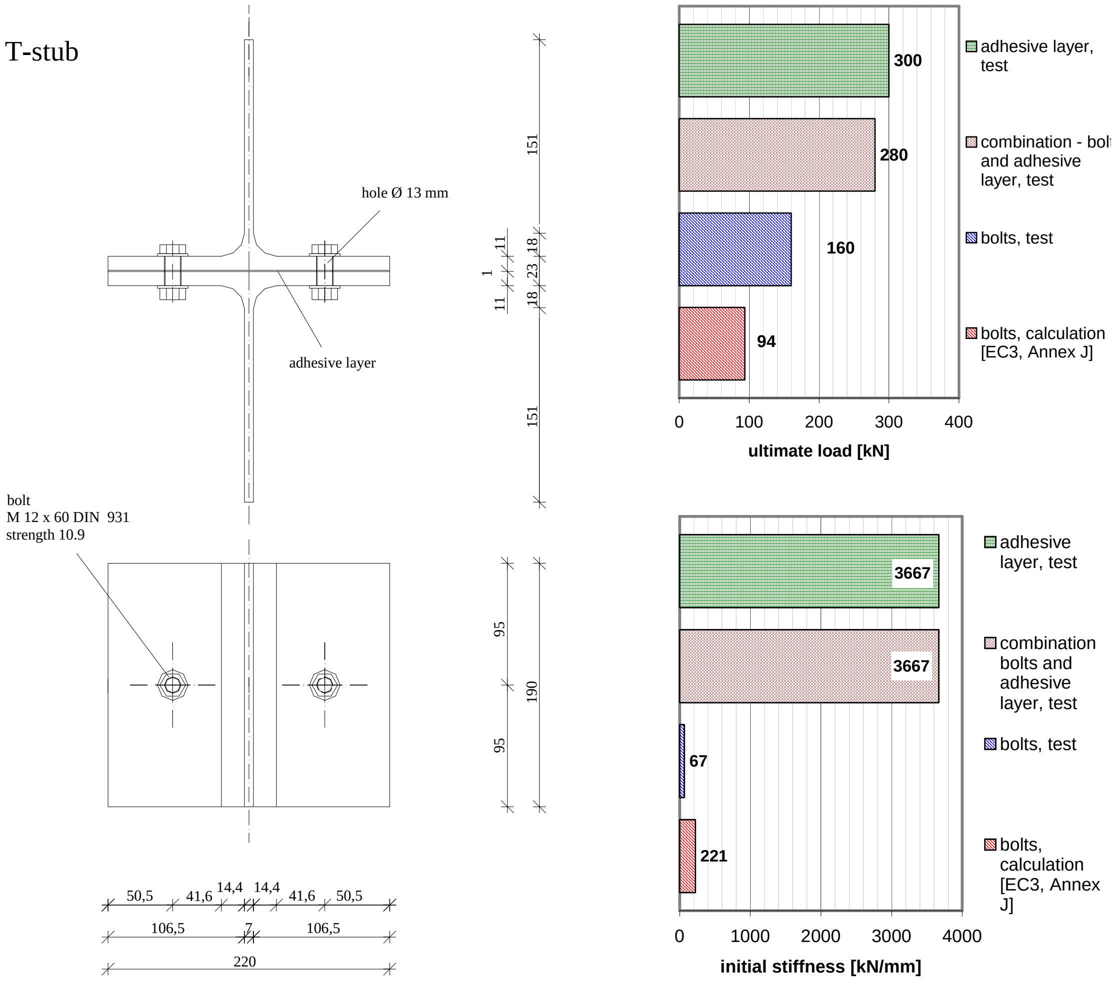


Fig. 7. Test specimen t-stub and comparison

The test specimens were loaded with an axial tension force. The loading was monotonic and displacement controlled. Displacement transducer (HBM) were used to measure the distance between the two flanges (Fig. 8). The force-displacement diagrams are based on measured displacements and forces during the test. The stiffness is calculated from these results. By using adhesives, the ultimate load and initial stiffness could be increased significantly. In the comparison of the t-stub with an adhesive layer and the combined connection, the initial stiffness of both variations was the same, as the stiffness is determined by the composite system of the adhesive bonding.

Fig. 8. Displacement measurement

The three adhesives had very different strengths (Fig. 9). Generally, failure could not be foreseen. In some cases, however, especially with adhesive Penloc GTI, a slight plastic behaviour could be observed.

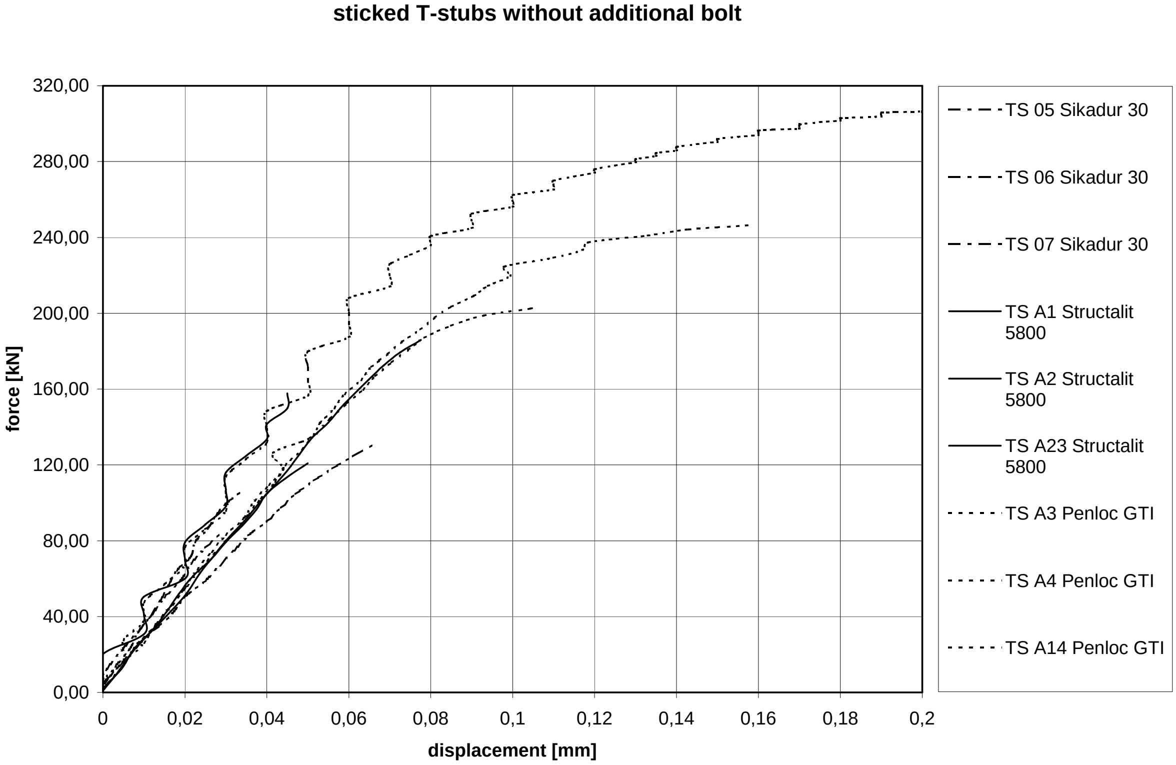


Fig. 9. Force-displacement graphs of the sticked specimen (without bolts)

The specimens with combined connections show very different strengths, as well. Therefore one has to differentiate between the composite system and the t-stub. The t-stub still exists after the failure of the adhesive sealing (Fig. 10). The rise of the graph which describes the stiffness of the connection is nearly constant. The preloading of the bolts has no influence on the stiffness of the adhesive connection.

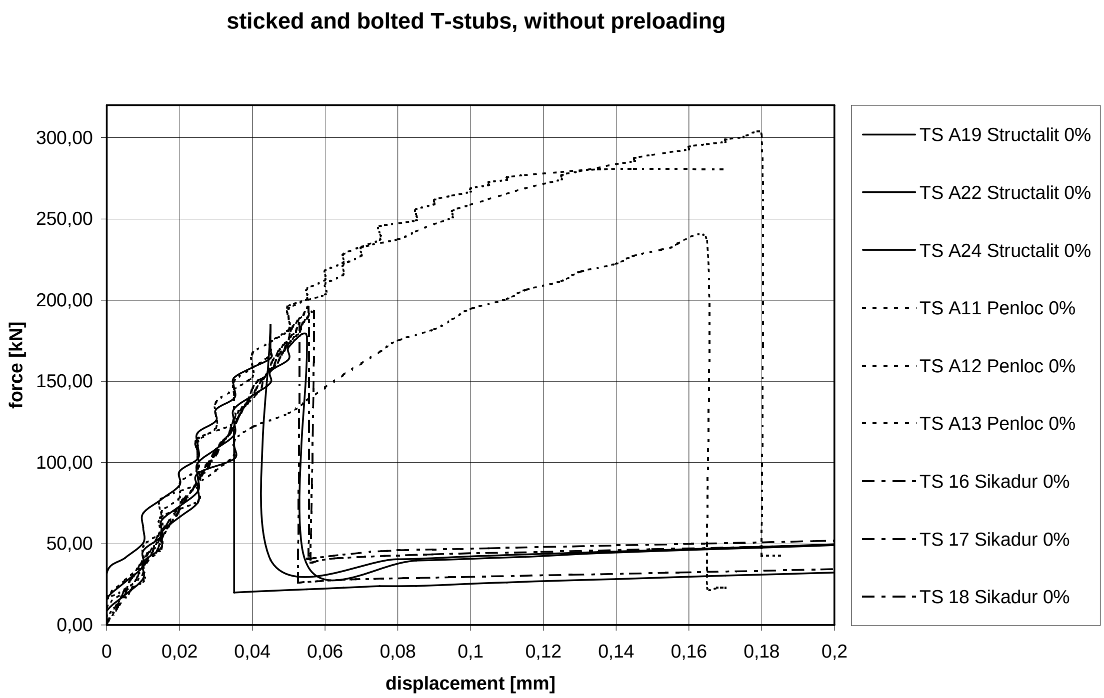


Fig. 10. Force-displacement graphs of the specimen with combined jointing

The increase of the stiffness after the failure of the adhesive-layer due to a higher preloading of the bolts is retained in the t-stub connection. The stiffness of the combined connection is mainly determined by the adhesive sealing.

Fig. 11 shows the comparison of the ultimate loads of the different connection types. The composite system of an adhesive connection has a higher ultimate load than the bolted connection. The disadvantage is the abrupt failure of the adhesive connection. The problem can be solved by additional application of bolts. The bolts are a safeguard against complete failure. Additionally, the carrying capacity can be increased compared to the adhesive connection.

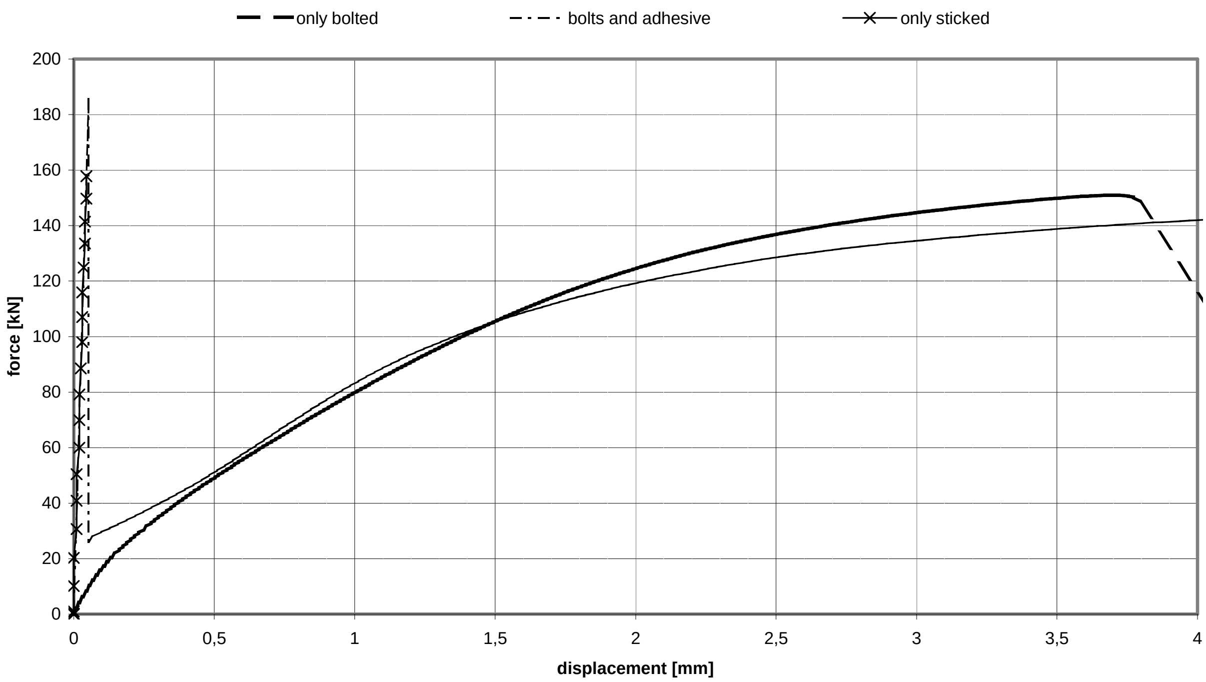
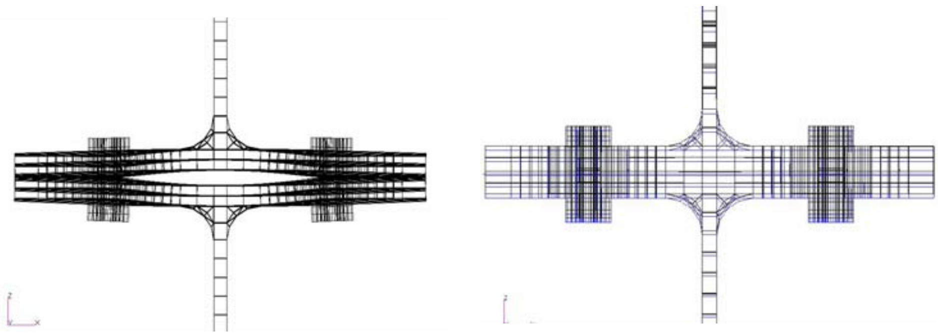


Fig. 11. Comparison of adhesive-connection, bolted connection and combined connection

FE Modelling

Following the tests, FE calculations were carried out using the program ABAQUS. Volume elements were applied in the modelling of the t-stubs. The aim of the analysis was finding a reasonable model for the completely cured adhesive layer in order to carry out a parameter study. The failure of the adhesive connection can occur in different types – cohesive and adhesive cracks. Therefore, the FE model must be able to realise the possible failure modes. There was always a cohesive failure in the FE calculations. The reason for this is that the strength of the adhesive is much lower than the strength of the jointing parts which were made of steel. The simulation of an adhesive crack could not be realised. Fig. 12 shows deformation plots of a bolted connection and a combined connection.

The ultimate loads could be validated by the FE calculations. With regard to the stiffness there are no satisfying results by now. In the next future it will be necessary to carry out more tests and modifications.



a) bolted t-stub b) bolted and sticked t-stub

Fig. 12. Comparison of deformations, tension force, preloading of 60%

CONCLUSION

The test results show the possibility of adhesive connections in steel constructions. In comparison to bolted connections adhesive connections show higher strength and stiffness. The main problems of adhesive connection are the abrupt failure and the long-time behaviour. The adhesive layer increases the stiffness and reduces the peaks of stress in combined connections. The safety is guaranteed by the bolts. The preloading of the bolts has no influence on the carrying capacity and stiffness of a combined connection.

Adhesives are an alternative to the common techniques to connect steel members. It is necessary to create a base of calculation for practical applications.

REFERENCES

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