Extension of the application limits of blind fasteners for joining high-strength steels in metal lightweight constructions

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Abstract

In the context of a publicly funded research project, which aims to develop new design rules for the application of blind fasteners in structures made of high-strength steels, systematic investigations are performed. The paper presents results from quasi-static shear tests on single-point connections with high-strength steel and different types of fastener for lightweight constructions. Two reference series with M6 bolts of strength grade 5.6 and 10.9 as well as two blind rivets Ø 6,4 mm were tested. The sleeve extending blind rivet (MANGA-LOK, ARCONIC *Inc.) and sleeve folding blind rivet (TIBULB,* TITGEMEYER *Group) were used. The steel grade was varied in the range from S235JR up to S700MC. The purpose of the tests is to investigate the effects of high-strength steels on the load-bearing behaviour of shear stressed single-point connections. The first tests results showed a significant reduction of the shear resistance up to 41 %, when using blind fasteners in combination with high-strength steels. Different effects could be identified, which are responsible for this behaviour. Further experimental tests and numerical simulation with single-point and multipoint connections are planned to investigate these effects more detailed. Aim of the investigations is to define rules in accordance with EUROCODE 3 for joints/connections with blind fasteners, which take into account the effects of the usage of high-strength steels.*

Keywords*:* blind fasteners, high-strength steel, design rules EUROCODE 3, blind rivet technology

1. Introduction

High-strength steel with yield strength of up to 1100 MPa has already found its way in applications of crane constructions and automotive manufacturing [1, 2, 3]. Due to their potential the use of high-strength steel for applications in steel and lightweight constructions has significantly increased in recent years [4, 5, 6]. Current examples are modern logistics centres which allow a highly dynamic and fully automated flow of goods. The design of these constructions is linked to the stability behaviour of the structure, which can be significant improved by the use of high-strength steel [7]. The joint designs in these constructions are characterized by small connection sizes, thin-walled components and one-side accessibility where blind rivet as the most common blind fasteners are primarily used. Figure 1 shows a typical joint design with blind rivets in high-rack warehouse systems.

Figure 1: Example of joints with blind rivets in high-rack warehouse system

The use of blind rivets in structural constructions causes problems for the structural engineers regarding the insufficient design rules for calculating the load-bearing capacity of the connection according to the EC3 [8, 9] (Table 1). However, the work of GLIENKE and BLUNK has led to the development of design rules for connections with low- and medium-strength steel and various types of blind rivets according to the EC3 model. [10, 11]

Table 1: Design rules according EC3 for bearing type connections with bolts and blind rivets

Standard	***Bolt***	***Blind rivet***	***Failure mode***
EN 1993-1-3 bearing resistance for 0,45 mm ≤ t_{cor} ≤ 4 mm (<3 mm)1)	$F_{b,Rd}=\frac{2,5\cdot k_t\cdot \alpha_b\cdot f_u\cdot d\cdot t}{\gamma_{M2}}$	$F_{b,Rd}=\frac{\alpha\cdot f_u\cdot d\cdot t}{\gamma_{M2}}$ or $F_{b,Rd}\leq\frac{f_u\cdot e_1\cdot t}{1,2\cdot\gamma_{M2}}$	
EN 1993-1-8 bearing resistance for t_{cor} ≥ 3 mm1)	$F_{b,Rd}=\frac{k_1\cdot \alpha_b\cdot f_u\cdot d\cdot t}{\gamma_{M2}}$	-	
EN 1993-1-3 shear resistance per shear plane	$F_{v,Rd}=\frac{\alpha_v\cdot f_{ub}\cdot A}{\gamma_{M2}}$	Experiments!	
EN 1993-1-8 shear resistance per shear plane for t_{cor} ≥ 3 mm1)		-	
EN 1993-1-1 ultimate resistance of the net cross-section	$N_{u,Rd}=\frac{0,9\cdot A_{net}\cdot f_u}{\gamma_{M2}}$		
1) bolted connections			

New problems in the load-bearing behaviour appear when using high-strength steel in connections with blind rivets. In comparison to a bolted connection the increasing material strength of the components cannot be countered by an increasing strength grade of the blind rivet. The deformation capacity is important for the functionality of blind fasteners. So the connection resistance is directly linked to the constructive design of the blind rivets with their inhomogeneous cross-section and the position of the shear plane related to the mandrel (Figure 2). "Cutting effects" from thin walled components of high-strength steel could lead to a significant reduction of the shear resistance of the connection.

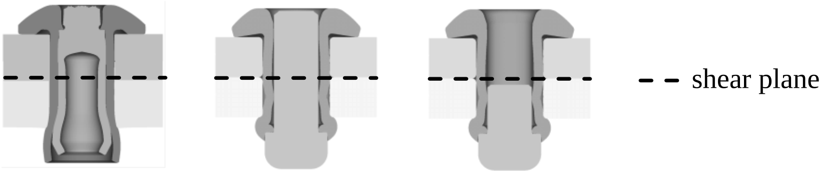


Figure 2: Different type of blind rivets with position of the shear plane [12]

The tests results presented in this paper intend to extend the design rules according to GLIENKE and BLUNK to the application of high-strength steels.

2. Experimental studies

The influences of the steel grade and sheet thickness on the load-bearing behaviour were evaluated by quasi-static shear tests on single-pointed connections. The test specimens consist of two steel sheets with the dimensions from Figure 3. The material strength of the first steel sheet was increased systematically from low-strength steel (S235JR) up to high-strength steel (S700MC). Furthermore the nominal sheet thickness t_{nom} was variegated from 1 mm to 3 mm. For all specimens a second sheet with a nominal thickness of $t_{\text{nom}} = 6$ mm and steel grade S355J2+N was used as substructure. This assumption was made based on the results of [12], where a separate verification of blind fastener and components according the design rules of EC3 was proved, if a supported connection exists ($2{,}5\, t_{\text{I}} \geq t_{\text{II}}$). As Figure 3 shows the end distance of the fastener in load direction was constant with $e_1 = 10$ mm. This distance corresponds to $e_1 = 1{,}5d_0$ mm, the minimal allowed distance for blind rivets according to EN 1993-1-3 [8]. The hole diameter for the specimens with bolts was $d_0 = 6{,}6$ mm according to DIN EN 20273 [13] and $d_0 = 6{,}7$ mm according to the data sheets of the blind rivets.

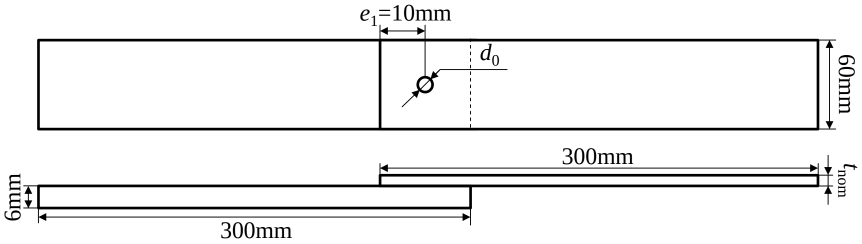


Figure 3: Specimen for shear tests on connections with bolts and blind rivets

For the shear tests a test machine Zwick/Roell Z400E was used. The displacement in the connection was measured with macroextensometer and a free measurement length of $L_0 = 150$ mm according the ECCS document [14]. The tests were terminated when a drop of 80 % of the test load occurred. The test velocity with v = 1 mm/s is based on the specification of the DIN EN 18807-4-E [15] and DIBt statement [16]. Object of the investigation were connections with two different types of blind rivets Ø 6,4 mm, a sleeve extending blind rivet (Manga-Lok, Arconic Inc.) and a sleeve folding blind rivet (Tibulb, Titgemeyer Group), as well as bolts according to DIN EN ISO 4014 [17] of the strength grade 5.6 and 10.9, which served as references. Figure 4 shows the test setup for the quasi-static shear tests (left side) and the different types of fasteners in the connection (right side). All blind rivets were set with the Taurus 4 setting tool (Gesipa GmbH). The bolts were tightened by hand. In Table 2 all test results in comparison to the characteristic values of EC3 are presented. The mechanical properties of the materials for the calculation of the characteristic values were determined in tensile tests in accordance with DIN EN ISO 6892-1 [18] using specimens of type 2 in accordance with annex B.

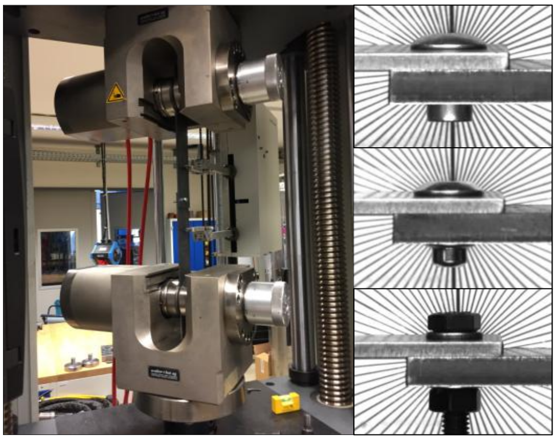
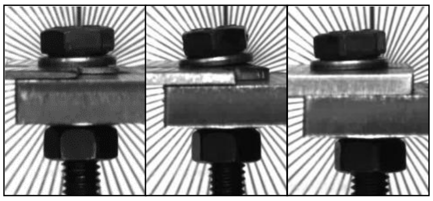
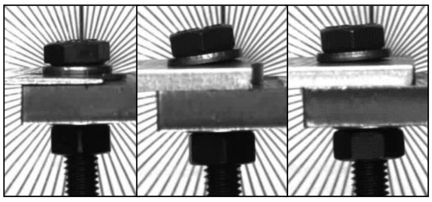
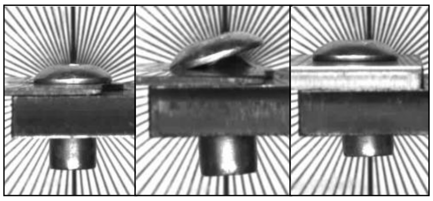
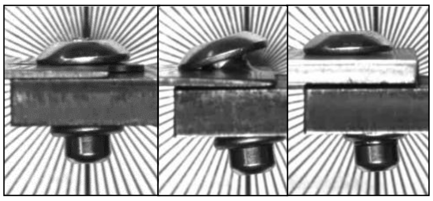


Figure 4: Test setup and type of connections in shear tests

Table 2: Test results and comparison to characteristic values according to EC3

Fastener	***Material***	t_{nom} **[mm]**	***EC3***		$F_{\text{obs,max}}$ **[N]**	***Failure mode***	
			$F_{\text{b,Rk}}$ **[N]**	$F_{\text{v,Rk}}$ **[N]**			
ISO 4014 M6 – 5.6	**S235JR**	**1**	**3.708**	**8.482**	**5.816**	**1**	
		2	**7.173**		**9.584**	**1**	
		3	**10.800***		**11.289**	**2**	
	S355MC	**1**	**3.985**	**8.482**	**5.985**	**1**	
		2	**7.750**		**10.213**	**1**	
		3	**11.860***		**11.329**	**2**	
	S500MC	**1**	**4.922**	**8.482**	**7.146**	**1**	
		2	**10.100**		**10.976**	**2**	
		3	**15.390***		**11.173**	**2**	
	S700MC	**1**	**6.668**	**8.482**	**9.753**	**1**	
		2	**13.133**		**10.960**	**2**	
		3	**19.780***		**11.083**	**2**	
ISO 4014 M6 – 10.9	**S235JR**	**1**	**3.708**	**17.643***	**5.970**	**1**	
		2	**7.173**		**10.229**	**1**	
		3	**10.800***		**15.455**	**1**	
	S355MC	**1**	**3.985**	**17.643***	**5.837**	**1**	
		2	**7.750**		**10.196**	**1**	
		3	**11.860***		**15.792**	**1**	
	S500MC	**1**	**4.922**	**17.643***	**7.287**	**1**	
		2	**10.100**		**14.306**	**1**	
		3	**15.390***		**20.231**	**2**	
	S700MC	**1**	**6.668**	**17.643***	**10.402**	**1**	
		2	**13.133**		**20.155**	**2**	
		3	**19.780***		**20.084**	**2**	
MAGNA-LOK Ø6,4	**S235JR**	**1**	**3.708**	**11.100**	**5.394**	**1**	
		2	**7.173**		**9.721**	**1**	
		3	**10.800**		**11.927**	**2**	
	S355MC	**1**	**3.985**	**11.100**	**6.088**	**1**	
		2	**7.750**		**10.065**	**1**	
		3	**11.860**		**11.598**	**2**	
	S500MC	**1**	**4.922**	**11.100**	**7.549**	**1**	
		2	**10.100**		**12.390**	**2**	
		3	**15.390**		**11.390**	**2**	
	S700MC	**1**	**6.668**	**11.100**	**9.319**	**2**	
		2	**13.133**		**12.062**	**2**	
		3	**19.780**		**11.475**	**2**	
TIBULB Ø6,4	**S235JR**	**1**	**3.708**	**11.100**	**5.650**	**1**	
		2	**7.173**		**6.712**	**2**	
		3	**10.800**		**10.888**	**2**	
	S355MC	**1**	**3.985**	**11.100**	**6.300**	**1**	
		2	**7.750**		**6.497**	**2**	
		3	**11.860**		**10.778**	**2**	
	S500MC	**1**	**4.922**	**11.100**	**7.562**	**1**	
		2	**10.100**		**7.050**	**2**	
		3	**15.390**		**10.721**	**2**	
	S700MC	**1**	**6.668**	**11.100**	**8.712**	**2**	
		2	**13.133**		**7.511**	**2**	
		3	**19.780**		**10.927**	**2**	

1 – bearing failure of component *I*
2 – fastener shear failure
*** – value according EN 1993-1-8**

During the shear tests two failure modes were detected. The first mode was the bearing failure of component I and the second mode was fastener failure due to shear. The reference tests with bolts of strength grades 5.6 and 10.9 provide for all variants conservative results in comparison to the values calculated by EC3. By increasing the material strength and sheet thickness, the failure mode changed from bearing failure of component *I* to fastener shear failure. The maximal resistance of the connection is limited to the shear resistance of the bolts.

The connections with blind rivets behave similar. However, a discrepancy between the nominal shear resistance of the blind rivet from the data sheets and the tests results was observed. Especially for the thin walled component I ($t_{\mathrm{nom}} = 1$ mm) and the higher strength of steel sheet (S700MC) the shear resistance drops down in case of blind rivet failure. By visualization of the load-bearing behaviour during the tests different possible aspects for the reduced shear resistance of the connection could be identified.

Aspects for the effect of reduced shear resistance:

- position of the shear plane in the connection
- “cutting effect” of thin walled, high-strength steel components
- material deflection in direction of material thickness
- secondary bending and inclination of the blind rivet with additional tension force
- constructive design of the blind rivet

In the opinion of the authors the test results of the sleeve extending blind rivet MAGNA-LOK are less affected by the mentioned aspects. This may be caused by the two side self-locking system and the defined breaking point of the mandrel. In comparison, the sleeve folding blind rivet TIBULB seems to be more affected to inclination and “cutting effect”, which leads to a reduction in shear resistance of up to 41 % compared to the data sheet. This uncertainty must be investigated more detailed and later taken into account by adapted design rules.

3. Outlook

The tests showed the application of high-strength steel in combination with blind fasteners could lead to a significant reduced shear resistance. Additionally, numerical simulations will be performed to investigate the load-bearing behaviour under increasing shear load more detailed. With the numerical model, additional parameters of the connection design e.g. type of blind fastener, edge distance or hole diameter which influence this behaviour should be identified. Blind rivets are often used in joints with several fasteners or in cyclically loaded constructions. The description of the load transmission in these joints and their fatigue resistance is essential for the load-bearing behaviour when using high-strength steel. For this issue, tests and numerical simulation of multipoint connections with high-strength steel under static and cyclic loads are planned to find new or adapted design rules according to the design rules of EC3.

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