Numerical Investigation of a Blind Rivet Nut Screw System in LS-DYNA

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1 Preamble

Optimizing existing joining technologies and developing new methods in production technology is increasingly dependent on numeric simulation techniques. Due to the finite element simulation in LS-DYNA this process can be simplified significantly and therefore help to verify important developments such as the introduction of new material approaches or changes of geometric parameters. These parameters are often changed during a development process and are cost intensive if the impact of these changes is determined via experiments. To improve this aspect, numerical models are created to investigate the effects of such parameter changes in sensitivity studies. The advantage of numerical simulation is the possibility to investigate the influence of a single parameter at a time without the influence of side effects of other system relevant parameters.

2 Introducing blind rivet nut systems

The following section gives a brief introduction into the technology of a blind rivet nut and introduces the conventional two step method to install such a fastener. Furthermore, a blind rivet nut screw system is presented. This system combines the installation and the screwing process into one single step process.

2.1 State of the art - Conventional blind rivet nut

Conventional blind rivet nuts (BRN) are often used in car body manufacturing. They do provide a bearing thread in thin walled sheet metal or hollow profiles (cf. Fig.1:).

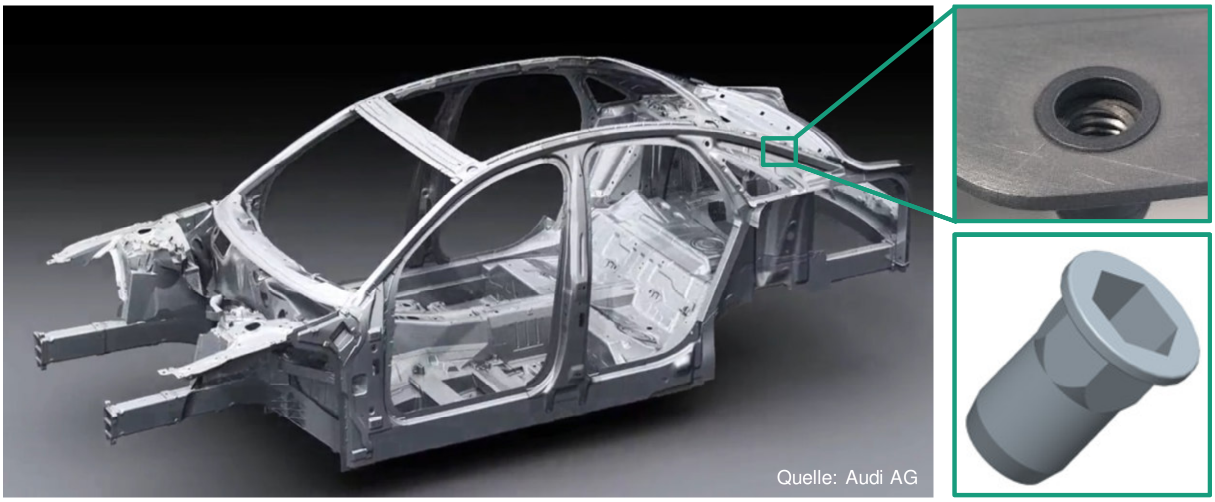


Fig.1: Blind rivet nut in a car body, Audi Space Frame, Audi A8

To realize different applications a variety of BRNs is available. For example, to avoid large gaps between two sheets BRN with a countersunk head or different shaft forms to counteract a twisting of the BRN can be used. If contact corrosion needs to be considered, BRNs with different materials can be used to equalize the electrochemical potential between BRN and sheet metal. Further information on these topics can be found in [1] or [2]. Regardless of the specific geometry or material properties, the general definitions are generalized (cf. Fig.2:).

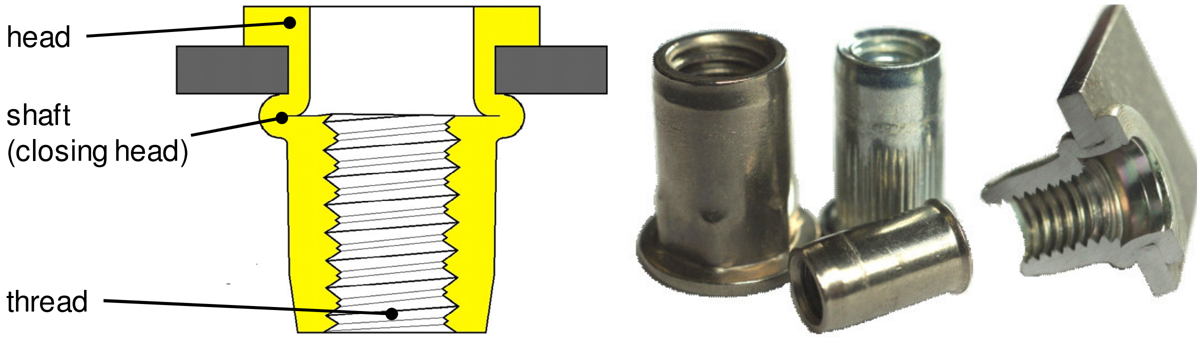


Fig.2: Structure of a blind rivet nut and various BRNs

The traditional process of a blind rivet nut is a complex translative forming process that is followed by a second rotational screwing process (cf. Fig.3:). Therefore, several steps are carried out until the screw can finally be torqued. These steps are independent from geometry or material of the BRN.
In the first step the BRN has to be spindled on the tool stud (electric, pneumatic or manual drive). Afterwards the BRN is placed in the pre-hole of the sheet metal of the first component and the tool is activated so that the shaft of the BRN is compressed until the closing head is formed satisfactory. The final process step of the installation process of the BRN is to unspindle the BRN from the tool stud. Subsequently the second component which should be mounted has to be placed in the designated position and can be screwed using the thread of the BRN installed in the first component. In the last step the screw is tightened with the corresponding torque.

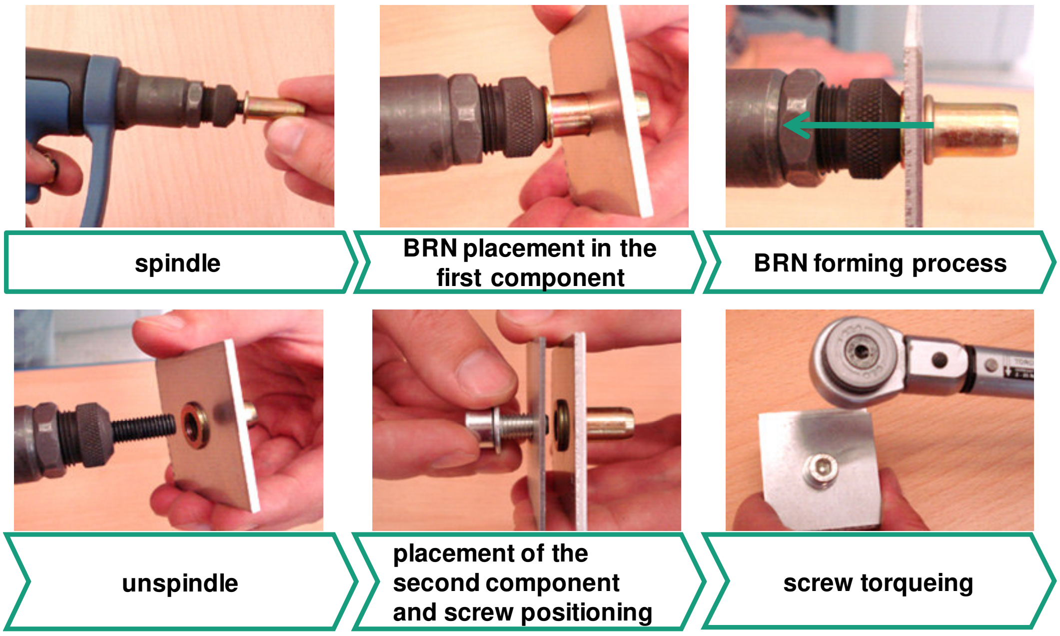


Fig.3: Installation process of a traditional blind rivet nut (cf. [3])

As described above this process is relatively time intensive and least two different tools are needed. To speed up this process and to eliminate one tool needed a blind rivet nut screw system has been developed.

2.2 Newly developed - Blind rivet nut screw system

In order to combine the installation and the screwing process, the BRN and the screw have to be combined into one single mechanical joining element. Consequently, a way to prevent the BRN twisting within the installation process is needed. This is achieved by using a BRN with a semi hexagonal shaft geometry. The chosen fastener concept is presented in Fig.4:.

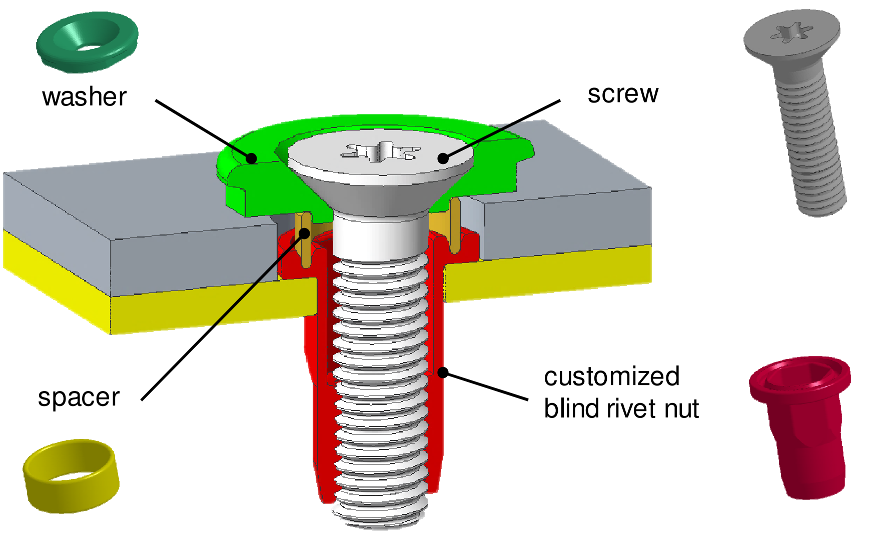


Fig.4: Cross section and 3D-parts of a blind rivet nut screw system

The blind rivet nut screw system (generalized: BRNS | brand name: G-Fast®) consist of four parts. The customized blind rivet nut has a circumferential groove at the head to stabilize the spacer and to hold it into position. As mentioned, the semi hexagonal shaft of the blind rivet nut serves to prevent rotation. The spacer is fixing the blind rivet nut until its closing head is formed satisfactory. The washer clamps the upper sheet metal and the screw provides the torque that is needed to form the closing head as well as the spacer and to clamp the upper sheet metal.

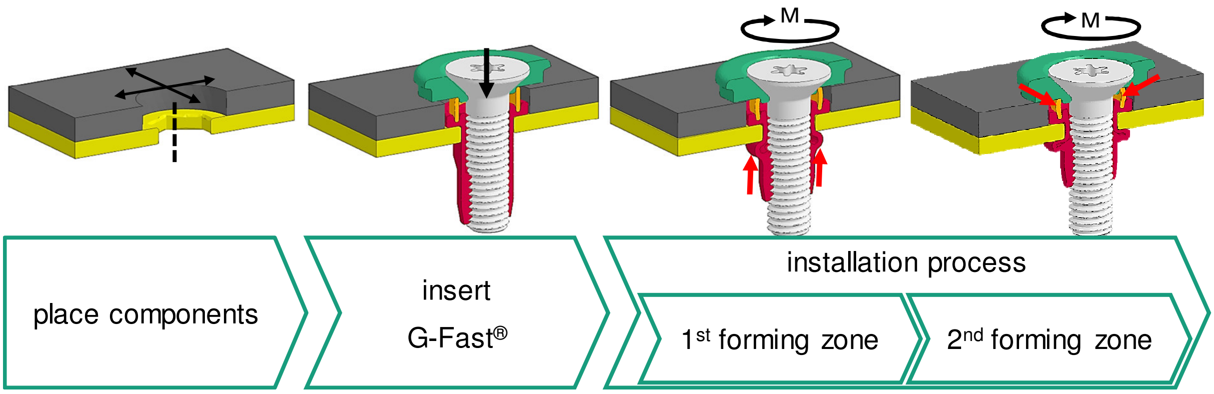


Fig.5: Installation process of the blind rivet nut screw system

The BRNS is a joining element used in sheet metal applications to install a bearing thread and a second component in one step. In comparison with a conventional blind rivet nut the installation process of the BRNS has only four stages. The blind rivet nut has the task to clamp on the lower sheet and to provide the bearing tread for the screw. The washer clamps the upper sheet and the screw provides the needed force to form the 1st and 2nd forming zone. The spacer (2nd forming zone) keeps the washer from clamping the upper sheet until the 1st forming zone of the blind rivet nut is clamped properly on the lower sheet. The idea of installing both components in one step saves up to 50 % of time compared to a conventional blind rivet nut. For a fast market entry of the G-Fast® System and to save time during development, numerical investigations in LS-DYNA were carried out.
An efficient finite element modeling strategy enables a fastener behavior estimation during the installation process without expensive production efforts or experiments. As part of a AiF research project (16727BR, cf. [3]) and in close cooperation with the company GESIPA Blindniettechnik GmbH, this new joining element has been developed.

3 Numerical approach

In the following section the numerical approach to develop a mechanical fastener on the example of a BRN is discussed. Additional to the geometry of the system, material and friction properties are the most important physical values needed in a numerical simulation. Therefore, the characterization of those parameters is discussed in the first and second subsection. Subsequent the chosen model setup in LS-DYNA is presented in the third subsection.

3.1 Defining material properties

The material of a mechanical fastener has to endure various production steps before it is finally formed during the fastener installation process. The shape of a mechanical fastener is made from a metal wire. Small sections of the wire were cold formed in four to six steps until the designated shape is achieved. Subsequently the mechanical fastener has to undergo a heat treatment to equalize the material microstructure and finally the thread is cold formed into the fastener. Afterwards a coating is applied to the surface to protect the mechanical fastener from corrosion and to reduce the friction within the thread.

Based on specimens according to DIN 50125:2016 [4], with a specific heat treatment, tensile tests were performed in accordance to DIN EN ISO 6892-1:2017 [5]. The selected heat treatment process has been equal to the process designated for the fastener.

As a result of those test, curves displaying load and elongation have been gained (cf. I in Fig.6:). Those curves have been transformed in true stress true strain curves. Starting from the beginning of flow stress up to the uniform strain where local necking of the specimen starts data have been extracted (cf. II in Fig.6:). Those data are used to extrapolate the curves to higher stresses and strains respectively (cf. III in Fig.6). Furthermore a hardening effect due to higher strain rates is applied which scales the yield stress (cf. IV in Fig.6)).

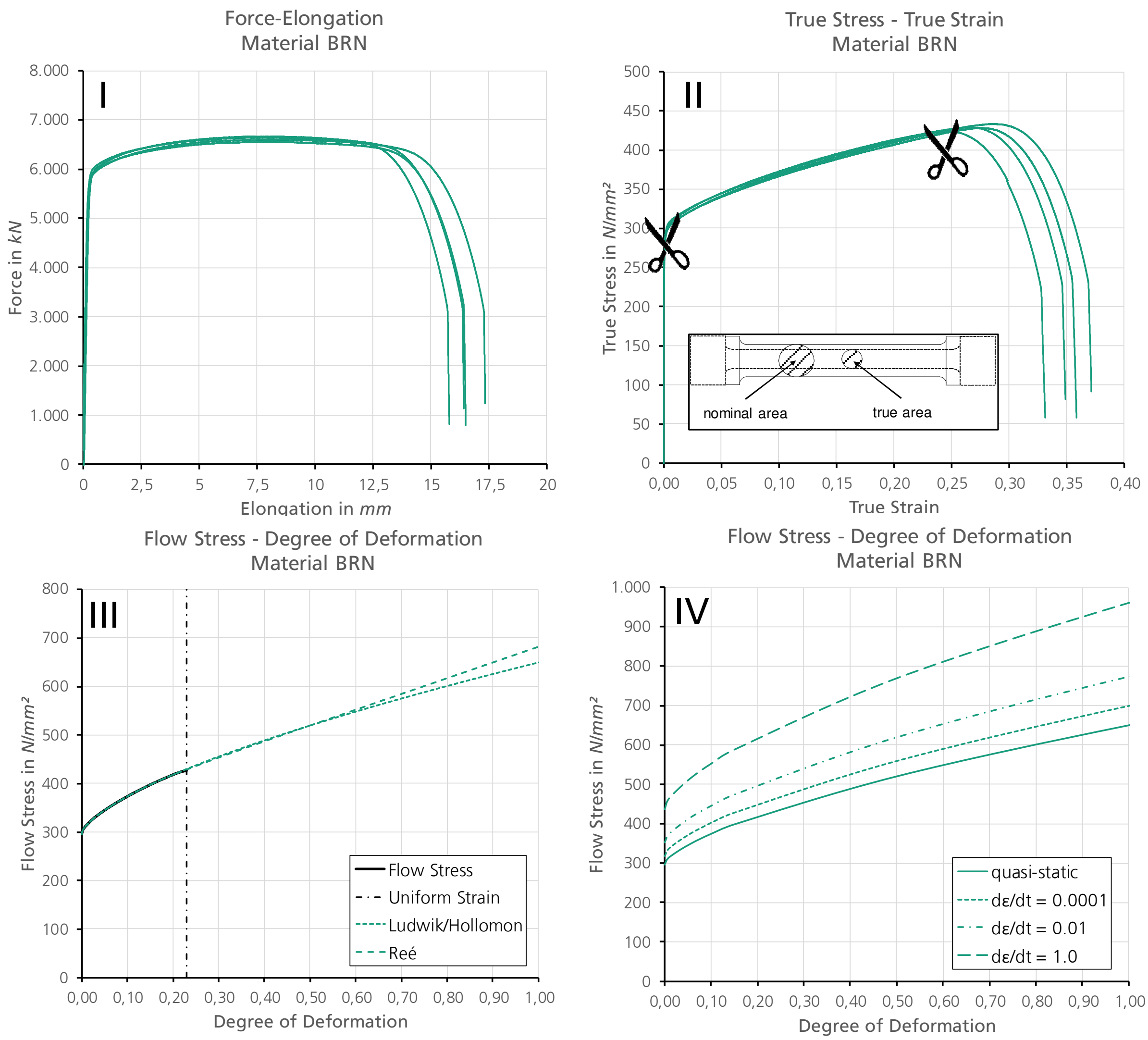


Fig.6: Determination of material properties

Several extrapolation approaches were carried to on those data. The best fit was achieved by approaches according to REÉ (cf. [6])used for various metals (1):

$$\sigma_F = C_1 * \varphi + C_2 - C_3 * e^{-C_4 \varphi} - C_5 * e^{-C_6 \varphi} \tag{1}$$

$$C_1 = 0{,}5\ R_m$$
$$C_2 = R_m$$
$$C_3 = 0{,}25\ R_m$$
$$C_4 = 100\ n$$
$$C_5 = 0{,}25\ R_m$$
$$C_6 = 10\ n$$

and LUDWIK/HOLLOMON (cf. [7, 8]) especially used for unalloyed steel (2):

$$\sigma_F = C_1 * \varphi^{C_2} + C_3 \tag{2}$$

$$C_1 = 2\ R_m$$
$$C_2 = n$$
$$C_3 = 0{,}5\ R_m$$

Both approaches determine the hardening law (flow curve) using material properties like the tensile strength R_m and a parameter n that can be chosen to fit the curve properly to the experimental data. The Parameter φ represents the degree of deformation. In the simulation the approach by LUDWIK/HOLLOMON was chosen because it fits the data properly and has a smooth transition to the experimental data. With regard to higher degrees of deformation the hardening is less compared to the approach estimated by REÉ.

3.2 Defining friction properties

Friction is another important parameter in the numerical simulation of a mechanical fasteners. It occurs within the installations process of a BRNS due to the relative translational and rotational movement of the fastener parts. In tests according to DIN EN ISO 16047:2013 [9] the friction properties of the blind rivet nut element of the BRNS and the screw have been determined. The test setup is presented in Fig.7:.

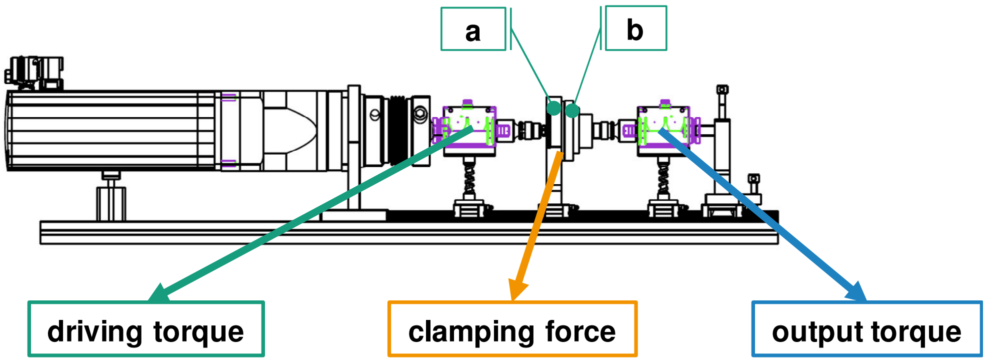


Fig.7: Test setup according to DIN EN ISO 16047:2013

The blind rivet nut is placed into the test bench whereas the blind nut head is fixed, so it cannot move. The screw starts rotating and thereby forms the blind rivet nut. Meanwhile the clamp load F between plate a and b, as well as the needed torque T_b and the resultant moment in the thread T_{th} of the blind rivet nut of the BRNS is measured. These values are needed to calculate the friction coefficient in the thread (3):

$$\mu_{head} = \frac{T_b}{0{,}5 * D_b * F} \tag{3}$$

As well as the friction coefficient underneath the head of the screw (4):

$$\mu_{thread} = \frac{\frac{T_{th}}{F} - \frac{P}{2\pi}}{0{,}577 * d_2} \tag{4}$$

The color-coded parameters can be measured directly within the test bench. All other parameters are geometric values which are constant, e.g. like the thread pitch *P*.

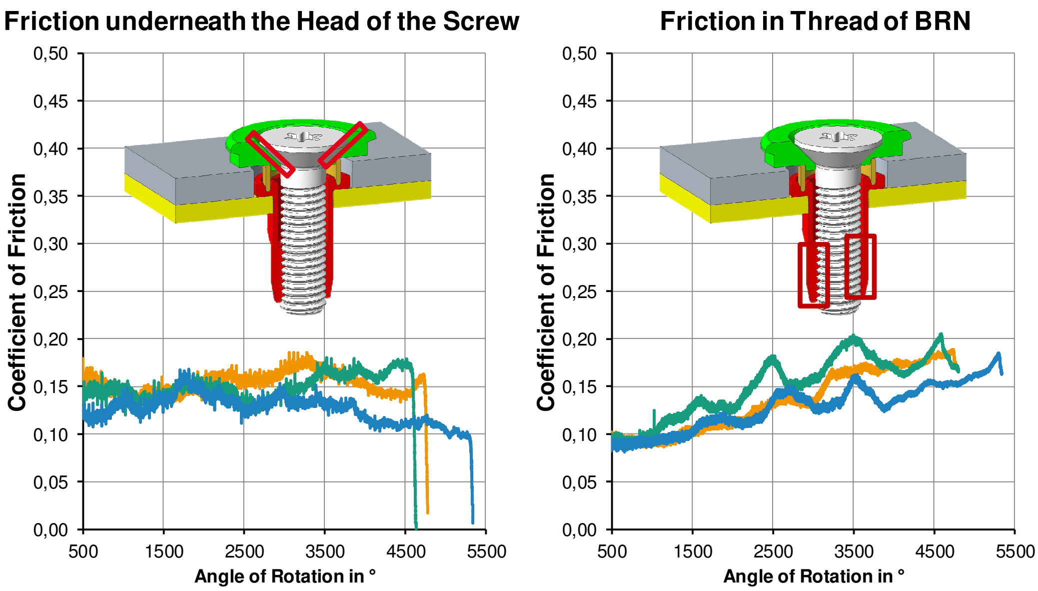


Fig.8: Results of friction properties of blind rivet nut part of the BRNS and head of the screw

These tests have determined the frictional properties between the blind rivet nut part of the BRNS and the head of the screw during the installation process as well as the thread friction (cf. Figure 8). The results indicate the dynamic coefficient of friction based on an averaging process between a rotational angle of 1000° and 3500°. The static coefficient of friction cannot be determined in these tests. This value is estimated based on the value of the dynamic friction. These parameters are included in **`*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE`** keyword and define the frictional properties.

Table 1: Values of friction bases on averaging and calculation

Area of Contact	**Dynamic Coefficient of Friction (FD)**	**Static Coefficient of Friction (FS = 1.1*FD)**
Thread of the BRN	0.13	0.143
Head Rest	0.14	0.154

3.3 Model setup

Based on data from a CAD/CAM program a quartered model of the BRNS was setup in LS-PrePost. This simplification was made to reduce the calculation time. A conducted comparison with a full-scale model showed no significant differences between both approaches. The model was build using 3D solid elements. In this process the 1st and the 2nd forming zone have been modeled with a fine mesh to ensure that the forming process is approximated correctly. The whole simulation model was setup with tetrahedral elements using **`*SECTION_SOLID ELFORM 10)`** and does consist of approximately 400˙000 elements with edge lenths from 0.1 mm to 0.5 mm. The material properties were determined

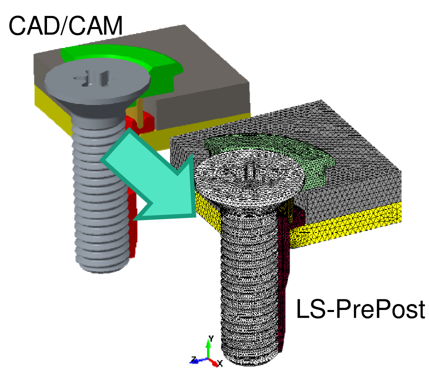
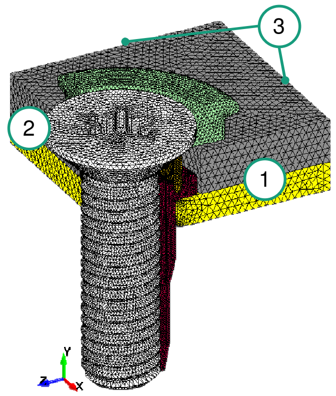
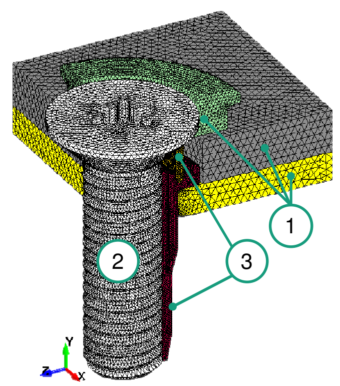
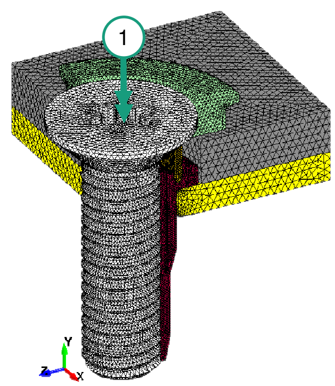


Fig.9: Model Transition

in experiments and the extrapolation approach described in section 3.1. The material law was included in ***MAT024_PIECEWISE_LINEAR_PLASTICITY** by means of using the VON MISES plasticity law with a straine rate depending hardening effect according to COWPER/SYMONDS (cf. [10]). Contact is realized with ***CONTACT_AUTOMATIC_SURFACE_TO_SURFACE** where friction properties have been determined in experimental tests described in section 3.2. The required torque of the screw was taken from previous investigations of an experimental M5 BRNS and have been applied to screw modelled as a rigid body using ***LOAD_RIGID_BODY**. The model setup is summarized in Table 2:

Table 2: Overview of applied Boundary Conditions in LS-PrePost

SPCs (*Boundary_SPC_SET)	**Material** **(various *KEYWORDS)**	**Load** (*LOAD_RIGID_BODY)
		
	Settings	
1) xyzRxRyRz: 011100 (Symmetry y-z-plane) 2) xyzRxRyRz: 110001 (Symmetry x-y-plane) 3) xyzRxRyRz: 111111 (Fixation in space)	1) ***MAT_ELASTIC** (Properties of Steel) 2) ***MAT_RIGID** (Properties of Steel, CMO =+1, CON1 = 6, CON2 = 6) 3) ***MAT_PIECEWISE_ LINEAR_PLASTICITY** (Properties of Steel, cf. 3.1, C = 40, P = 5, VP = -1)	1) ***LOAD_RIGID_BODY** (Load curve (Torque) defined in experiments, DOF = 6)

4 Simulation and Results

As can be seen in Figure 10 the forming process of the BRNS system can be sufficiently approximated for various configurations. The finite element model is able to ensure a reliable solution for different configurations of spacer and sheet combinations. Based on this model validation the properties of different mounting conditions, such as a varying sheet metal thickness or pre-hole diameter, can be investigated.
Furthermore, it is possible to analyze different engineering values which cannot be investigated experimentally or just with a high experimental effort. These are in particular characteristic parameters such as stress (VON MISES, TRESCA), strain (effective plastic strain), the stress state defined as triaxiality or the clamp load between the sheets generated by the BRNS. These parameters and their resultant values are monitored during the

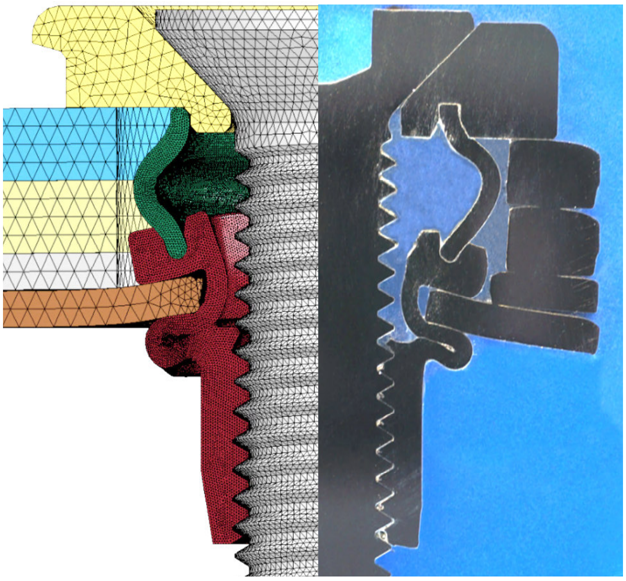


Fig.10: Result for a specific BRNS Configuration

simulation in which case their evolution can be determined. Subsequently important design criteria can be evaluated, such as:

1. The deformation history of a finite element.
2. The possible damage of a finite element can be approximated.
3. Critical geometry sections of the fastener can be extracted.
4. The clamp load can be evaluated precisely.

Taking the last-mentioned parameter as an example, a comparison of the numerical calculated clamping force to experimental data gained in several tests (cf. 3.2) can confirm the validity of the approach. The prediction of the clamp load is presented in Fig.11:.

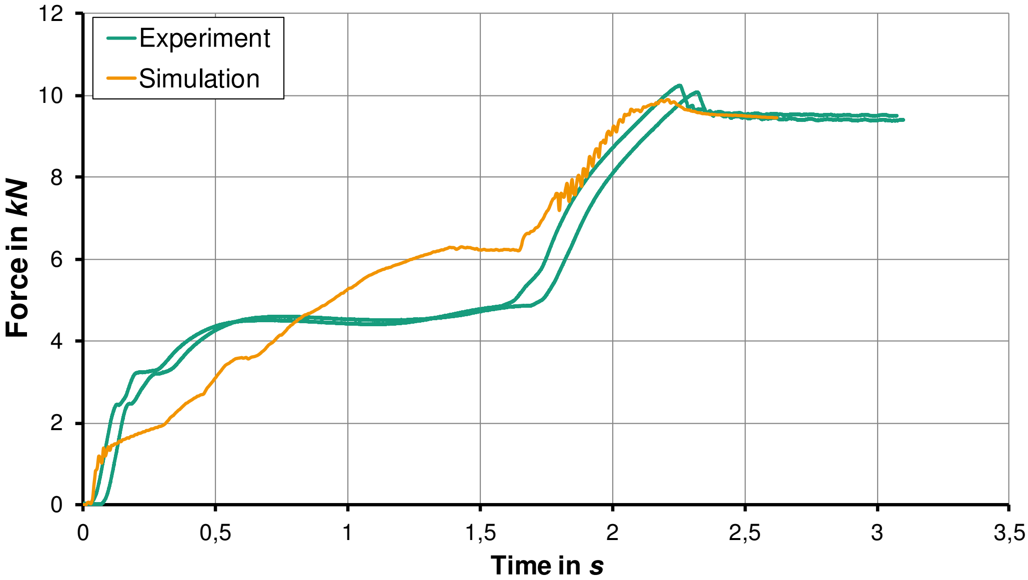
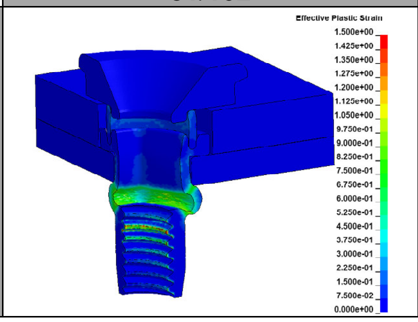
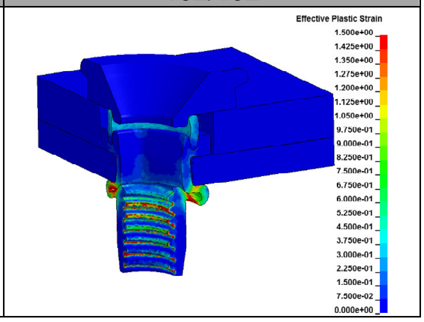


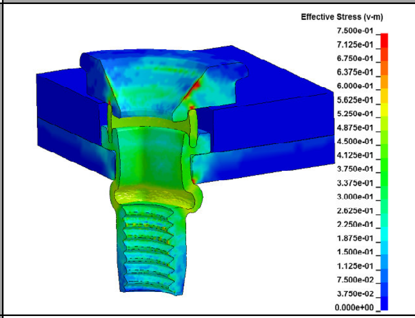
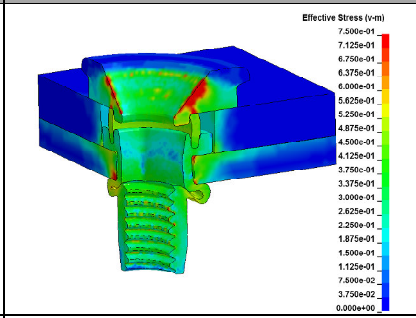
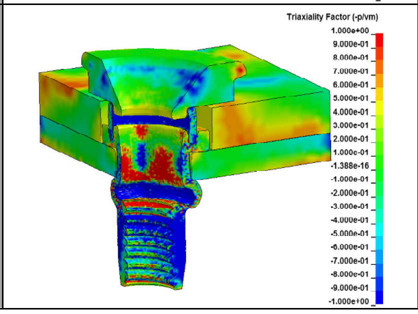
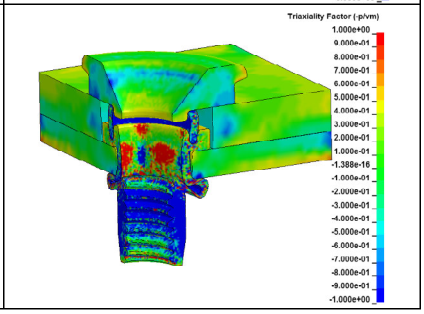
Fig.11: Comparison of the installation process (FEA simulation vs. experiment)

The comparison shows that the final clamp load level can be predicted with high precision. The force needed during the forming process of the blind rivet nut part of the BRNS and the spacer differs from the experimental data due to the test setup used to gain the experimental data. In the experiments no spacer can be used because otherwise the clamp load cannot be monitored. Therefore, the calculated force during the installation process is higher than monitored in the experiment. Due to the fastener modifications necessary to carry out the experimental tests, the numerical model validity is not affected. Regardless of these differences the prediction of the clamp load is the more important value for an engineer and its prognosis is indispensable. The value mainly defines the load bearing capacity of the BRNS.

As previously mentioned, various engineering values can be monitored during the simulation of the installation process. Table 3 gives an overview of two different states in the process simulation.

Table 3: Comparison of engineering values during simulation (screw is blanked out)

	State	
	51/102	102/102
Strain		

	State	
	51/102	102/102
Stress (von Mises)		
Triaxiality		

The figures in Table 3 represent the forming process at a state of 51 and 102. Compared to Fig.11: these states represent the process at 1.25 s and 2.5 s. In the middle of the installation process the plastic strain is concentrated at the 1st forming zone (BRN). At the end of the process it can be observed that a plastic deformation occurs in the 2nd forming zone and the first three threads of the blind rivet nut part of the BRNS have also been plastically deformed because there are the most loaded. This effect is in accordance with the theory of a bolted joint (cf. [11–13]).
The highest plastic deformation is localized in the thin walled area of the blind rivet nut part of the BRNS. Due to the semi hexahedral shaft the wall of the shaft has a thick and a thin area at the transition from a hexahedral to a round shaft. This is also the area, where the maximum effective plastic strain occurs. The calculated distribution of the stresses is plausible. Relatively high stresses in the 1st and 2nd forming zone occur in the middle and respectively at the end of the installation process. They are higher than the initial flow stress so that plastic deformation can take place. High stresses can also be observed at the edge of the lower sheet. If a plasticity law would be applied to the metal sheet a plastic deformation would appear.
One conspicuousness has to be mentioned by analyzing the calculated stress data. Stresses which appear at the symmetry planes are artificial and were generated due to the revolution of the screw relative to these planes. These stresses did not occur in the full-scale model simulation whereas the results like clamp load have been the same in comparison to a quartered model. Therefore, these stresses and respectively the results in these areas are not taken into account in the evaluation.
The triaxiality is an important characteristic value in the analysis of an unknown mechanical system. Based on this parameter it is possible to determine the stress state of a specific area of interest. Thereby the stress state evolution during the installation process can be analyzed. For example, the first bearing thread is changing its stress state during the installation process. Until the flange touches the thread the stress state is rather tension dominated. Afterwards the stress state is pressure and shear dominated due the fact that flange and thread are pressed together.
Additionally, to the simulation of the BRNS system some more detailed analyzes revealed that the forming process of the spacer induced a relatively high plastic deformation. To reduce this plastic deformation in this thin walled part and to prevent the spacer from extensive material hardening some geometric changes were proposed. These changes at the head of the blind rivet nut, helped to decrease the plastic strain at the spacer by about 20 %. Further information regarding this topic can be found in [14].

5 Conclusion

The simulation of the BRNS system, so called G-Fast® system, revealed the potential of this mechanical fastener. Two different geometric approaches have been investigated. The results of the numeric investigations helped to increase the performance of the four components and to overall optimize the G-Fast® system. Some difficulties regarding false element stresses have been identified

in the symmetry plane of the quartered model approach, where SPCs have been applied. These false results are minor and can be neglected after validating the simulation with a full-scale model.
Due to different geometric parameter values investigated in the research project the G-Fast® system is able to be used for various applications and combinations of metal sheets, while there are no compromises in load bearing capacity compared to a conventional blind rivet nut. Therefore, a conventional fastener can be replaced with a G-Fast® system to speed up the installation process and maintain the same properties.

6 Acknowledgment

The project *"Numerische und experimentelle Untersuchungen von Blindnietmutter-Schraub-Systemen"* Ref.-No. AiF (16727 BR) was managed and supervised by the European Research Association for Sheet Metal Working (EFB). In the scope of the Program to Promote Industrial Collective Research it was funded by the German Federation of Industrial Research Associations (AiF) with means of the Federal Ministry of Economic Affairs and Energy (BMWi) on the basis of a decision by the German Bundestag.

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