Stiffness analysis of spot joints as a condition for the numeric modelling - new test methods

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ABSTRACT: Accurate numerical calculation of stresses in structures with a multitude of spot joints continues to be a challenge, especially if local stresses are located in the area of joining positions or if crack endangerment needs to be addressed. In addition to inadequate FE modelling, a major cause for this is the unavailability of exact primary data, which describe the properties of the joints. New methods for determining the stiffness behaviour of joint connections bases on the measurement of the relative displacement of the sheet metals between the joints during applying a load. The measured relative displacement is proportional to the deformations in the joint area. Strain of the test specimen as well as deformations of the load frame or the force measuring cells have no effect in the relative displacement. Two test methods and the necessary measurement technology will be described. On the one hand a method for symmetric joint connections will be shown and on the other hand a method for unsymmetrical pairings of sheets. For the first case a 2-point-shear-load-specimen is used, for the second a 3-point-torsion-test.

KEYWORDS: Structure testing, spot joint, spot joint stiffness, identification, mechanical joining, simulation

1 INTRODUCTION

The employment of joint connections today takes place in diverse structures and in different types. A basic condition for the choice of suitable joining processes with the construction of large structures represents the predictability and ability for dimensioning of the connections. Conflicting aims are on the one hand: the connections should not be over-designed under the criterion of mass savings and on the other hand: design the connections safely for new highly loaded multi-material structures. This leads to higher requirements to the quality of the investigation of the loading of joints. Depending on the demand of a construction the static and cyclic stresses, the crash performance or the stiffness behaviour are taken as a basis. The characteristics of the products - also the joints themselves - are essentially dominated of the characteristics of the structural elements, however joints under operational loading can be subject to substantial local stresses, which can lead to damages or to the failure of the connection. An important role relating engineering the connections comes to the static stiffness of the joints. Static stiffness is meant here as the ratio of force, affecting the connection zone, and the deformation.

Inaccurate experimental results, like e.g. global static stiffness values, lead to time-intensive and thus to costly design loops for calibration and verification of the simulation models for assembly units.

Up to now the stiffness values for connections are determined at one-point-samples or construction-unit-similar samples by measurement of the deformation of the test specimens under loading. With this measuring method it is difficulty to separate the portions of deformation of connection zone and construction unit. Therefore to small stiffness values are usually derived. The reasons are among other things the inaccurate capture of the regions of deformed volume of the connection zone as well as the influence of strains of the basic material and the stiffness of transducers.

This article describes a new method for the determination of the static stiffness of point-to-point connections on the basis of the measurement of relative displacements of the joining partners during load and gives notes for the use of the measured values for simplified models in FEA.

2 Measurement method of relative displacements and Optimization of specimen geometry

2.1 SYMEMETRIC SPECIMEN FOR SHEAR-TENSOIN-TEST

The principle of measuring the relative displacements for the determination of joint stiffness was developed in accordance of the 2-point specimen for shear-tension-test. Basis for this kind of test specimen is the point symmetry. This means, that symmetry for geometry, material and connector type exists. In Fig. 1 the principle of the measuring method is described with a spring model for 2-point shear-tension. Under shear-tension loading the both connection zones will be loaded balanced due to symmetry. Both the base material of the

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sample and the joint are deformed. The deformation of the connection zone consists of the deformation of joints and the basis material in the zone. The deformation of both zones leads to a relative displacement of the sheet metals, which can be measured in the point of symmetry between the joints. The measured size of the relative displacement is equal to the size of the deformation of connection zones. The deformation of the base material outside of the connection zones is symmetrical in both sheet metals and causes no relative displacement. Thus the joint stiffness C_N can be derived from the ratio of force per joint $F_G/2$ and the measured relative displacement S_R.

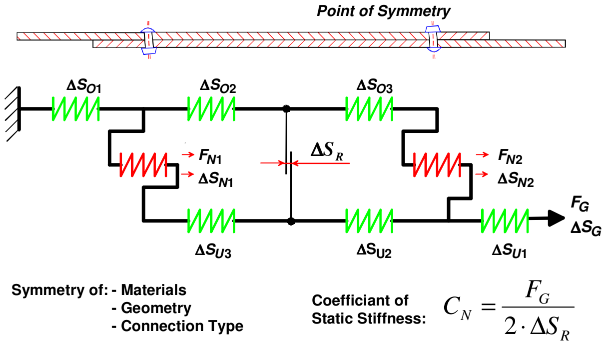

Figure 1: *Principle of measurement method for the joint stiffness – Symmetrical test specimen*

The 2-point-shear-tension specimen is then tested in tensile load equipment. The tensile load is determined by means of force measuring instrument of the machine. For the measurement of the relative displacement a sensor was developed, which is attached within the region of the point of symmetry between the joints at the specimen and contains a DMS equipped bending bar. The resolution of the sensor must be suitable for the collection of measured values in the µm range. Fig. 2 shows a specimen with blind rivets as connectors in the tensile load equipment with the sensor for the relative displacement measurement. Elasticity of load framework, clamps and load cell have no influence on the measured values for the relative displacement.

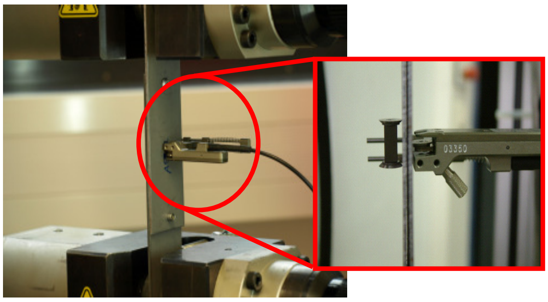

Figure 2: *Test set-up with relative displacement sensor*

In extensive test series the geometry of the test specimen was optimized. On the one hand the dimensions had to be minimized. On the other hand the geometry must have no influence on the measurement of the relative displacement. Fig. 3 shows the optimized geometry for the symmetric 2-point-shear-tension specimen.

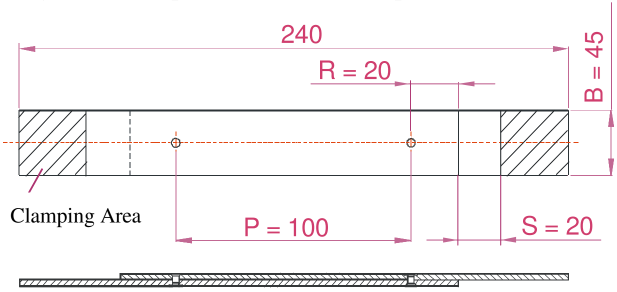

Figure 3: *Geometry of the optimized 2-point-shear-tension specimen*

2.2 SPECIMEN FOR TORSION TEST

The majority of joining connections is asymmetrically. Usually different sheet metal thicknesses or different materials are involved. In this case a 2-point-shear-tension specimen would be loaded unequally and thus also unequally deformed. Neither the measured tensile forces nor the measured relative displacements can be assigned clearly to a joint. For these non-symmetrical connections the torsion test specimen was developed. It consists of an outside sheet metal ring and an internal disk, which are connected with two or more joints, see Fig. 4. Within the test the outside ring is clamped and the internal disk is loaded with a torque. Thus the joints are loaded with shear-tension. With this experimental set-up all joints are loaded and deformed evenly. The specimen geometry was developed in such a way that with a 3-point-torsion specimen the arc length of the joint-connecting-circle between two joints amounts to 100 mm. Hence the results of a 2-point-shear-tension test and a 3-point-torsion-test become more easily comparable.

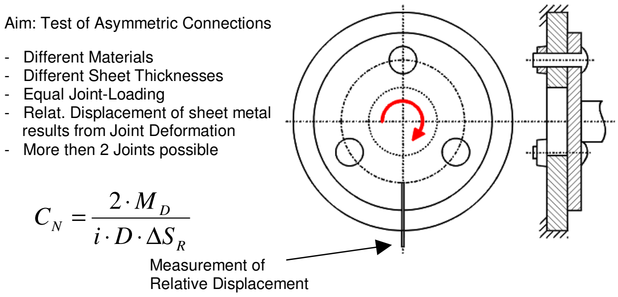

Figure 4: *Torsion Test Set-Up and Specimen Geometry*

The force affecting the joint is determined from the measurement of the applied torque M_D. The relative displacement of the sheet metals S_R is measured in the center between the joints on the diameter of the joint-connecting circle D. The same sensor is used as with the 2-point-shear-tension loading test. The joint stiffness C_N results from the ratio of torque M_D and the number of joints i as well as the joint-connecting-circle radius D/2 and the relative displacement S_R. The test set-up is shown in Fig. 5. The individual parts of the specimen were manufactured by laser cutting (Fig. 6).

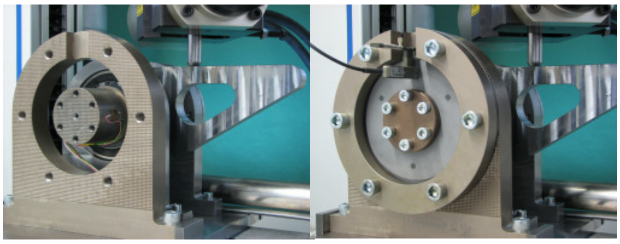

Figure 5: *Test Set-Up of the Torsion Loading Test*

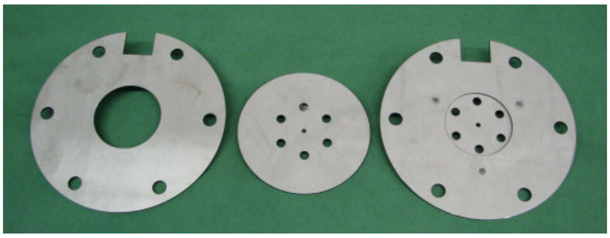

Figure 6: *Torsion Specimen: inner disk and outer ring (left and mid-side), 3-point-torsion specimen joined with self piercing solid-rivets (right side)*

3 COMPARISION CONVENTIONAL, 2-POINT SHEAR-TENSION TEST

Fig. 7 exemplarily shows typical force-displacement plots of a test series with 2-point shear-tension specimen joined with self-piercing rivets. The same force results are plotted on the one hand with the global specimen displacement as x-axis and on the other hand with the relative displacement as x-axis. The global displacement was computed in consideration of elasticity of: load framework, load cell and clamps. Both curve families show comparable tendencies. The thick curves with the measurement of relative displacement however reflect better the suggested higher stiffness of the connection (first linear slope region of curves).

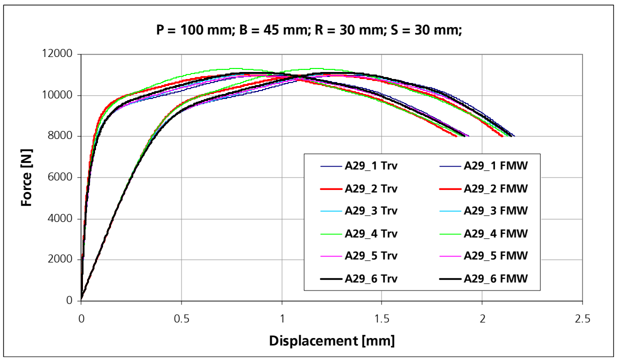

Figure7: *Force-Displacement – Comparison: conventional measurement with 2-point shear-tension test*

Fig. 8 shows the force - relative displacement plots of 2-point shear-tension test and 3-point torsion test. The forces are divided by the maximum number of rivets of the specimen. Within the production of both specimen the same material (S355J2G3), same sheet thicknesses (upper and lower sheet: 2.5mm) and same type of connector (blind rivet) was used. The differences are: specimen geometry/ clamping and number of connectors. The results are identical in the first range of the curves, in which the connection stiffnesses are determined (Fig. 9). From the beginning of connection damage the results differ slightly. This is caused by the differences in clamping conditions and geometry between the specimen types, that influence the stress distribution more and more in the damage stage.

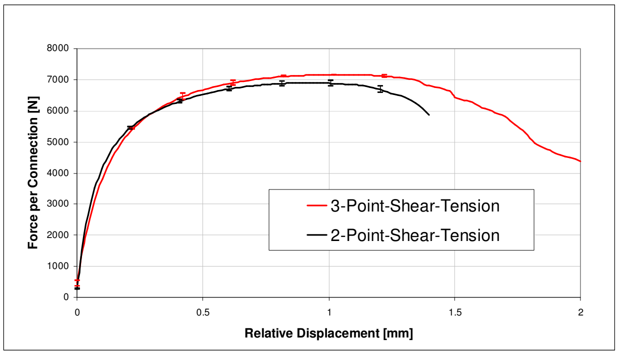

Figure 8: *Force - Relative Displacement – Comparison: 2-point shear-tension test with 3-point torsion test*

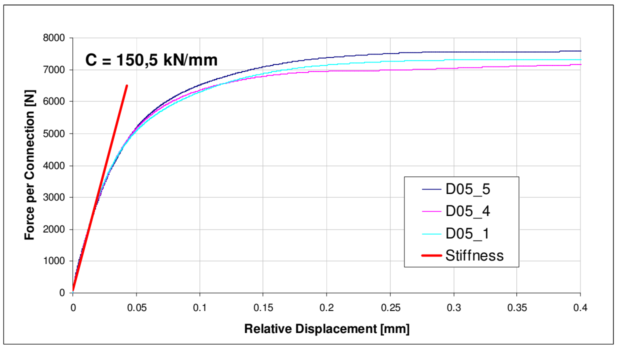

Figure 9: *Stiffness Value of a self-piercing rivet connection*

4 VALIDATION FE-MODEL

Not only the determined stiffness values but also the simplified force-displacement regimes were implemented in a small FE model. Fig. 10 shows the model of the shear-tension specimen. For the connectors nonlinear 3D link elements were chosen. The calibration of this simplified connector model was performed with assignment of the experimentally determined stiffness to the link elements and red shell elements and scaling with an effective v. Mises yield criterion for the shells. The stiffness and yield values for the sheet metal were investigated in a separate tension test.

Fig. 12 shows the FE results within pure tension along the longitudinal axis (thick curves). Also shown in the diagram are the curves from a shear-tension test series with self-piercing rivets. The curves show the total force, which amounts twice the force values in Fig. 7 (2 connectors). The thick red curve represents the force – relative displacement, of the specimen.

The results for the measuring of relative and absolute displacement are in good agreement with the experimental results due to calibration of the model.

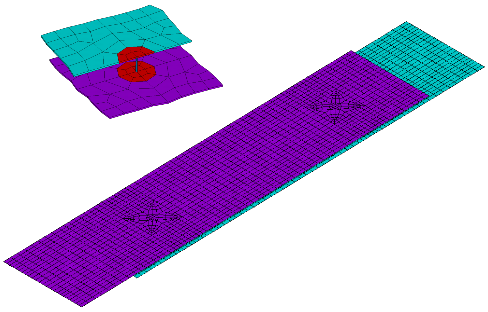

Figure 10: *FE model of shear-tension specimen*

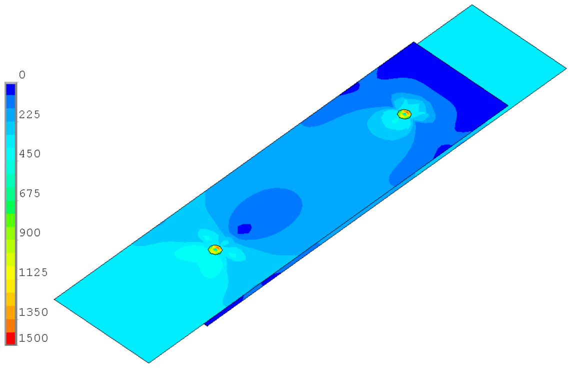

Figure 11: *v.Mises eqv. stress shear-tension specimen*

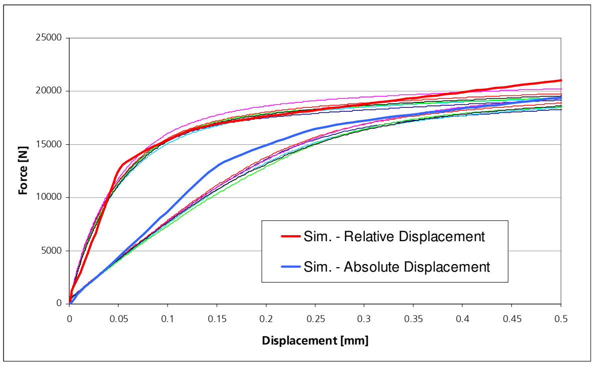

Figure 12: *Total force-displacement*

5 SUMMARY AND OUTLOOK

The accurate and correct computation of loadings at structures with a multiplicity of punctiform joints is still a challenge, in particular if local demands in the region of the joints have to be evaluated or a break endangerment be judged. Reasons for this are insufficient FE-models for the representation of the joints, and the lack of accurate source data describing the joint characteristics. Therefore a new method was systematically examined and evaluated for the determination of the stiffness behaviour of joints. The applicability of the determined characteristic values in the structural computation was examined.

The principle of this new method is based on the measurement of the relative displacement of the sheet metals between the joints during shear-tension loading. The measured relative displacement is proportional the deformations of the joint. Strains of the sheet metal material as well as deformations of the load framework or the force analyzers are not part of the relative displacement.

Two testing methods and the necessary measuring technique were developed and tested. For symmetrical joining partners, this means with same plate thickness and same material, the 2-point shear-tension specimen was used. For not-symmetrical joining partners the 3-point torsion specimen was examined. Within this test three joints are loaded evenly by shear-tension.

As expected, for the connections of 2-point specimen, a stiffer behaviour than for commonly used 1-point specimen was detected. The relative displacement measurement is a very sensitive method for the determination of the joint stiffness. The stiffness curves determined with the relative displacement are more appropriate to present in detail the discrete stiffness behaviour in relation to 1-point specimen. The results of the numerical study show a good agreement with the experimental results. The differences in total and relative displacement measurement are outlined.

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