GIRDERS WITH PROFILED AND STRUCTURED WEB - ONGOING RESEARCH – PART 1

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Abstract: *In an ongoing research project, welded girders with I-section and thin "honey-comb" structured web will be investigated. A series of plate girders with different webs (flat, profiled or structured) are being modeled and analyzed under shear load. The numerical analysis will be based on nonlinear finite element method. Several plate girders were built for tests. The aim of the tests is to query if the structured web has a better buckling behavior than a normal flat web or even comparable corrugated web. Finally a comparison between numerical and experimental test results will be made. The paper describes former investigations on the shear capacity of the structured sheets, ongoing numerical analysis and experimental tests on global and local buckling.*

Key words*: steel plate, shear resistance, numerical analysis*

1. Introduction

Multi-dimensional structures are used today in the field of the car industry or the home appliance. Structured metal sheets improve the essential properties of the initial material, e.g. its stiffness. Structured metal sheets with regular bumps offer a higher bending stiffness compared to flat sheets. The application of those structured sheets requires new investigations regarding their strength and deformation behavior.

In an ongoing research project, welded girders with I-section and thin "honey-comb" structured web will be investigated. A number of plate girders with different webs (flat, profiled or structured) are modeled and analyzed under shear load. The numerical analysis will be based on nonlinear finite element method. It is necessary to choose different parameters for the thickness, the wrench size or the depth of the structured sheets. The girder will be modeled by means of shell elements, and the ABAQUS program will be applied.

For the experimental tests plate girders with a planar, a trapezoidal or sinusoidal corrugated and structured web were built. The geometry of all girders is identical. The aim of the tests is to query if the structured web has a better buckling behavior than a normal planar web or even a comparable trapezoidal or sinusoidal corrugated web.

Finally a comparison between numerical and experimental test results will be made. The paper describes former investigations on the shear capacity of the structured sheets, ongoing numerical analysis and experimental tests on global and local buckling.

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2. State of art

Structured plates are an innovated lightweight product. There are two types of production methods. The first is the "buckling-structuring" which is used by Dr. Mirtsch GmbH, the second is the hydro forming for structured plates produced by FQZ GmbH or borit® Leichtbau-Technik GmbH.

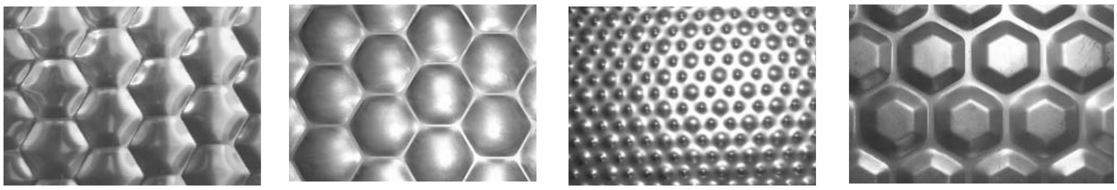

Fig. 1. Example of structured plates

In this research sheets from FQZ GmbH are used. The structure is a hexagonal regular bump structure with a small bridge of 2,0 mm between the bumps and a depth of the bump about 3 mm. The basic material is the low alloyed steel DC04 (1.0338). The thickness of the metal sheet is 0,5 mm. During the hydro-forming manufacturing process from flat sheet to a structured sheet, the material thickness is reduced particularly. In order to find the real material properties it is necessary to adapt the specimen dimension from DIN EN ISO 6892-1.

Therefore the Chair of Joining and Welding Technology, BTU, Cottbus, Germany, modified the specimen test length in adaption of the proposed ratio between width and length in the DIN code. In Fig. 2 are given the stress-strain relationship for one selected specimen dimension [1].

The other structured webs (two types), which are used, are produced from borit® Leichtbau-Technik GmbH. The sheets have a twelve-angled regular bump structure. Type one has a width of the bridge of 8 mm, type two of 3mm. The depth of a bump is in first case 8 mm. In the second sheet the depth is about 3 mm. Both sheet- metal has a thickness of 0,6 mm.

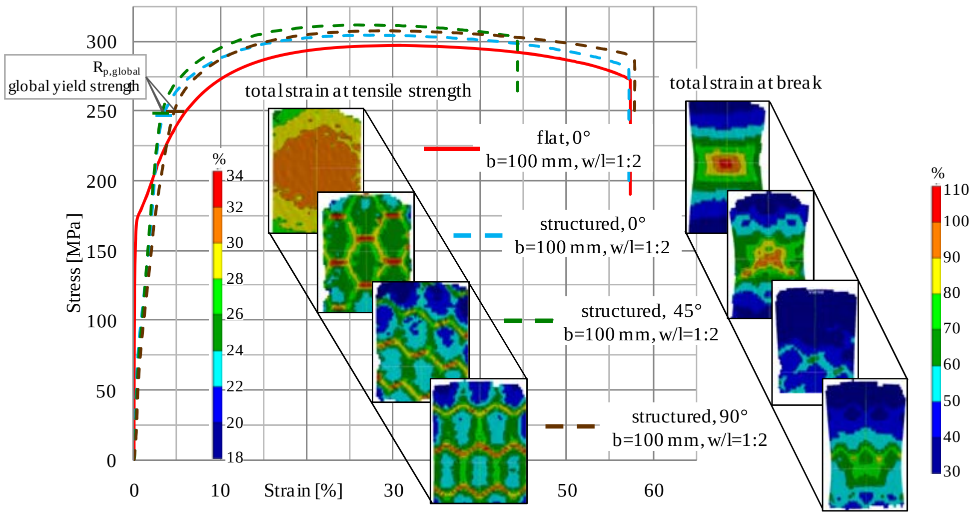

Fig. 2. Stress-strain curves for a selected specimen dimension for three tested structure positions and a flat sheet metal with corresponding deformation images [1]

Another research topic is spot welding of structured plates. The same Chair of Joining and Welding Technology made tests on assembling method. For retaining the structure and the properties of the sheets during the welding process, not all positions of fixing two plates are possible. As well a stabile position is one condition for welding two sheets for a sandwich assembly.

There are 7 variants to create a sandwich with two structured plates. Fig. 3 shows the chosen variant with the joining comp-comp and other possibilities [2]. In the future there will be tested the variant of the joining bridge-bridge too. For producing a sandwich element consisting of two sheets from Borit®, the company uses a bonding technology.

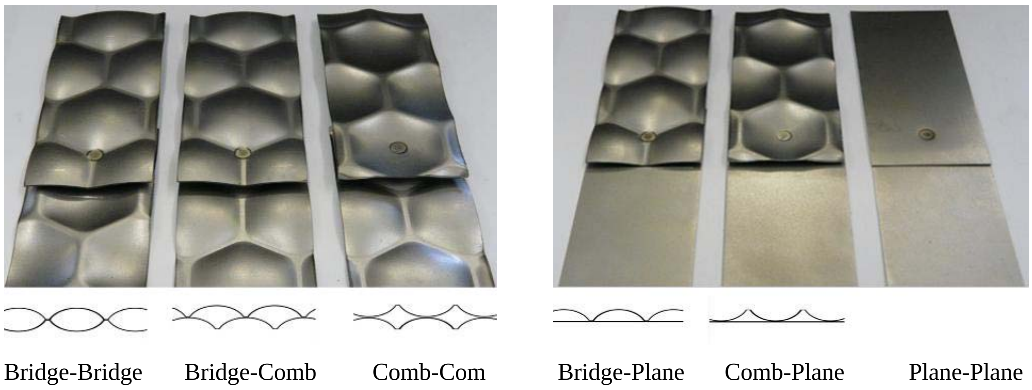

Fig. 3. Variants of joining [2]

The design of welded I-section girders (with a planar or profiled web) contains DIN EN 1993-1-5:2010 [3]. Another design method can be found in the German DASt-Richtlinie 015 [4]. For the design of girders with structured webs the methods from [3] and [4] can be adapted.

3. Numerical Simulation

3.1. Verification of the experiments

For modeling the girder under a mid-span load, the software ABAQUS [5] was used. In order to find the best model, which behavior is near to the real shear load test, a lot of models were tested.

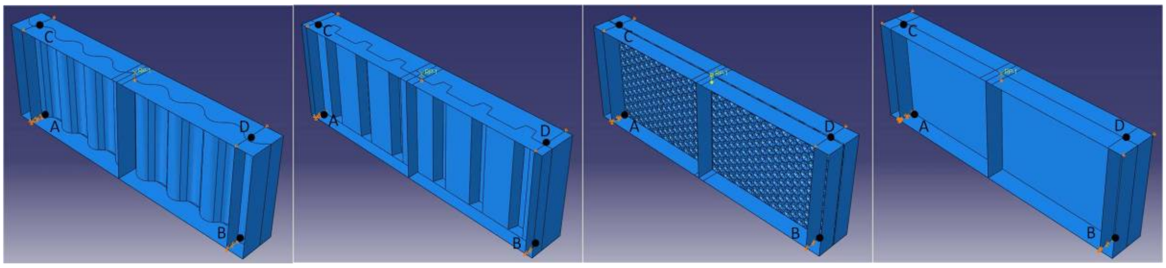

Fig. 4. Geometry of all girders in ABAQUS

As material properties, the true stress and true strain curve from the tensile test were used. The boundary conditions are defined as shown in figure 4 and table 1. The several parts of the girder are modeled with shell element S4R5 and meshed with a size of 20 mm.

Table 1. Boundary conditions of the girders (not constraint = 0; constraint = 1)

Location	u_x	u_y	u_z	rot_x	rot_y	rot_z
Point A	1	1	1	0	0	0
Point B	0	1	1	0	0	0
Point C	0	0	1	0	0	0
Point D	0	0	1	0	0	0

The first step for the Finite Element Method was a linear buckling analysis. The initial imperfection (geometric imperfection and residual stress) was measured at the real test sample

[6]. Later it was imported to the next step, the general static analysis which lets one find the ultimate load. The numerical results of the girders with a planar, trapezoidal shaped or sinusoidal corrugated web are shown in figure 3. Generally, the results from the FEM of the girder with planar web confirm those from the tests.

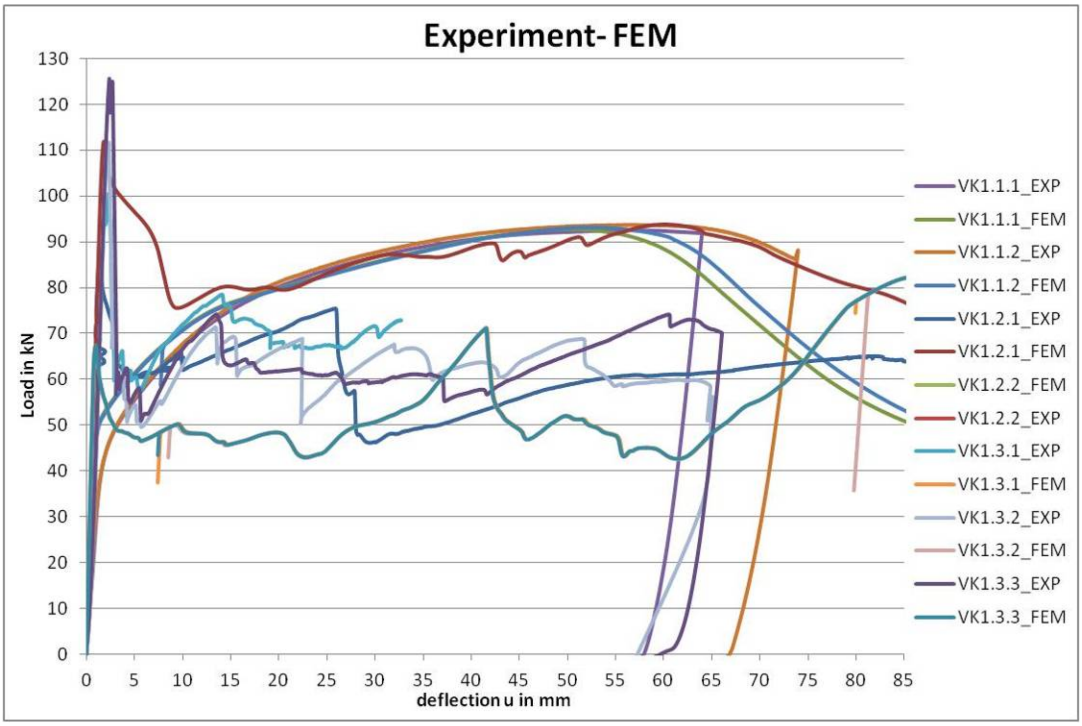

Fig. 5. Load-deflection curve for girders with planar, trapezoidal or sinusoidal corrugated web from tests and FE simulations

The experimental results from the girder with the trapezoidal and sinusoidal corrugated webs are different to those of the FEM for the critical (buckling) load and ultimate load. All test-parameter are included in the ABAQUS-Model, but never the less, the behavior of the web is nearly in every experiment not the same, that's why it is difficult to implement the right horizontal imperfection.

Table 2. Comparison of test and simulation results (s- small comb, b- big comb)

Specimen	Web	$F_{cr,exp}$ [kN]	$F_{u,exp}$ [kN]	$F_{cr,FEM}$ [kN]	$F_{u,FEM}$ [kN]	$F_{u,FEM}$ / $F_{u,exp}$	$F_{cr,FEM}$ / $F_{cr,exp}$
VK1.1.1	Planar	38,5*	92,6	50,4*	92,7	1,001	1,309
VK1.1.2	Planar	39,0*	93,8	51,2*	93,2	0,993	1,313
VK1.2.1	Trapez	89,7	67,5	107,2	78,6	1,164	1,195
VK1.2.2	Trapez	86,9	65,1	112,0	93,8	1,442 (?)	1,289
VK1.3.1	Sinus	100,5	78,5	67,4	82,7	1,053	0,670
VK1.3.2	Sinus	111,6	69,3	67,2	82,8	1,195	0,602
VK1.3.3	Sinus	125,7	74,2	67,3	82,7	1,115	0,535
VK1.4.1	FQZ 0°	36,4	89,2	X	X	X	X
VK1.5.1	FQZ 90°	35,5*	89,8	X	X	X	X
VK1.6.1	Borit 0°s	54,6	91,4	X	X	X	X
VK1.7.1	Borit 90°s	44,9	91,8	X	X	X	X
VK1.7.2	Borit 90°s	58,5	87,4	X	X	X	X
VK1.8.1	Borit 0°b	29,5*	95,0	X	X	X	X

* The critical load was assumed to correspond to a deflection of 1,5 mm

The modeling of the girder with the structured web as a sandwich element in FEM produces about 20500 shell elements of type S4R5, S3 and S4R. The single structured plate was modeled with the software ProEngineer [7].

Small part of the mesh Welded structured element FQZ and Borit ® [8]

Fig. 6

3.2. Parameter analysis of the girders (planar, trapezoidal shaped or sinusoidal corrugated)

After calibration of the tests with ABAQUS the sensivity analysis starts with different parameters. For all web geometry there were carried out about 40 models with differences in length, height and thickness of the web; shear aspect ratio and thickness to height ratio. The results are shown in Fig. 7 and Fig. 8 for the first sensivity analysis for all girders.

Table 3. Differences in sensivity analysis; *E= equal; *D= different

Sensivity analysis	Length	Height	Thickness	Shear aspect ratio	Thickness/ Height ratio	Status
1	E	E	D	E	D	Done
2	D	E	E	D	E	Done
3	E	D	E	D	D	Done
4	D	D	D	E	E	Done
5	D	D	E	E	D	Not finished
6	D	E	D	D	D	Not finished
7	E	D	D	D	E	Not finished

The influences of thickness and the shear aspect ratio of the web on the shear load are not new. The analysis 1 describes nearly a direct linear relationship between the thickness and the load for all 3 types of girders. But for the trapezoidal and sinusoidal corrugated web in the analysis 2 one can realize that the influence is not so big because of the local buckling behavior of the web.

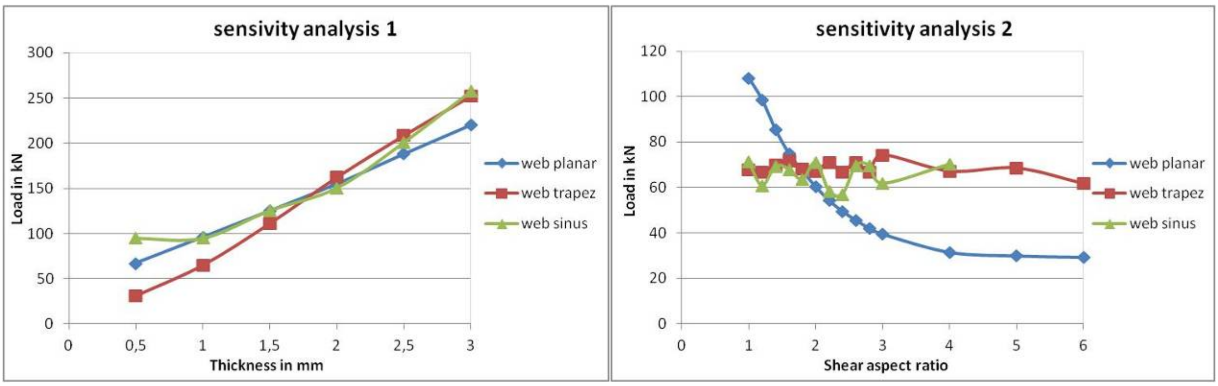

Fig. 7. Load over shear aspect ratio and thickness - results from FE- simulation, 1 and 2

Even in analysis 3 the girder with a sinusoidal corrugated web has an indirect relationship until a shear aspect ratio of 3. In analysis 4 the ultimate loads of the girder with a trapezoidal and sinusoidal corrugated web are higher than those of the girder with a planar web (constant thickness assumed).

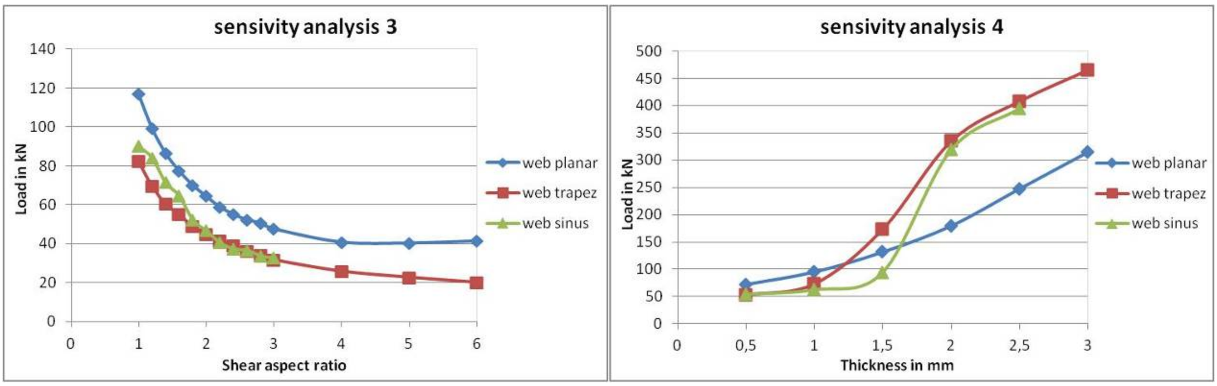

Fig. 8. Load over shear aspect ratio and thickness - results from FE- simulation, 3 and 4

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