TEXTILE BASED METAL SANDWICHES AND METAL-MATRIX-COMPOSITES REINFORCED WITH 3D WIRE STRUCTURES: PART 1: DEVELOPMENT AND REALISATION OF CELLULAR 3D WIRE STRUCTURES

C. Sennewald[1*], O. Andersen[2], R. Böhm[3], Ch. Cherif[1], G. Hoffmann[1], A, Gruhl[3], W. Hufenbach[3], S. Kaina[4], B. Kieback[3], G. Staphani[2], M.Thieme[3], D. Weck[3]

[1]*Institute of Textile Machinery and High Performance Material Technology, TU Dresden, 01062 Dresden, Germany*
[2]*Fraunhofer Institute for Manufacturing and Advanced Materials, Winterbergstraße 28, 01277 Dresden, Germany*
[3]*Institute of Lightweight Structures and Polymer Technology, TU Dresden, 01062 Dresden, Germany*
[4]*Institute of Materials Science, TU Dresden, 01062 Dresden, Germany*
**cornelia.sennewald@tu-dresden.de*

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Abstract

The aim of these research works is a systematic development of textile-based metallic reinforcement structures in cellular design for multifunctional multi component-composite semi-finished products for economically efficient and resource-conserving processing into textile-based lightweight-constructions in multi-material design. These requirements can be fulfilled particularly well by three-dimensional cellular wire structures with stress-appropriate reinforcement materials. The integration of z-reinforcing wire materials, in particular, requires substantial constructive and technological development effort. Selected structures have been successfully realised and supplied for additional process stages. These materials offer, apart from geometric variability, outstanding specific mechanical properties, e.g. a high energy absorption capacity and defined rigidity.

1 Introduction

Textile based composite materials consisting of polymer or metal reinforcement structure and metal matrix offer a high potential to fulfil the increasing demands for flexible and adaptive structures for light weight constructions [1, 2]. The combination of metal components with carbon and glass fibre based textile reinforcement or metal reinforcements results in textile based composites for multi material design. Hence new opportunities for light weight constructions particularly in machinery and plant engineering and vehicle construction are created. Two research areas in the field of light weight construction engineering are currently being pursued. For one, light metal alloys such as aluminium or magnesium are being tested, while textile reinforced composites such as carbon and glass fibre based textile reinforcements are also being intensively developed. Both material fields offer special characteristics, however no one material currently meets all the needs for high performance light weight applications. Advanced textile based reinforcements for metal composites (TRM) combine the superior properties of the reinforcement material with the advantages of metal matrices. Although TRMs possess a huge potential for major adaptation and introduction in the commercial market and novel applications, their exploitation remains hindered by the wide range of principle composition and the difficulties involved in processing them. To create composites with textile based reinforcements which meet the requirements of lightweight constructions concerning weight, density, heat resistance and mechanical strength, novel three-dimensional structures have to be developed [1-4].

2 Development of cellular three-dimensional woven wire structures (3DWT) and development of manufacturing technology

2.1 Structural Development

Three-dimensional woven wire structures (3DWT) are considered especially suitable for metal matrix composites and metal sandwich constructions for impact and crash applications. Structural properties such as geometric variability and adjustable mechanical properties which enable plastic deformation in case of impact are required. Further objective is the prevention of penetration of structures by smaller objects. These requirements can be fulfilled particularly well by three-dimensional cellular wire structures (3DWT) with stress-appropriate reinforcement materials. A special challenge is presented by the spatial assembly of the wire materials required to attain the required defined rigidity in every spatial direction. The textile weaving process offers possibilities to process metallic wires and to produce two-dimensional wire structures. Inherent stability of three-dimensional structures is to be achieved only be means of weaving process without any auxiliary devices. To increase the bending stiffness a considerable high thickness of structures is required. Repetitive symmetric geometries are the first approach for the development of wire structures. The geometries have to fulfill the requirement and have to be realizable by weaving process. Table 1 shows the basic types of suitable geometries. These basic types can be combined in offsetting positions and among themselves in different directions of structures.

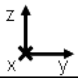
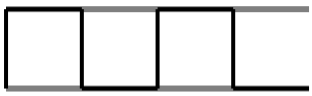
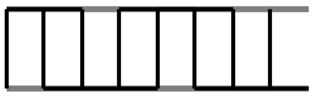
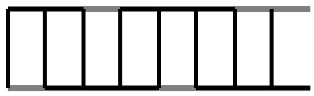
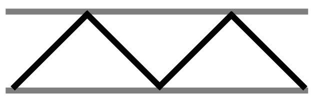
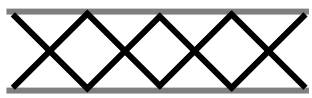
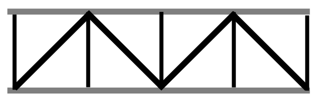
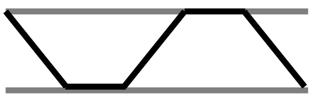
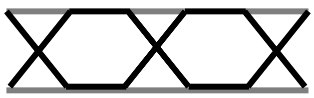
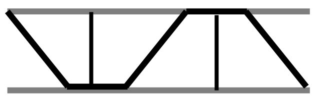
	Basic type	Combination in offsetting position	Combination in different directions
Rectangle			
Zick-Zack			
Trapeze			

Table 1. Basic types of three-dimensional wire structures

Three-dimensional structures, such as pile fabrics or spacer fabrics, can be formed on special weaving machines. As of yet, this is only possible with textile, flexurally soft yarn materials. To realise three-dimensional woven wire structures a plastic deformation of wires especially in thickness-direction (z-direction) is required. Hence two promising approaches for practical realization of woven wire structures are arising. The orientation of wires in z-direction can take place inside or outside of weaving machine. If the orientation of wires takes place inside of a weaving machine, the required forming forces have to be applied during weaving process. The available forming forces of weaving machines are limited. Hence only relatively soft materials and wires with small diameter can be applied. If the orientation of wires takes place outside of a weaving machine, the profiled wires have to be processed during weaving process. Using profiled wires a large variety of different structures and combination of different geometries with a relatively low manufacturing effort is possible. Machine load decreases and special adaption of weaving machines for realization of forming forces will not be necessary. Hence the applicable wire diameter and the wire material are not depending on weaving machine configuration. Furthermore, it is also possible to use both possibilities for wire orientation. A large variety of textile based three-dimensional wire structures (3DWT) have been developed regarding the above mentioned conditions. The wire structures are consisting of top layers and bottom layers made from warps and wefts, and profiled wires running between them (figure 1).

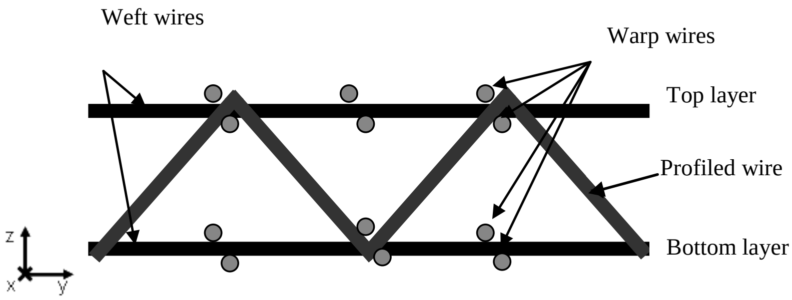


Figure 1. Schematic structure of 3DWT

The weaving technique's purposeful modification and the development of attaching elements enables the pile wires' attachment to top and bottom layers as well as it lends inherent stability to the structures, making them self-supporting. This is exemplarily shown in figure 2.

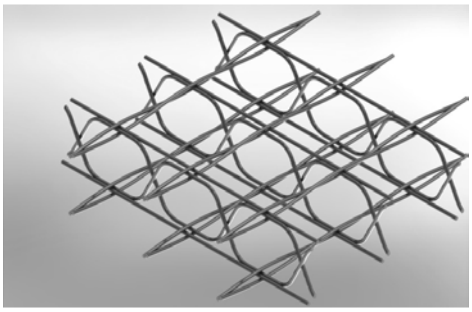


Figure 2. CAD model of 3DWT

All kind of developed structures are producible in a weaving process. Different types of structures can be combined with each other. The cellular structures' mesh can be changed as desired. Depending on the loading condition, the geometry, assembly and number of pile wires can vary. To increase inherent stability, the pile wires can run in warp as well as in weft direction. Owing to the complex structure composition, the high variability and the large number of combination possibilities within the structure, component properties can be adjusted specifically. The manufacturing of wire structures requires the development of a distinct weaving technology.

2.2 Development of manufacturing technology for the realization of three-dimensional wire structures (3DWT)

2.2.1 Basic technology

Using the weaving process as an established manufacturing method, for realization of 3DWT enables considerable economic advantages in production of semi-finished products. The development of manufacturing technology and the realization of the newly developed structures are implemented in laboratory scale first. To align the wire materials in z-direction and attain the required three-dimensionality, appropriate solutions were and are still devised and technically applied.

2.2.2 Development of wire bending device

To increase the number of processible wire materials and wire diameters the profiling of wires (creation of links in z-direction in wire structure) takes place outside of a weaving machine. Therefore a wire bending device has been developed. The wire bending device consists of two gear-wheels rotating against each others. The horizontal positioning of these gear-wheels takes place according to wire diameter. The wire profile is determined by the geometry of the deployed gear-wheels. Almost any kind of geometry with different angles of inclination, different distances between links and height of links can be achieved. The coupling of wire bending device with weaving machine is possible.

2.2.3 Wire feeding

Conventional weaving machines are processing the warp yarns from a warp beam. As there are different types of wires (for example different wire diameters) to be processed together in warp direction, warp beams cannot be used. Consequently a creel should be used for wire feeding. Different materials can be processed together and different needs of wire length can be easily compensated. Conventional creels and yarn tensioners had to be adapted for the processing of wires.

2.2.4 Shedding

To ensure a reproducible manufacturing of 3DWT and reliable shedding the wires have to be processed with constant tensile force, which is important for shedding. A reliable shedding is necessary for weft insertion. The maximum thickness of 3DWT is limited by the amount of space given in open shed position. 3DWT can be realized using the shedding of conventional weaving machines.

2.2.5 Weft Insertion

As there are different types of wires (elongated and profiled) to be processed together rapier systems are suitable for weft insertion. Conventional rapier systems have to be adapted according to requirements of processing of wires. Feeding of weft wires as well as friction lining had to be adapted.

2.2.6 Take-up device

Conventional drum pull off mechanisms are unsuitable for three-dimensional wire structures due to their clamping principle, as they would destroy the structures' integrity and the metal wires' three-dimensional assembly. The pull off of the structures from the work spot is performed with the help of a linear pull off with stepping motor drive (figure 3). The structure's mesh is adjusted by means of variable pull off lengths. Automation of the complete manufacturing process is generally possible.

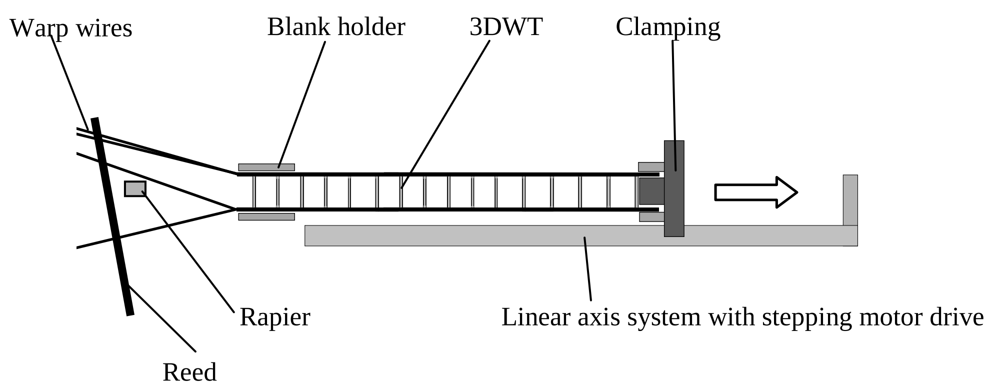


Figure 3. Take-up device for 3DWT

3 Results

Based on the preceding theoretical considerations concerning technological and design conditions the dimensioning and construction of three-dimensional structures considering weaving technique has taken place Select structures (figure 4) have been successfully realised and supplied for additional process stages.

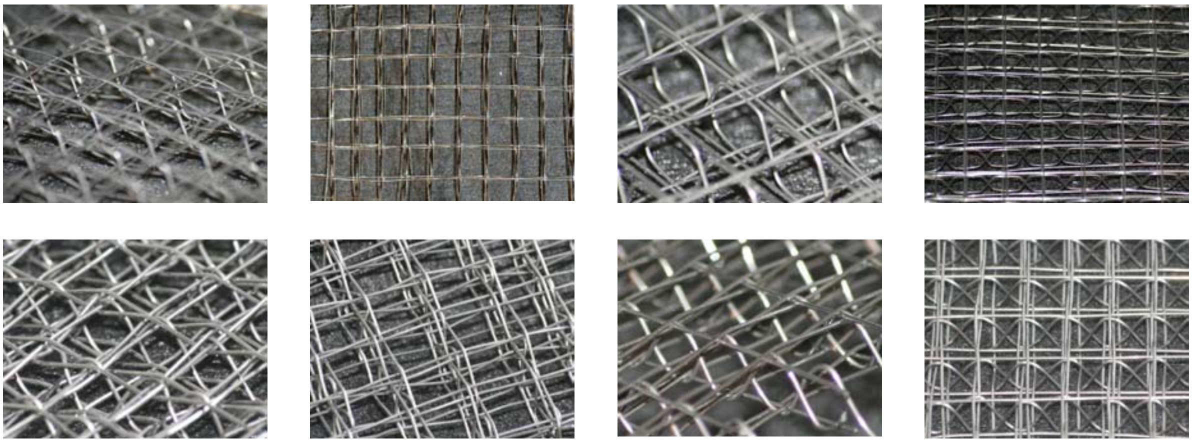


Figure 4. Selected three-dimensional woven wire structures

The three-dimensional wire fabrics' mechanical structure stability is increased with soldering and heat treatment techniques, without increasing their mass or their open structure. The development of the necessary processes as well as the soldering and heat treatment processes are performed by the Institute of Materials Science at the TU Dresden. The resulting reinforced structures are suitable for use in sandwich cores for sandwich constructions, e.g. for application in impact-absorbing elements, as well as reinforcement structures in metallic or thermoplastic matrix. Impact experiments at the Institute of Lightweight Engineering and Polymer Technology of the TU Dresden proved a feasible 400 per cent increase in energy absorption capacity by using three-dimensional wire structures in comparison to non-reinforced samples. There is still a considerable increase potential.

References

[1] Kowtsch, C.; Andersen, O.; Böhm, R.; Cherif, Ch.; Engelmann, F.; Hoffmann, G.; Hufenbach, W.; Kaina, S.; Kieback, B.; Stephani, G.; Thieme, M.: *Innovative textile based structures for novel composite materials*. In: CD-Rom and Book of Abstracts. 9th *World Textile Conference AUTEX 2010, Vilnius (Lithuania)*, June 21-23, 2010, pp. 65

[2] Cherif, Ch.; Böhm, R. et al.: *Zellulare Metallstrukturen – Schlüssel für Leichtbauwerkstoffe mit anforderungsgerecht einstellbaren Deformationseigenschaften*. Tagungsband *2nd International ECEMP Colloquium*, Dresden, 27.-28. Oktober 2011

[3] Hoffmann, G.; Andersen, O.; Böhm, R.; Cherif, Ch.; Engelmann, F.; Hufenbach, W.; Kaina, S.; Kieback, B., Kowtsch, C.; Stephani, G.; Thieme, M.; Weck, D.: *Innovativer Metallleichtbau mit gewebten Drahtstrukturen*. In: Tagungsband. *1st International ECEMP Colloquium*, Dresden, 02.-03. Dezember 2010

[4] Kaina, S.; Kieback, B.; Hufenbach, W.; Gottwald, R.; Weck, D.; Kieselstein, E.; Studnitzky, T.; Stephani, G.: *Joining technologies and mechanical properties for a new kind of 3D wire structures*. In: Tagungsband *CellMat2010*, Dresden, 27.-28. Oktober 2010, S. 445-452

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