Cellular metal for lightweight design based on textile wire structures

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Introduction

3d wire structures

Regularly arranged cellular metals with truss-type inner structures like pyramidal lattice truss structures [1], wire-woven bulk kagome (WBK) [2] or 3D wire structure called strucwire® [3] are a special type called periodic cellular metals (PCM). These constructed materials are manufactured by assembling metal wires in a systematic way. A new kind in this group is a three dimensional wire structure manufactured with a modified textile weaving technique with a high potential for automatic manufacturing, which should be presented in this study. These materials are designed as lightweight structures for example as core material for sandwiches or reinforcement in metal matrix composites (MMC). Disadvantages of conventional sandwiches like honeycomb especially with synthetic core materials are their low temperature stability and mostly restricted open cell characteristic. By using metallic wires as core material, these disadvantages can be avoided. Furthermore these materials are able to infiltrate with other materials like a light metal to create a MMC with new material properties. In this context, the "European Centre for Emerging Materials and Processes (ECEMP)" in Dresden adopts a contribution to develop this new material that combines an efficient manufacturing technology with high potential of material properties. In this study the way of development from the manufacturing processes, the joining step, up to the mechanical characterization of the structures and composites are described. For the future it is necessary to look also at these special classes of material to achieve the high demand of developments in the energy, transportation and environment sector. To fulfill these requirements it is essential to think in a new way of multi material design where the right material or composite is placed at the right point.

Three dimensional woven wire structure (3DWT) development

Textile manufacturing process

The textile weaving technology is an effective manufacturing process and was chosen to generate the novel wire woven structures. The process allows also to interweave metallic wires and/or synthetic fibres and offers a wide range of structural parameters. To increase the bending stiffness a considerable high structure stiffness is required. Therefore a plastic deformation of wires especially in thickness (z) direction is necessary. The deformation of these wires can be processed inside or outside of the weaving machine. Because of the limited forming forces of weaving machines the forming process takes place outside of the weaving machine. Therefore a wire bending device has been developed, which consists of two gear-wheels rotating against each others. For the future it is also possible to couple the bending device with the weaving machine. The so profiled wires allow a large variety of different structures and combinations. The wire structures are consisting of top layers and bottom layers made from wraps and welfs, and profiled wires running between them [4]. A schematic structure is given in figure 1.

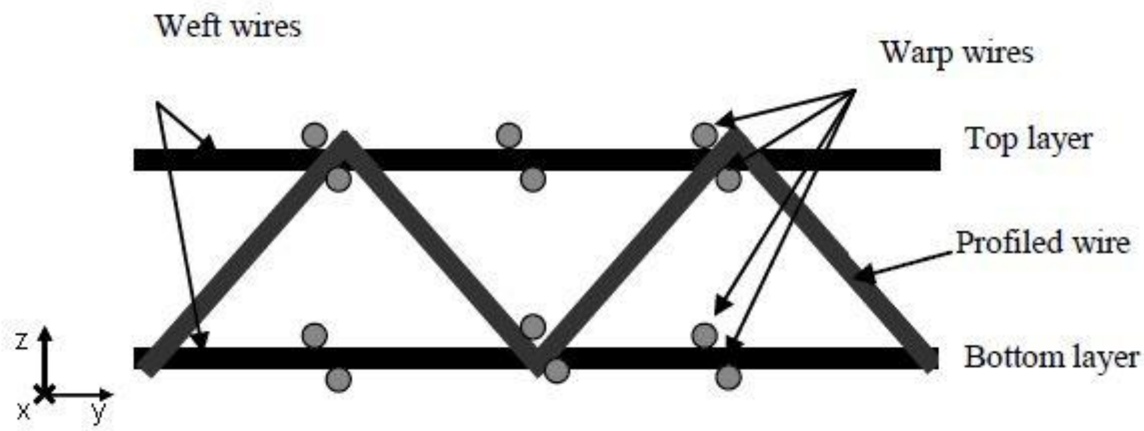

Figure1: Schematic structure of 3 DWT [TUD ITM]

Two pictures of the first developmental stage of this new textile 3D wire structure are shown in figure 2 to give an idea of the geometric characteristic of these new materials.

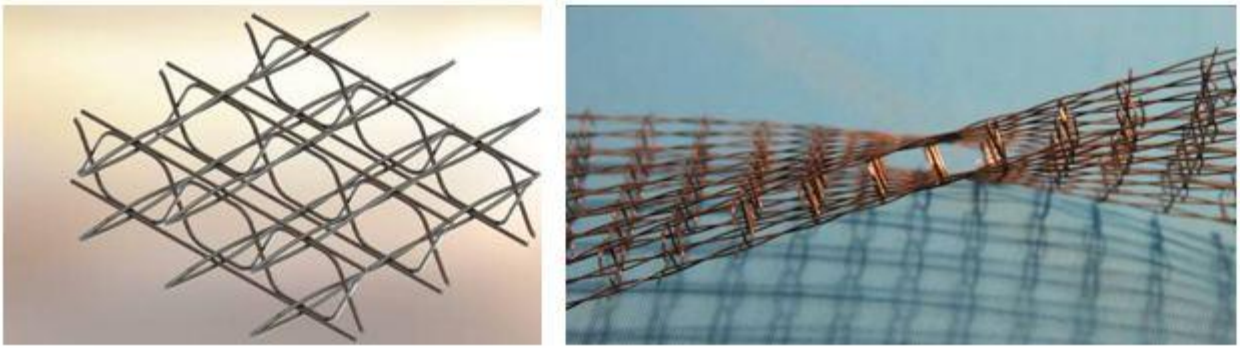

Figure 2: (left picture) CAD picture of the textile wire structure; (right picture) photograph of 3DWT

To achieve a reproducible manufacturing of the wire structures a reliable shedding has to be realized with a constant tensile force. Even the maximum thickness of 3 DWT is limited by the amount of space given in open shed position. The mechanical pull of mechanism is performed with the help of a linear pull off device with a stepping motor drive (figure 3) [4].

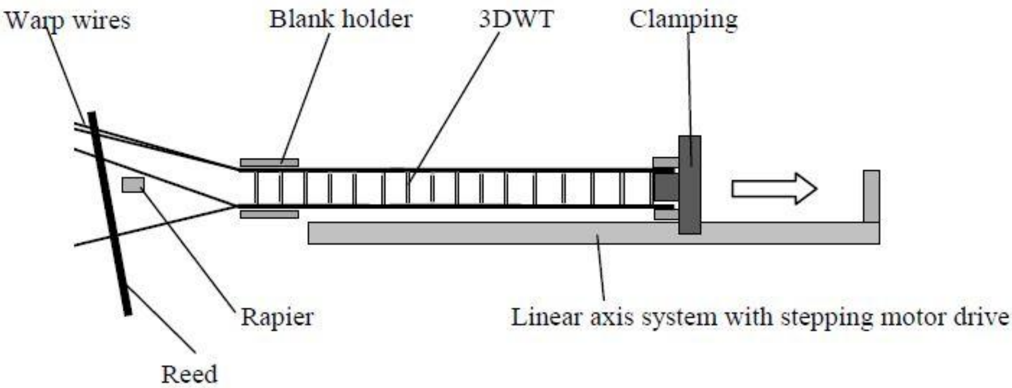

Figure 3: schematic picture of the linear pull of device with stepping motor drive [TUD ITM]

Joining Process

To join the crosspoints of the structures an application technology had to be developed to braze the structures. Therefore, two ways lead to the desired results. They are described in the following chapter.

2.2.1 Specimen preparation and brazing techniques

Conventional technologies like welding and brazing with gas torch e.g. seem not to be suited for an automated process because of the limited accessibility inside the wire structures.

The first step to join the nodes of the structures is a specimen preparation to achieve a good wettability of the wire surface. Therefore, the specimens were put in several baths for repeated degrease and rinse. The chosen process steps to braze the wire structures are:

- galvanic degreasing with a special alkaline bath
- rinse with water and ethanol
- application / integration of the brazing material
- heat treatment in argon atmosphere.

To braze the whole metallic wire structure, several technologies like metallic coatings, brazing pastes and the integration of brazing wires were tested. At the end two ways seemed to be practicable. The first is the galvanic coating technology because of its possibility to bring a brazing metal on the wire surface with a defined thickness. In the galvanic coating processes the deposition of pure metal films like copper, nickel or silver on the structure surface is possible. Basically, copper is the most used braze for stainless and carbon steels [5] because of its very good wettability and ductile character (no brittle phases). Figure 4 shows a galvanic cell and a copper coated wire structure after the galvanic process.

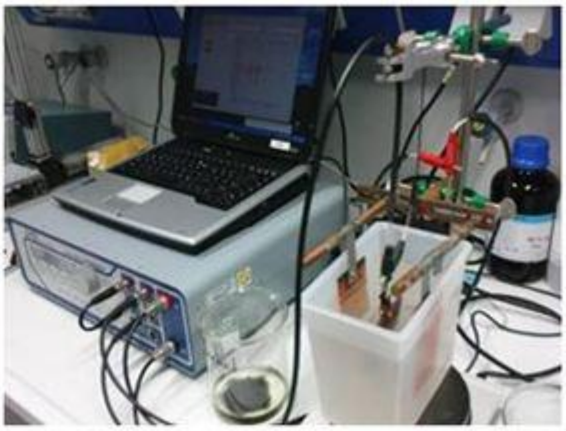 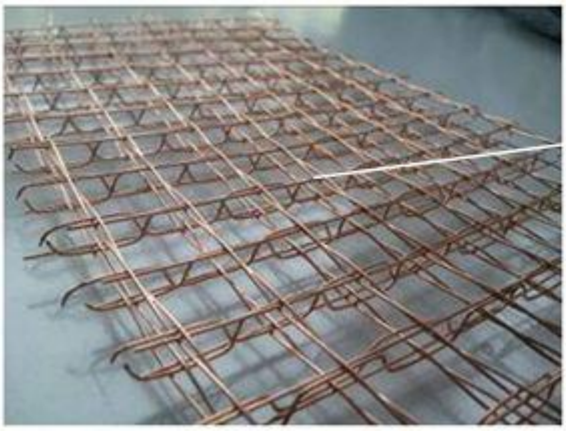

Figure 4: (left) galvanic cell - laboratory size, (right) copper coated textile wire structure

The other possibility is to integrate a special brazing wire into the weaving process. In this work a thin copper wire with a diameter of 0.4 mm was integrated in the fill direction of the weaving process. The advantage is a much easier process route because of the minimizing of the process steps. Furthermore, it gives the opportunity to use standardized brazing wires with different compounds and performances.

Metallic Sandwiches with 3D wire textile core

To obtain a novel lightweight structure the 3D wire textile is used as core material for sandwich structures. The preferred setup consists of two carbon steel sheets (thickness 0,6 mm), two thin copper brazing sheets with a thickness of 0,1 mm and the wire structures with a thickness of 10 mm. The components are soldered to obtain the sandwich part. Figure 5 shows a picture of structures after the brazing process.

Figure 5: metallic sandwich structure with 3D wire textile core

Metal Matrix Composite with 3D wire reinforcement

To create a new metal matrix composite the open cell wire structure can be filled with magnesium alloy. For the experiments magnesium as the lightest metallic engineering material has been chosen, in detail the alloy AZ91 due to its good castability combined with high mechanical properties. To realize a good metallic connection between the carbon steel wires and the magnesium alloy AZ91 (9 wt% Al, 1 wt% Zn; Ts: 580 °C) a metallic coating on the wires is necessary because of the insolubility of magnesium in iron. The diffusion process between the wire, metallic coating and the magnesium alloy has to be very fast because of a short reaction time (seconds) where the alloy is in a liquid condition due to the rapid cooling, for example in die casting processes. Therefore, also copper, the brazing material that stabilized the wire structure during the cast process, was chosen. The experimental setup to analyze the general reaction at the interface between the wire and the magnesium alloy is given in the following list:

- galvanic copper coated carbon steel bar with a diameter of 6 mm
- a cylindrical carbon steel casting die with a inner diameter of 10 mm and a outer diameter of 12 mm
- magnesium alloy AZ91
- inductive heating
- argon inert gas atmosphere (closed furnace).

To simulate a very short process and reaction time, the magnesium alloy melt in the die under inductive heating conditions up to 620 °C under an argon inert gas atmosphere. After that the coated steel bar (being at room temperature) was inserted into the

magnesium melt and the inductive heating was shut down immediately for rapid cooling. The solidification time of the magnesium melt was about 2 seconds.
The material bonding between steel bar and cast alloy was analyzed with optical microscopy and scanning electron microscopy. The element distribution in the boundary layer measured by energy dispersive x-ray (EDX).

Results

Mechanical characterisation - compression test of sandwich structures

The mechanical properties determined and compared to sandwich materials which are commercially available like FRP honeycomb, aluminum honeycomb sandwich, sandwich with strucwire core. Quasi static compression test and bending tests are chosen for the comparison. Figure 6 shows the first results of the quasi static compression test and dynamic bending test.

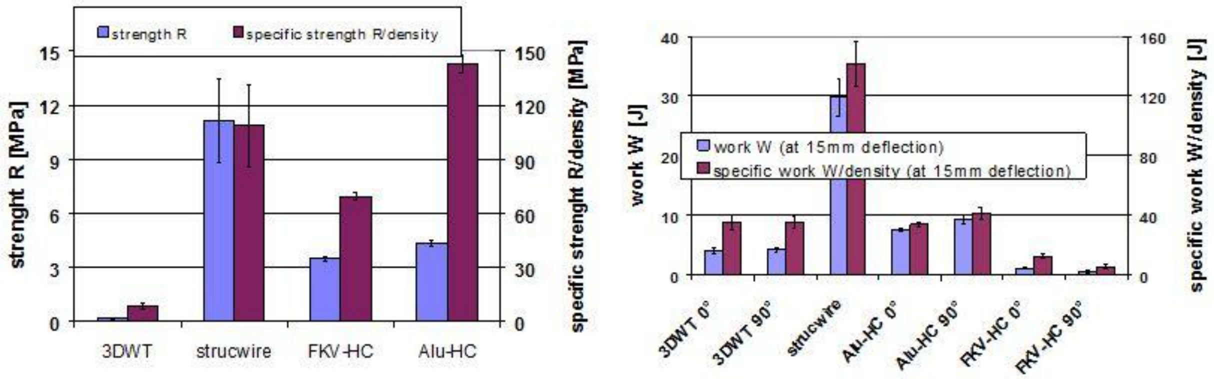

Figure 6: Quasi static compression test (left) and dynamic bending test (right) of 3DWT compared with other sandwich materials [TUD ILK]

Results of the casting experiments

In the following, it will be shown that a copper coated carbon steel wire can form a stable metallic interface without porosity with a magnesium alloy (here AZ91) even during a very short reaction time. Figure 7 shows an optical microscopy picture of a boundary layer section of the copper coated steel and the magnesium alloy matrix after the casting process.

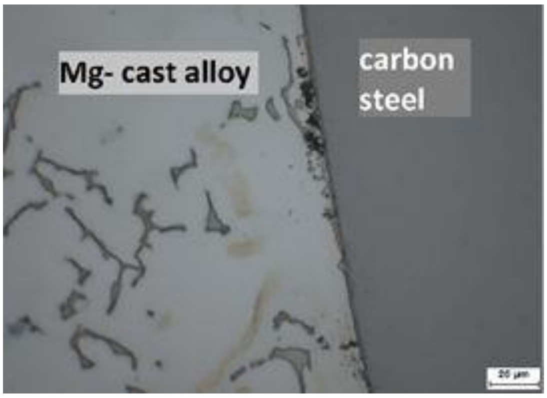

Figure 7: Optical microscopy picture between a copper coated steel bar and the magnesium alloy matrix AZ91 after casting (620 °C, Ar atmosphere, carbon steel bar at 25 °C)

In order to gain further information, EDX mappings were done to determine the element distribution at the interface. This became necessary because the copper coating was no longer optically identifiable after the casting procedure. Figure 8 shows the distribution of the elements involved in the diffusion process like Al, Fe, Cu, Zn and Mg. It shows that the copper from the coating completely reacts with the magnesium melt, especially with the aluminum to form a new phase within the cast structure. The analysis (XRD, not shown here) shows that the Al_2Cu phase is formed and acts as bonding interlayer between the different materials.

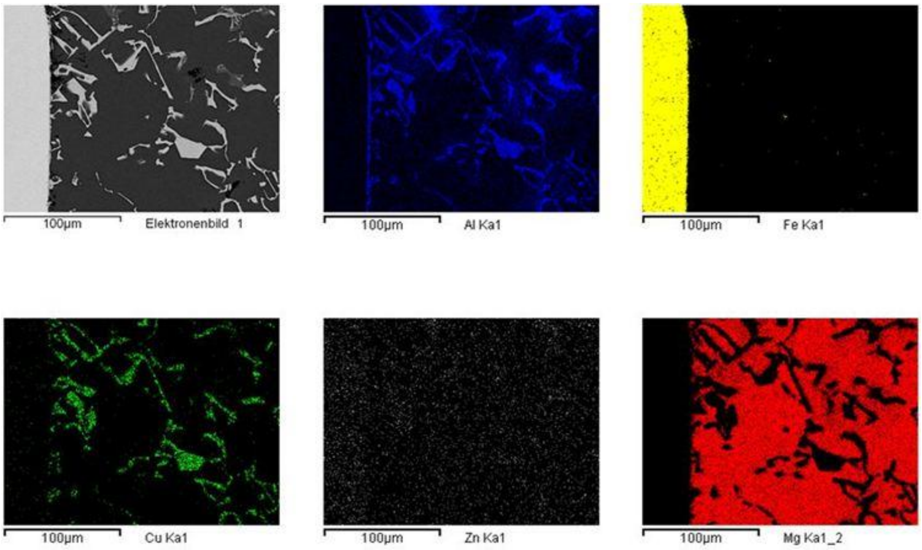

Figure 8: EDX mapping of the element distribution near the boundary layer of the carbon steel bar and the magnesium cast alloy after casting

Conclusion

It could be shown that is it possible to manufacture a novel 3D wire based lightweight textile called 3WDT. This metallic wire structure fabricated by a weaving technique is unique. After joining the structure by brazing it is possible to process this to sandwich structures or metal matrix composites by infiltration. Furthermore it could be indicated that the brazing metal can act as a coupling agent between the carbon steel and the liquid magnesium alloy to create a good interface for a MMC with a magnesium alloy as matrix material. The study shows that it is possible to use the joining material to bond the nodes of the wire structure in a first brazing step to generate a stiffer structure and to use it as a coupling agent between carbon steel and the magnesium alloy to create a new MMC material.

Acknowledgment

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