

## **Manufacturing of cellular structures from perforated metallic materials**

V. Mironovs<sup>1</sup>, M. Lisicins<sup>1</sup>, I. Boiko<sup>2,\*</sup> and V. Zemchenkova<sup>1</sup>

<sup>1</sup>Riga Technical University, Laboratory of Powder Materials, Azenes 16/20, LV1048 Riga, Latvia

<sup>2</sup>Riga Technical University, Institute of Mechanical Engineering, Ezermalas 6k, LV1006 Riga, Latvia; \*Correspondence: irina.boiko@rtu.lv

**Abstract:** This research regards the manufacturing of cellular structures with through channels of different form from perforated steel tape. These methods allow recycling of metal wastes (tapes), which are obtained during stamping of fine-sized details. There are given examples of steel wastes with different physical-mechanical properties and geometry. The methods of profiling and welding of thin perforated materials are studied. A method of through channel parameter evaluation is suggested. The estimation of parameters of cellular structures during deformation is suggested.

**Key words:** waste materials, perforated steel tape, cellular structures, deformation.

### **INTRODUCTION**

Valuable usage of the materials is one of the most significant modern tasks of material science. One output of this task is the reiterative usage of manufacturing waste. There are a number of factories, whose production waste can be re-used for different purposes. Thus the perforated steel tape as waste material is obtained after punching. The aim of this paper is to investigate the possibility to recycle the metal wastes (tapes), which are obtained during stamping of fine-sized details, by manufacturing from them cellular structures by profiling and welding.

### **MATERIALS AND METHODS**

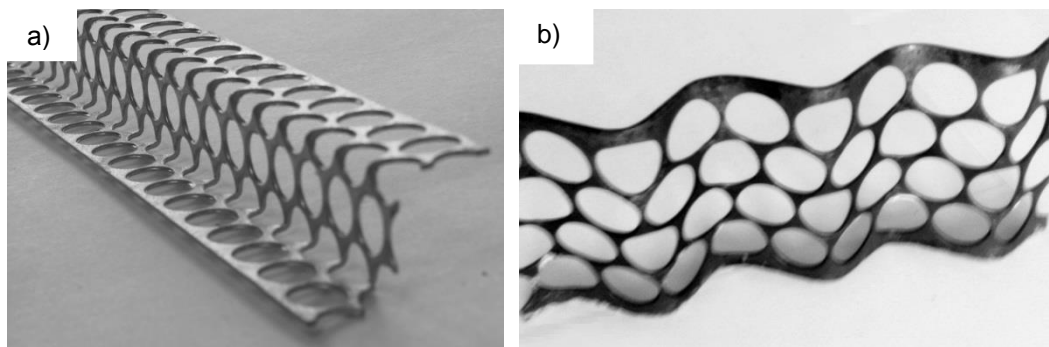
There are several approaches for manufacturing of cellular structures made of sheet materials. Main methods for the manufacturing of different type cellular structures from perforated metallic waste materials are the following: method of stretching, method of corrugation, method of plate shearing, method of cut-sheet and stretching, perforated tape twisting, method of interlacement, profiling and welding (Wadley et al., 2003; Mironovs et al., 2012).

As a raw material a perforated metal tape made of high-quality carbon steel was used. After punching the tape is subjected to cleaning, corrosion protection and surface degreasing. This material can also be subjected to galvanising or painting. Tape specifications, such as type of perforations, location of holes, specific area of perforations, thickness and width are of great importance.

Basically, for the manufacture of cellular material a perforated tape with round and oval holes should be used, especially in those cases where the final product requires a certain fixed location of perforated band. Oval and rectangular holes make it easy to connect multiple tapes with an offset relative to each other. Diameter of circular holes is usually in the range of 1 to 10 mm. The distance between holes is in the range of 0.6–4.0 mm that allows a flexibility in combinations of different tapes.

Results of investigations of mechanical properties of perforated steel band produced by punching are given in (Lisicins et al., 2011). In our experimental studies we analysed properties of through-channel structure during deformation under compression load.

For experimental studies we mainly used methods of interlacement, tape twisting, profiling and welding. Production of profiles shown on Fig. 1 was made by bending in a stamp. Profiling was made in longitudinal direction (Fig. 1, a) and in crosswise direction (Fig. 1, b).



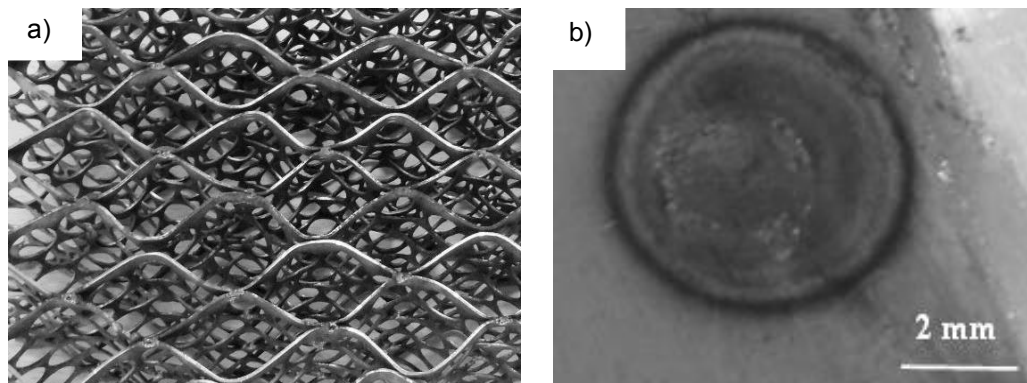
**Figure 1.** Profiles from steel perforated tape (width 100 mm, thickness 1.2 mm) produced by longitudinal (a) and crosswise (b) profiling.

Previously profiled tapes were joined by resistance spot welding (RSW) using experimental AC RSW equipment ‘Impulse KM’ earlier elaborated in Riga Technical University. Welding was performed by using copper electrodes with a diameter of 7 mm. The view of the welded cellular structure is given in Fig. 2, a, but view of the welding nugget is shown on the Fig. 2, b. The main RSW welding parameters for steel S235JRG2 welding (material thickness is 1.2 mm) are given in Table 1.

Obtained cavities may be filled by powder, granular and fibrous filler. Metallic cellular structures with or without filling could be effectively used in production of the cellular building construction, in aircraft building, in catalyser, filter production, etc. (Annual report, Fraunhofer, 2010; Kim et al., 2010; Vityaz et al., 2010).

For analysis of properties of cellular structure during deformation under compression load we used two approaches: experimental and computer simulation. Experimental tests were performed on the press equipment Zwick Z100. Evaluation of mechanical properties was carried out on samples (Fig. 3) shaped to the cellular structure shown in Fig. 2, a. This structure was made from tapes LPM-1 (trade mark of JSC ‘Ditton Driving Chain Factory’). Main characteristics of this tape from steel S235JRG2 are the following: thickness 1.0 mm; permeable area 66.83%; yield strength

320 Mpa (Lisicins, 2013). Parts of the sample have been joined by RSW as was mentioned earlier. The outer diameter of the spot weld is in the range of 4–5 mm.

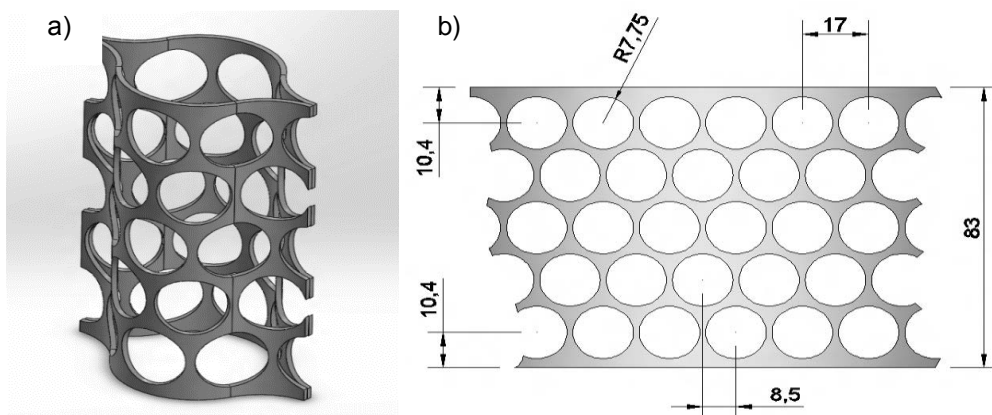


**Figure 2.** View of cellular structure with welded spots (a) and welding nugget produced by RSW (b).

**Table 1.** RSW welding parameters.

Welding parameters	Welding current range, kA	Electrode force, kN	Weld time, sec (50 Hz cycles)
Conditions	8–9	3.5–4	0.18–0.20

The deformation calculations were made using FEM (Finite Element Method) programme COSMOS Works. The calculating model of cellular structure is shown in Fig. 3, a.

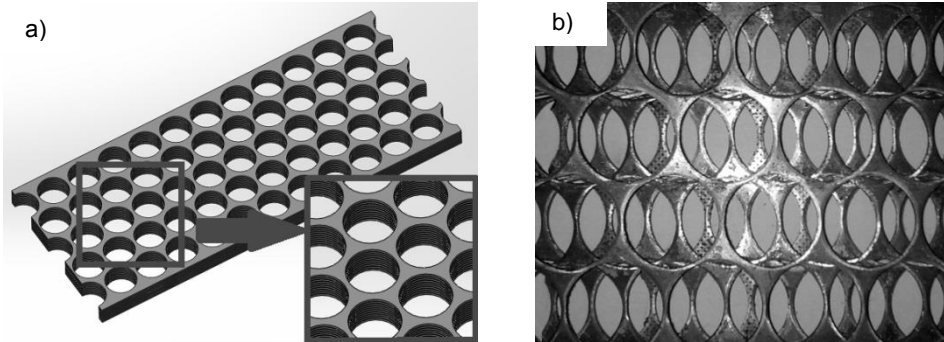


**Figure 3.** Model of cellular structure (fragment): height 83 mm, width 55 mm (a) and perforated tape LPM-1 (fragment).

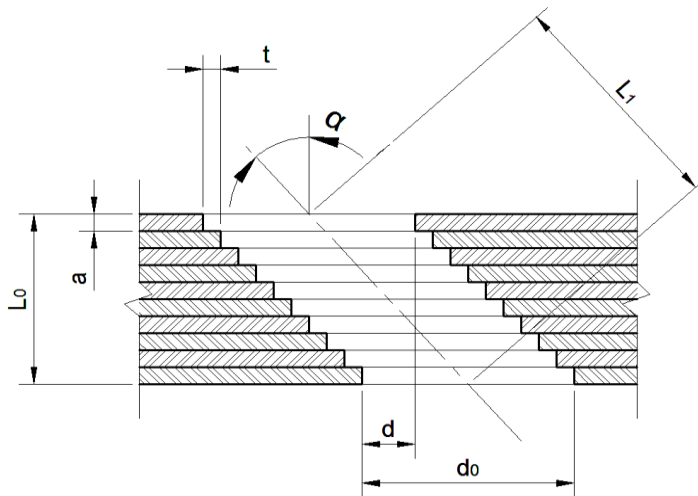
## RESULTS AND DISCUSSION

The main difficulty in the modeling of cellular structures made of the perforated tape is to determine the geometrical characteristics of the cross-section, as well as parameters of channels formed.

We investigated the method of layer-stacking and subsequent shear tapes. This method allows obtaining a cellular structure with adjustable through-channels (Fig. 4). When a displacement of perforated elements at a step size ( $t$ ) occurs, the length of through channel in the package is changed (Fig. 5).



**Figure 4.** Formation of through channels by coaxial stacking of perforated sheets (a) and the longitudinal displacement of the perforated elements (b).



**Figure 5.** The scheme for calculating the length of the through channel.

Channel parameters can be determined using the following equations:

$$\alpha = 90^\circ - \cot \frac{a}{t}, \quad (1)$$

$$L_0 = a \cdot n, \quad (2)$$

$$L_1 = \frac{a \cdot n}{\cos \alpha}, \quad (3)$$

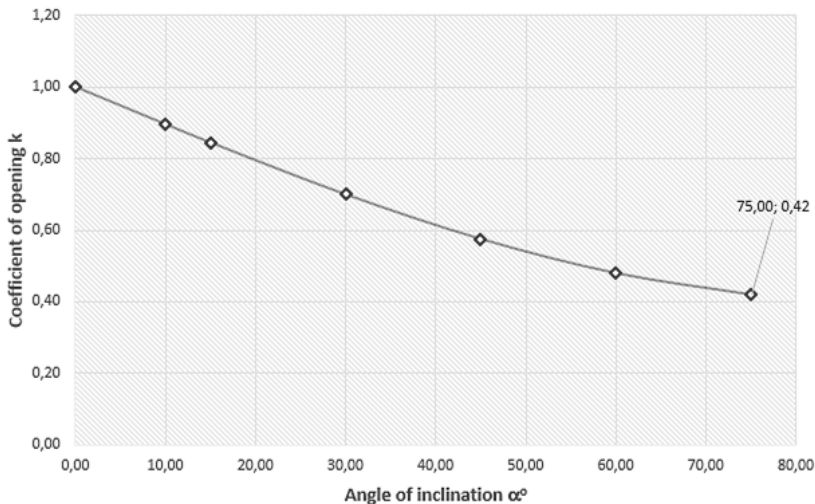
where  $a$  – plate thickness;  $t$  – a step of plate displacement;  $n$  – number of plates per package;  $L_0$  – package thickness;  $L_1$  – full length of the channel;  $d_0$  – diameter (for circular shape of through-hole plate) or width (for another shape);  $d$  – the width of through channel in a package (opening);  $\alpha$  – angle between axis and vertical channel (Fig. 5).

It can be noticed that the slope of the through channel depends on the thickness of the plate package (assuming that all the plates are of uniform thickness) and their displacement step (Eq. 1–3). These equations also show that the slope of the channel is directly proportional to the magnitude of the displacement step, and inversely proportional to the thickness of the plate.

A length of through-channel is determined by the thickness of the plates, their number in the package, as well as on the angle at which the channel is located in relation to the vertical axis is perpendicular to the plane of the plate (the package). Through-channels are characterised by the coefficient of opening  $k$ :

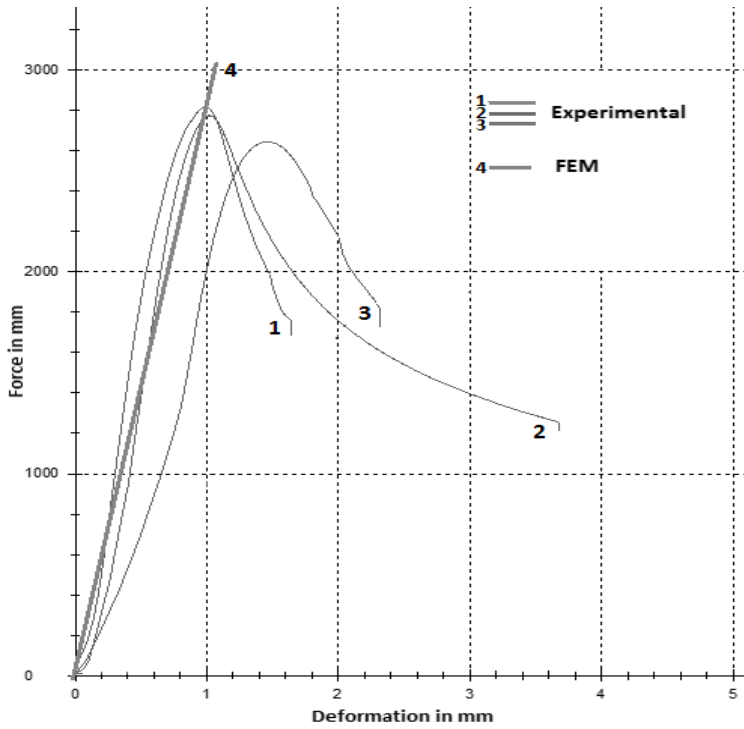
$$k = \frac{d}{d_0}. \quad (4)$$

The curved splayed in Fig. 6 reflects the ratio of the opening depending on the angle of inclination of permeable channels. The constant thickness of the tape 1.5 mm was used in the calculation.

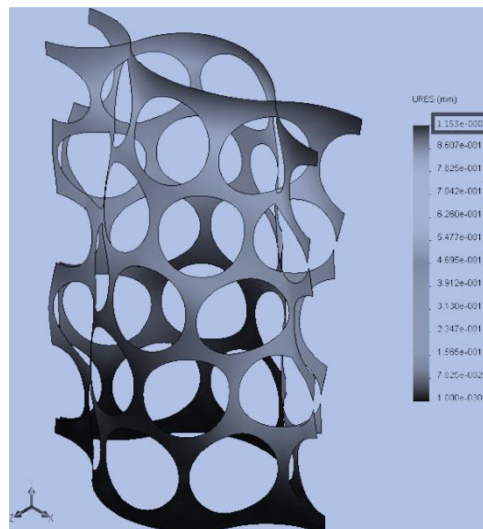


**Figure 6.** Coefficient of opening ( $k$ ) depends on angle of inclination of permeable channels ( $\alpha^\circ$ ).

Results of experimental and computer tests are shown in Figs 7–8. The maximal compression force was from 2644 N to 2815 N. The maximum deformation by the y axis is 1.0–1.4 mm. So the average compression force (2744 N) results in average maximum deformation of 1.17 mm.



**Figure 7.** The curves of the deformation of the S235JRG2 band under compression load.



**Figure 8.** Plot of deformation due to compression force.

After linear analysis under static loading using COSMOS Works the obtained maximum deformation was 1.15 mm, which is by 1.17% lower than experimental results. The difference between results obtained by computer simulation and experiment is in the range of 5%. Thus, computer simulation is a feasible way to predict the deformation of geometrically complex cellular structures, using the perforated tapes. It should be taken into account to determine the displacement of any point of structure in any direction.

It is also worth noting that all welds passed the above-mentioned load, and hence the strength of joints provided not less than the strength of the material.

## CONCLUSIONS

The possibility to recycle the metal wastes (tapes), which are obtained during stamping of fine-sized details, by manufacturing from them cellular structures by profiling and welding was proved. Thus it was shown that the method of layered packing and subsequent shear tapes allows us to achieve cellular structure with through-and quite easily adjustable channels. The estimation of parameters of cellular structures during deformation is suggested. It is revealed that the tape specifications, such as type of perforations, location of holes, and specific area of perforations, thickness and width are of great importance.

It is also shown that the obtained cellular structure have high strength under compressive load (average force was 2744 N). The FEM model of developed cellular structures is created. FEM simulation using COSMOS Works show good compliance with experimental data: the difference between results obtained by computer simulation (maximum deformation 1.15 mm) and experimental (maximum deformation 1.17 mm) is in the range of 5%. Hence it could be concluded that FEM simulation is an effective way to predict the deformation processes of these structures with acceptable accuracy.

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