

Flow curve determination of micro strip with aid of the plane strain compression test

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The determination of flow curves by plane strain compression testing becomes difficult when geometrical specimen dimensions, especially thickness, become small. Therefore, a multi-layered plane strain compression test is introduced. Experiments show that plane strain compression testing of multi-layered specimen is an accurate method to obtain flow curves, so that it can be used for flow curve determination of small and very thin micro strip.

1 Introduction

Modernisation of existing technology and products as well as the discovery of new technology and products have resulted in the development of more compact parts and products. In turn, advancements have taken place in the technology needed for miniaturisation. The products and associated knowledge have been applied broadly and in many fields. This has led to an increased demand for standardised parts, modular parts and semi-finished products. An often used and broadly applied semi-finished product is for example small and very thin strip. This type of strip is mostly produced by flat rolling of a thin round wire in multiple rolling steps. Small and very thin strip can be defined as micro strip if its thickness is in the sub-millimetre range and its width is in the lower millimetre range.

Watch making is a classic example of a practical area that has used diverse miniaturised parts, including micro strip, for a long time. Another, more modern example of the application of micro strip are the electrodes in nerve cuffs for peripheral nerve stimulation. A cuff electrode is an implantable electrode for the stimulation of nerves to artificially replace the natural human control and directly stimulate nerves or muscles [1]. Miniaturised strip material can also be found in other medical equipment, as for example in catheters [1,2] but also in measuring equipment, electronic components, sensors and micro electronic mechanical systems (MEMS).

Micro forming processes are characterised by some scaling effects. Under influence of these size effects, the down scaled process does not behave proportionally to the reference process due to changes in material properties and process parameters. In case of leaving the macroscopic domain, it is concluded that, due to the size effects, rules for similarity in metal forming processes [3-6] are not valid anymore.

Within the priority programme "SPP-1138" of the Deutsche Forschungsgemeinschaft (DFG) "Modelling of scaling effects on manufacturing processes" the production process of micro strip is investigated by means of a finite element simulation [7] and is validated by experiments in order to determine size effect in the rolling process and study the validity of this continuum approach in the microscopic domain. This article presents the determination of flow curves of the strip material, for the above mentioned finite element simulation, with aid of plane strain compression testing.

2 Plane strain compression test

Plane strain compression (psc) testing, put to practical use by Ford [8], is used to determine the flow curve of a material, represented in a true strain true yield stress curve, by the compression of rectangular specimen between two accurately aligned platen. The specimen is compressed across its width by the narrow platen that are wider than the strip (Fig. 1). Assuming ideal plane strain, i.e. no lateral spread, the deformation of the specimen occurs in the direction of the platen motion and in the length direction of the platen.

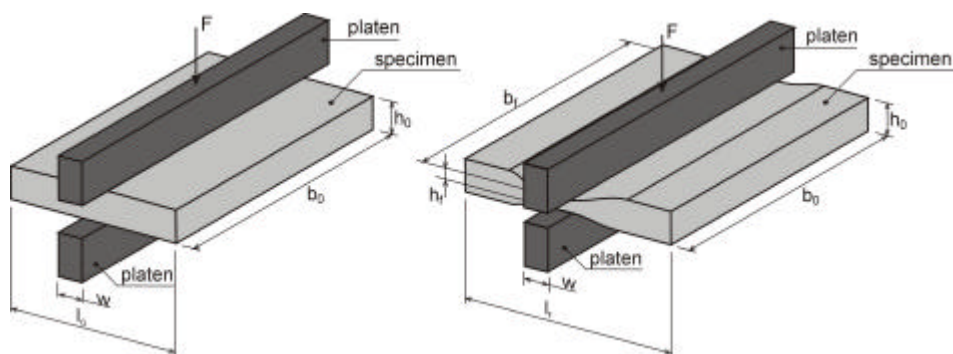


Fig. 1: Principle of the psc-test. An instantaneous rectangular specimen (left) is compressed between two platen and deforms due to the platen normal force (right).

The deformation is (desirable) symmetric. After psc-testing, the specimen characteristically has a deformed region between the tools with (almost) non-deformed regions outside this plastic region. Due to friction, the deformation in the centre is

accompanied by lateral spread, that disturbs the state of plane strain and should be taken into account [9,10].

Investigations on the effects of friction, lubrication, specimen size, spreading and strain rate led to the development of a spread correction factor to calculate the actual breadth of the specimen and introduced a correction factor to calculate the actual flow stress during compression [11]. A comprehensive review of all these aspects as well as practical instructions and tips are given in [12].

Determining the flow stress of a small, miniaturised specimen with the aid of the psc-test becomes very difficult if one sticks to specified ratios between specimen- and platen dimensions. More or less the same problem is found in the uniaxial compression test. But if one is not able to produce a massive specimen, e.g. of sheet material, it is possible to carry out a multi-layer axisymmetric compression test [13]. In order to determine flow curves for miniaturised parts the axisymmetric compression test can be miniaturised [14]. From this, it is concluded that producing a miniaturised multi-layer psc-test should be possible. When the initial thickness of the strip becomes thin it is possible to put multiple test specimen on top of each other and compress them.

3 Experimental setup

For the psc-test, a universal Instron 1195 testing machine with 100 kN press rating is used. Because of the small, miniaturised, specimen dimensions, the accuracy of the platen alignment is of major importance [15]. To guarantee a good platen alignment during compression, the platen are installed in a two pillar punch guide (Fig. 2), that for itself is installed in the testing machine.

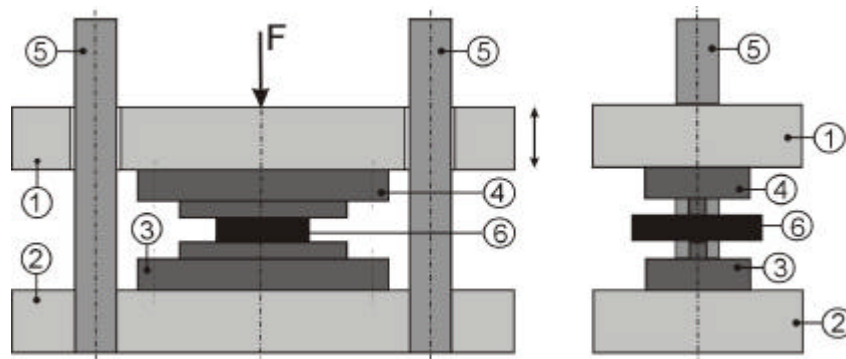


Fig. 2: Cross sectional principle sketch of a two pillar punch guide with attached platen in width (left) and length (right) direction.

The two pillar punch guide consists of two pillars (5), a lower ram (2) in which the pillars are fixed; and an upper ram (1) which moves along the pillars. The platen (3 and 4) are exchangeable attached to the rams. The compression velocity is constant and is adjusted to two millimetres per minute for all experiments.

To measure the thickness of the specimen (6), the distance between the two platen is optically registered, the applied force is measured by a load cell.

4 Specimen preparation

The specimen are cut out of commercial Al 99,5 sheet. Massive and multi-layered specimens, all with a breadth of 28 mm, length of 18 mm and final thickness of 4 mm, are made out of sheet of 1, 2 and 4 mm. The multi-layered specimen are divided in two groups, glued and unglued multi-layered specimens. At first, the experiments were carried out with un-annealed specimen. After that, the specimen were annealed in order to eliminate the influences of the cold formed microstructure and its influences on forming behaviour. For lubrication the specimen were wrapped with Teflon tape.

5 Massive specimens

In Fig. 3, the flow curves obtained by the plane strain compression of un-annealed and variously annealed specimen are shown.

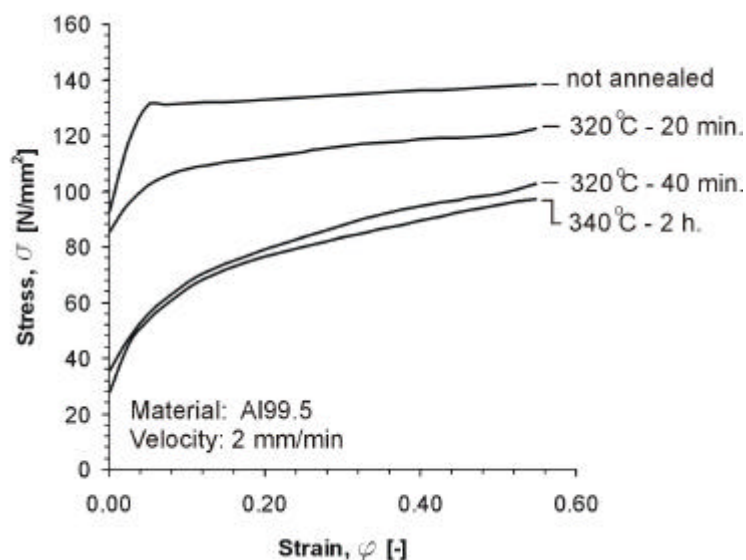


Fig. 3: Flow stress of massive specimen having undergone various heat treatments.

It is obvious that the specimen that isn't annealed (cold rolled state) has the highest flow stress and besides the (relatively) high flow stresses there are two recognisable areas: first there is a part of the curve where the flow stress increases with increasing strain and in the second part of the curve the flow stress remains nearly constant with increasing strain.

By annealing the specimen they become softer. Specimen which are annealed for 20 minutes at 320 °C clearly show a decrease of flow stress, although metallographic micrographs show that crystals in the core of the specimen are not affected by the annealing process. Increasing the time to 40 minutes at the same temperature of 320 °C worked out well, but did not give the desired complete homogenisation. This is reached by annealing at 340 °C for 2 hours. Although the microstructural difference there is only a slight difference in the flow curves of the specimens of 20min.-320°C and 2h.-340°C. This may be explained by the fact that the material in the core only deforms at high strains.

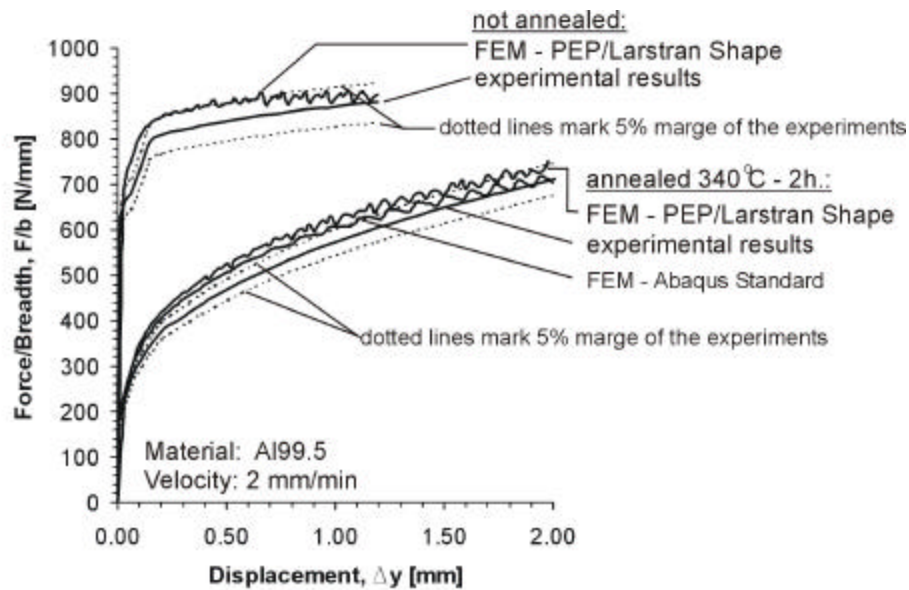


Fig. 4: Force-displacement diagram of massive specimen.

To validate the obtained flow curves, the plane strain compression test is simulated with the aid of the finite element method and afterwards the calculated forces are compared with forces measured during the tests. The process is a plane strain problem and therefore modelled two dimensionally. Elastic material properties are defined by the Young's modulus of 70000 N/mm² and a Poisson's ratio of 0.34, the mass density is 2700 kg/m³, the coefficient of friction is 0.01 [16]. The plastic material properties are defined by the obtained flow curves from the plane strain compression tests.

In general, forces calculated in the simulation show quite good agreement with those measured (Fig. 4). The calculated force curves lay for their major part in, or close to, the area of $\pm 5\%$ of the measured curve. All of the calculated curves show a better agreement at higher strains. This confirms the generally known fact that plane strain compression testing obtains more accurate flow stresses at higher strains than at lower strains.

6 Multi-layered specimen.

In order to compress multi-layered specimen glued and unglued multi-layered specimen are tested. During testing it is observed that unglued specimen bend open at the rigid regions outside deformed region. This results in totally different flow curves for glued and unglued specimens (Fig. 5).

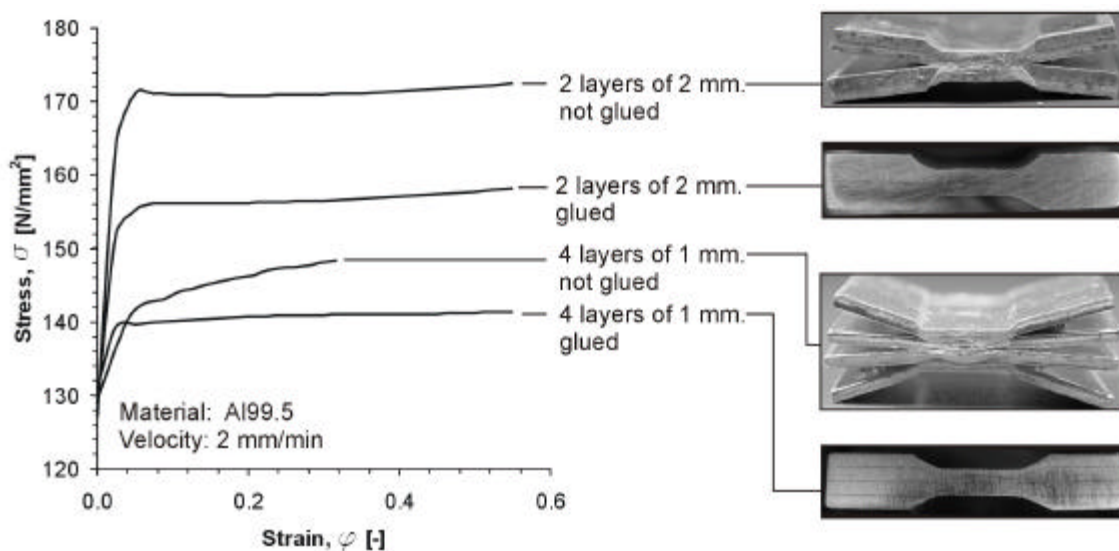


Fig. 5: Flow curves of un-annealed multi-layered specimen.

In both, the 2 layered and 4 layered specimens, the obtained flow stress for the specimen that are not glued are much higher than the glued layered specimen. The bending that occurs in the specimen that are not glued effects the psc-test in a negative way, the unglued specimen give incorrect results.

The flow curves of the un-annealed glued specimens (Fig. 5) show big differences between the two and four layered specimen, this probably because of their micro structural differences. Specimen of two and four layers, that are glued and annealed (2h.-320°C), have only small differences in their flow curves (Fig. 6). The flow curves of the two different kinds of annealed specimen are very near to each other (Fig. 6). The small differences can (partly) be explained by the fact that the annealing process is not yet optimised.

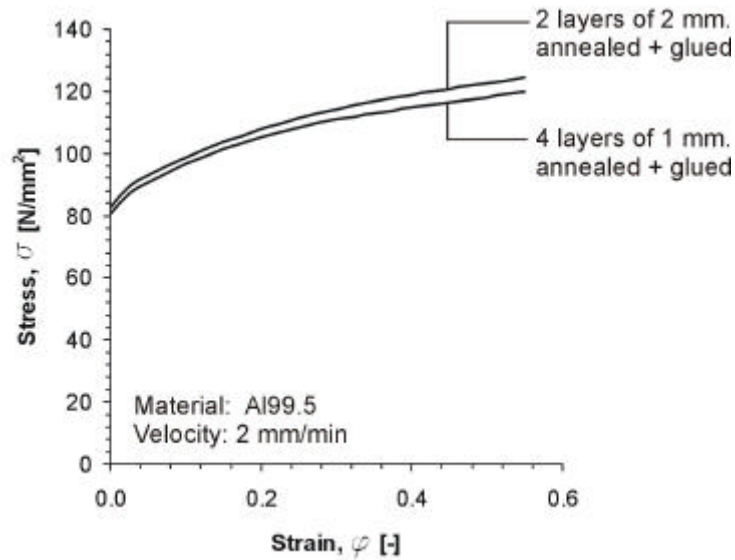


Fig. 6: Flow curves of annealed, glued multi-layered specimens.

7 Conclusion and outlook

From the experiments it can be concluded that it is possible to obtain accurate flow curves, stress strain curves, from a multi-layered psc-test. In case of concurrent microstructure of the material from which the specimen are composed, flow stresses obtained from psc-compression of specimen with various layers will be the same. On the other hand in case of differences in the microstructure, different flow curves are derived. From that it can be concluded that measuring size effects while miniaturising the specimen should be possible.

In the near future there are two facets for further development of psc-testing of miniaturised specimens. Firstly, the determined flow curves will be used in finite element simulations of the flat rolling process of small strips. The calculated forces and strip dimensions will be compared with experiments. Secondly, by decreasing specimen sizes with aid of similarity, it will be tried to determine size effects. The effects on the rolling process of these size effects will be investigated.

8 Acknowledgements

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9 Literature

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