

## Study of scaling effect on mechanical properties for milli-forming of sheet metal – Tensile test of a very thin sheet

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To find out scaling effect on the size-down of workpiece, many researches have been carried out in the case of tensile test with mini- or conventional tensile test machine. However no reason was conducted why mini-tensile test machine was necessary, or why conventional tensile test was enough to use. This paper shows the size effect of the tensile test equipment on scaling-down. Through this research, it is found out that the most important parameter for the tensile test of a very thin sheet is not on the size-down of machine but on minimizing the eccentricity of tensile specimen in the driving direction. An insert set was designed in order to minimize the eccentricity of the specimen. At least, until 25 $\mu$ m thickness of a specimen, the need of mini-tensile test machine is dispensed with the insert set and it is proved by several experiment: measurement of vibration and test using laser-extensometer, optical measurement system with CCD camera, and laser grid on the sheet metal.

### 1 Introduction

By the trend of manufacturing small and human oriented products, the needs of scaling down of the conventional sheet metal forming process is necessary. Milli components are classified as a component group for which the size is between macro- and micro-scales, i.e., less than about 10mm and larger than 10  $\mu$ m. However, it is very difficult to describe material properties and characteristics of very small (about 100 $\mu$ m) workpiece used in milli-forming. The miniaturization of several forming and material testing processes causes the so-called "scaling effect". They can be observed in tensile and upsetting tests as well as extrusion or bending processes. Not only metal forming but also fields of welding and surface, there are many researchers who studied on miniaturization. In Germany, Engel and Geiger studied the effect of miniaturization in the micro-bulk metal forming [2]. They did the double cup extrusion tests of different size from 4 to 0.5mm. Engel and Geiger studied the specific characteristics of micro sheet metal forming doing the miniaturized tensile test, too [1]. They found out that the flow stress decreases with increasing miniaturization. Weule et al. Studied the micro-cutting of steel to find out requirements in miniaturization [7]. Kals et al, found that the ratio of grain size to sheet thickness is a great role to determine material properties [3] [4]. Raulera *et al.* studied furthermore effect of large grain sizes through tensile and bending tests and he concluded the grain orientation and its anisotropy have a dominant role in plastic deformation behaviour [5] [6].

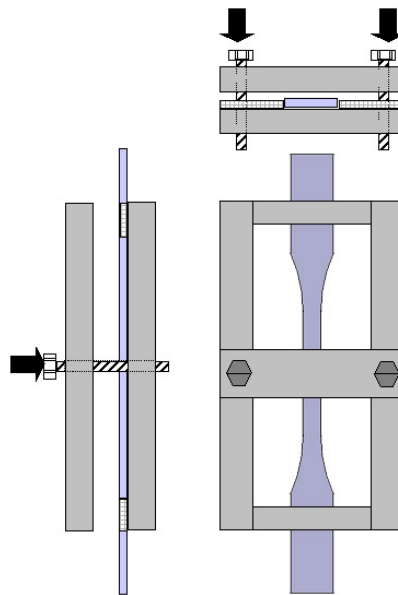
Thus many researches have been carried out to investigate the changes of material properties on scaling-down, however, for the hardware equipment, no specialized research has been carried out. This paper is focused on the hardware equipment for the mini-tensile test. In this research, the

size effect of the tensile test equipment by scaling-down was investigated and several tests were done to find out important parameters in doing mini-tensile test.

## 2 Goal and working program

The main goal of this study is to find out important parameters to perform mini-tensile test successful. In detail, if necessary, to develop an insert set for the mini-tensile test which helps to proceed the test accurately.

An insert set has been developed like Fig. 1 by preliminary research work in order to make the specimen straight to the driving direction. This decreases the eccentricity caused by clamping thin metal sheet.



**Fig. 1:** A schematic diagram of the inserting set without driving device

To find out, whether conventional tensile test machine is suitable for the experiment or not, following programs were performed:

- Measurement of vibration of tensile test machine
- Optical measurement (GOM)
- Measurement of laser grid on the surface of a tensile specimen

To compare material properties determined by methods above mention, a tensile test using mini-tensile test machine with a laser extensometer was performed.

Finally, to verify the reliability, a study of the scaling effect was compared with literature in its tendency.

### 3 Results and discussion

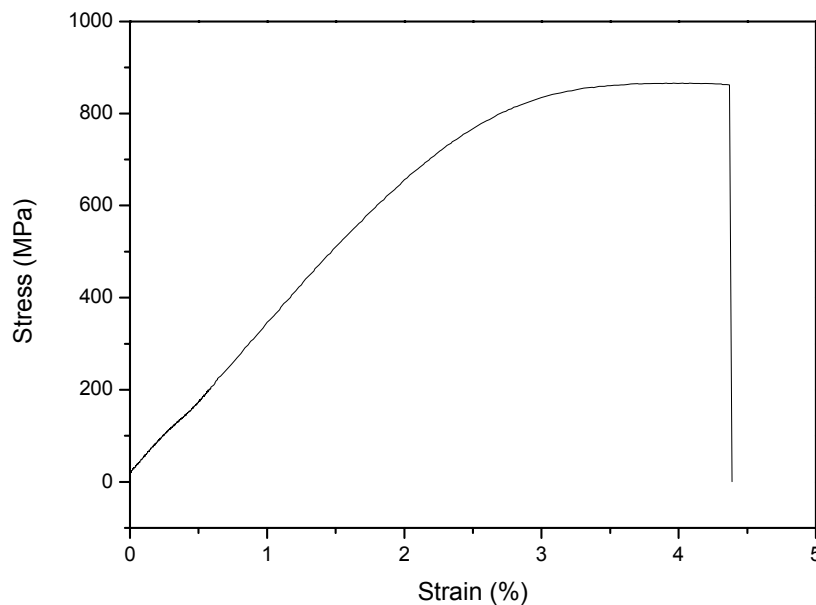
#### 3.1 Insertion set

In the preliminary experiment, with conventional clamp set, it is difficult to get uniform deformation (Fig. 2). These unexpected wrinkling and failure are caused by big eccentricity.



**Fig. 2:** Wrinkling and failure at conventional tension test of thin sheet (thickness 0.1 mm)

Therefore, an insert set was developed to minimized eccentricity to the driving direction during the test. The test material is stainless steel, 18Cr9Ni without heat treatment. In fact, in this study, the reason to use non-heat-treated material is to make the test in an extreme condition, because the maximum elongation of non-heat-treated sheet is too short and hard to measure. The test material in the chapters from 3.3 to 3.5 is always stainless steel, 18Cr9Ni and 0.075 mm of sheet thickness. As shown in Fig. 3, the maximum elongation is about 4.3 %.



**Fig. 3:** Stress-strain curve of stainless steel, 18Cr9Ni without heat treatment

#### 3.2 Vibration test

The first step to determine, whether the tensile test machine is suitable or not, is to check the machine vibration. Fig. 4 is shown the setting for the vibration test. Using the oscilloscope, it was

observed that the vibration of the driving direction was almost 0 (zero), exactly lower than 5 dB. Because of this reason, the further experiment with accurate measurement was necessary.

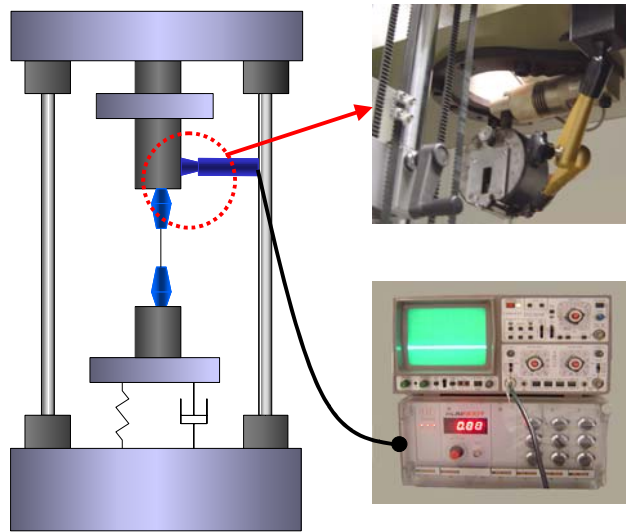


Fig. 4: Measurement of vibration with analogue oscilloscope

### 3.3 Experiment using an optical measurement system

The conventional test with machine from Zwick GmbH was coupled with the optical system Aramis of GOM GmbH. The optical measure system consists of two high-resolution-cameras, an external controller for data-recording and a PC. Using this system, translation displacements and deformation can be detected three-dimensional. Using the optical system, it was available to measure and calculate strain distribution of the specimen. As shown in Fig. 5, the maximum local strain is about 4.9% which has a good agreement with Fig. 3.

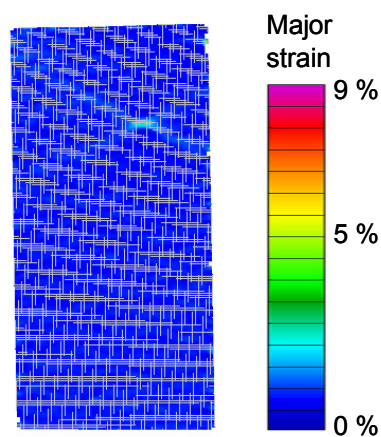
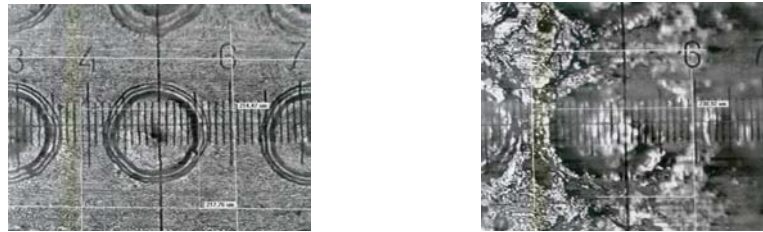


Fig. 5: An optical measurement of deformation with GOM Aramis

### 3.4 Measurement of micro-laser grid on the specimen

To observe local deformation and grain size, laser grid was printed on the surface of the tensile specimen. The distance between the points printed on the surface is 100  $\mu\text{m}$ . The maximum local strain was about 5.3% which shows a similar result like Fig. 3. Fig. 6 shows the printed grid and deformed grid after the test.

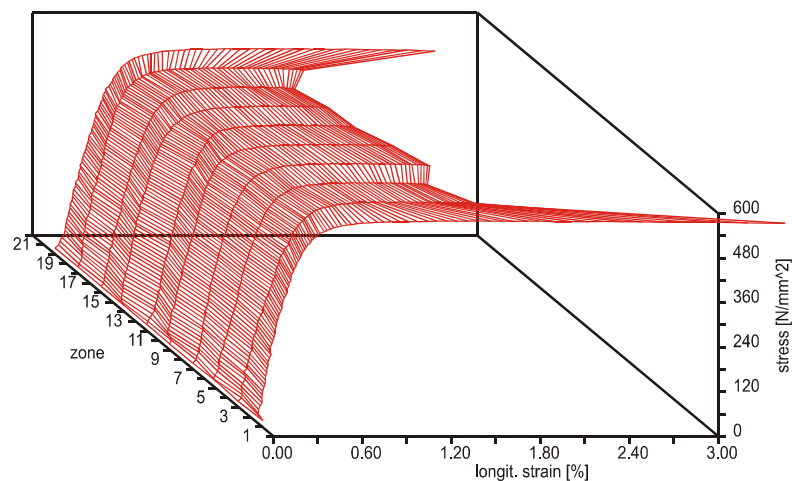


(a) Grid on the surface of the specimen (b) Fracture in the middle of the specimen

**Fig. 6:** Laser grid on a tensile specimen

### 3.5 Experiment with laser extensometer and mini-tensile test machine

A laser extensometer (Fiedler Optoelektronik GmbH, Germany) and mini-tensile test machine (Instron, 5kN load cell) were used to verify the reliability of measured strain in previous chapters. The specimen was equipped with 18 markers at a distance of 4mm each. Throughout the experiment, time, force and strain were recorded. The strain of the small specimens was measured free of contact and the resolution is about 0.1 $\mu\text{m}$ . Some strips are printed on a preselected area of the test sample. A laser beam driven by a rotating deflector scans continuously along the longitudinal axis of the specimen under load. Diffuse scattering of the scanning laser light occurs at the fringes. This scattered laser light is focused on a photodiode and transformed into an electrical pulse train. The time information of this pulse train is measured by a specially developed multi-stop-counter and relayed to a personal computer. Strain introduced into the test sample by the applied load changes the distance between the fringes and as a result changes the corresponding time pattern in the electrical pulse train. This change of time behaviour is analyzed and transformed into strain values between the fringes of the sample.



**Fig. 7:** Stress-strain relation of divided zones measured by laser extensometer

As shown in Fig. 7, the maximum local strain is about 4% which has about 1% difference with other test above done.

### 3.6 Study on scaling effects

The material(steel, 18Cr9Ni) investigated with the ranging from 0.025mm to 0.2mm (DIN 50125-E5316350). By recrystallization the grain size was changed from 10 to 50 $\mu$ m ( 2.5 hour, 650°C). They were calculated accorded to the standard method ASTM. As shown in Fig. 8 and Fig. 9, the decrease of the thickness leads to a decrease of elongation, yield stress and tensile strength. This is a typical tendency comparing with results from other scientists [3, 4, 5, 6]

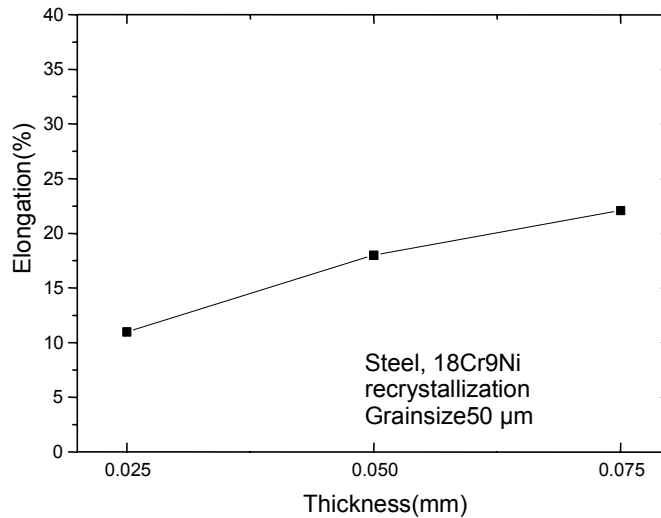


Fig. 8: Elongation by the variation of sheet thickness

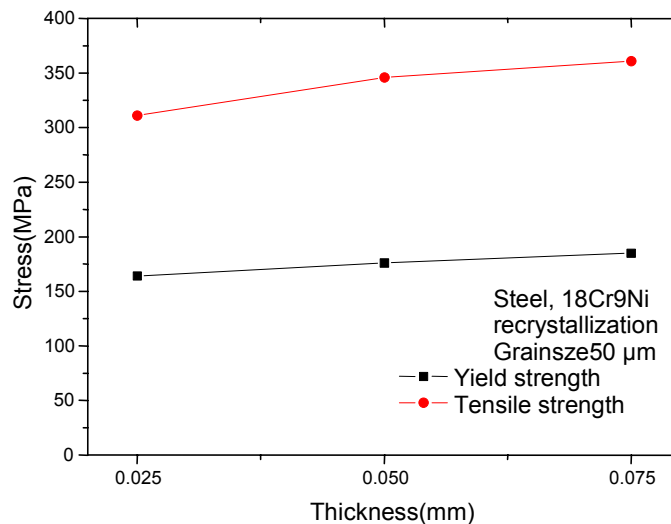


Fig. 9: Behavior of tensile strength and yield stress by sheet thickness

#### 4 Conclusion

It is found out that the most important parameter for the test equipment in mini-tensile test is not a scaling down of machine size but minimizing the eccentricity in the tensile test. Therefore the insert set was manufactured without driving component, for instance, motor or piezo-actuator only for making the specimen straight to the tensile direction. In addition, tensile test with accurate measuring equipment is necessary, for example, an optical measurement system or laser extensometer to find out the strain localization of the tensile specimen simultaneously.

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