VERIFICATION OF MEASUREMENT OF DYNAMIC LOADING DURING THE TAYLOR ANVIL TEST

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The Taylor Anvil test is used to estimate dynamic behaviour of materials in an interval of strain rates of 10^2 to 10^4 s^{-1}. The specimen is deformed due to impact on a rigid target instrumented with detectors. This measuring set provides an advantage in finding the forming force, which acted during the deformation. A Charpy hammer of nominal energy of 50J was used for the verification of dynamic loading induced by impact of a specimen. This measuring set is placed in the Laboratory of high strain rates at FME Brno, Institute of Manufacturing Technology, Department of Metal Forming and Plastics. The experiment arrangement allows comparing the results obtained independents by strain gauges and piezoelectric sensors.

KEYWORDS

high strain rates, Charpy hammer, Taylor anvil test, strain gauges, dynamic loading

1 INTRODUCTION

Modern bulk-forming technologies demand accurate constitutive modelling at strain rates exceeding 10^4 s^{-1}. Strain rates together with temperature are one of the main factors that significantly affect the process of plastic deformation of metals.

The Taylor anvil test (TAT) is a useful experiment for estimating material behaviour at high strain rates of 10^4 s^{-1}. The impact velocities of test specimens are relatively low. An advantage of TAT is the evaluation of dynamic yield stress based on empirical relations and specimen geometry. [Jones et al. 1998 , Meyers 1994, Woodwardr et al. 1994]

Further computer simulation of physical experiment allows obtaining parameters for constitutive equations like the Johnson-Cook equation. [Forejt et al. 2000, Forejt et al. 2002a, Forejt et al. 2002b]

The Taylor anvil test consists in impacting a cylinder specimen on a hard surface. The cylindrical specimen of 25 mm in length and 5 mm in diameter is placed into a specimen carrier and accelerated by expanding air in a gas gun towards the catch tank. The specimen is separated from the sabot just before its impact on the measuring bar. The resulting impact on the front of the measuring bar produces an elastic compressive pulse that is recorded by resistance strain gauges glued onto the measuring bar and connected in a full Wheatstone bridge.

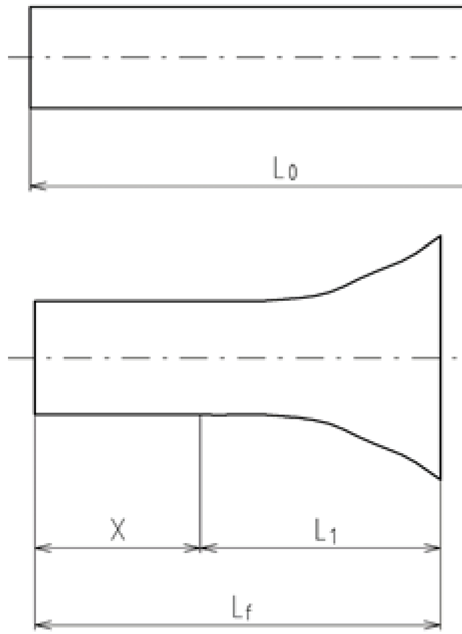

Figure 1. Illustration of initial and final shape of specimen

2 EXPERIMENTAL TECHNIQUES

The schematic illustration of TAT is shown in Fig. 2. The goal of experiment is a comparison of independent results measured by the Hettinger type foil resistance strain gauges and the Kistler piezoelectric sensor. A Charpy hammer of nominal energy of 50 J was used for creation of an elastic compressive pulse. This setting is useful due to unequivocal effect of dynamic pulse with easy repeatability. According to the setting where specimen impacts on a rigid wall there is no variability of specimen impact velocity. This variability may affect the amplitude of dynamic pulse.

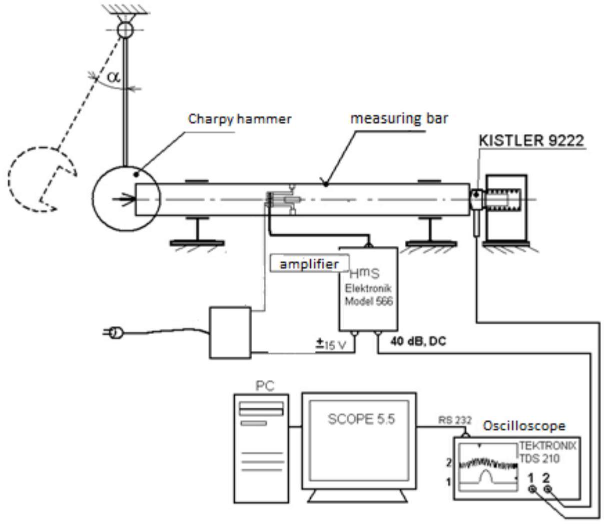

Figure 2. Illustration of setting at dynamic loading

The pulse reaches through the bar made of high-strength (quenched and tempered) steel after hammer impact. The measuring bar is of 20 mm in diameter and 800 mm in length. Four HBM 3/120 LY11 resistance strain gauges are glued in the middle of the bar (two lengthwise and two crosswise) and connected in a full Wheatstone bridge. The incident pulse created by hammer impact is recorded via an amplifier on a Tektronix TDS 210 oscilloscope. A piezoelectric sensor is placed on the other end of the measuring bar.

A typical recording is shown in Fig. 3. Wave 1 (bottom curve) represents the recording of the Kistler sensor. While reaching a voltage of 1.6 V pulse starts to be measured. Wave 2 (upper curve) corresponds to the recording of excitation voltage in the Wheatstone bridge. This voltage was magnified by an amplifier 100 times. Typical recording in Fig. 3 shows acceptable wave dispersion. Suitable mathematic filtering (e.g. Butterworth 4, LP = 6-20) in the Scope 5.5 programme can eliminate the dispersion mentioned. Amplitude sensitivity to different filtering levels is minimal.

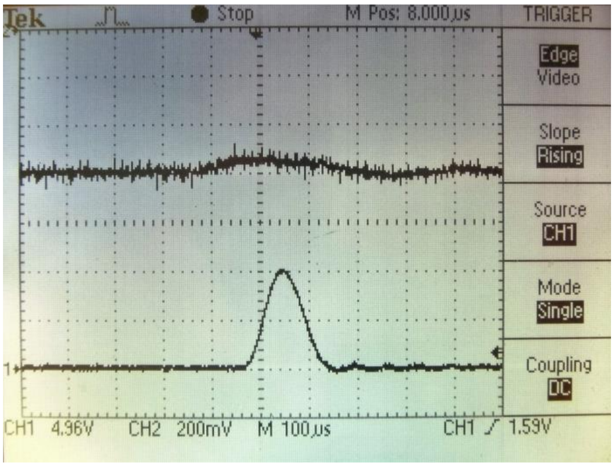

Figure 3. Typical recording of the Tektronix TDS 200 oscilloscope

As shown in Fig. 3 maximal transit time of both recordings of about 75-80 µs can be evaluated. This is the actual distance between sensors (about 400 mm) and can be calculated via the velocity of elastic wave propagation in the measuring bar (5 122 m/s). The recordings were captured for hammer deviation angles of the 10°, 20°, 30°, 40° and 50°. The resulting recordings is sensitive to deviation accuracy and the way the hammer is released.

3 RESULTS AND DISCUSSION

The dependence of force on bar strain was chosen for a comparison of recordings. The Kistler sensor worked with an output voltage range of 1kN / 1V. The maximum force was calculated from the recording using eq. 1 the bar strain was determined in microstrains [µm/m]. [NI 2016]

$$\varepsilon = \frac{F}{S \cdot E} 10^6 \qquad (1)$$

where F corresponds the maximum force in kN, S corresponds to the bar cross section area in mm², and E corresponds to the Yong modulus of bar in MPa.

The maximum force from strain gauges was calculated using eq. 2-4. Real strain was calculated using eq. 2.

$$\varepsilon = \frac{U_{BD}}{U_N} \cdot \frac{1}{K} \cdot \frac{1}{Z} \cdot \frac{1}{2} \qquad (2)$$

where U_{BD} is the increment in the measuring voltage, U_N is the supply voltage (1.756 mV), K is the strain gauge constant (2.0), Z is the amplification (100 times).

$$\sigma = \varepsilon \cdot E \text{ [MPa]} \qquad (3)$$

$$F = S \cdot \sigma \text{ [kN]} \qquad (4)$$

where σ corresponds to the axial stress in the bar.

A comparison of the results measured for different angle deviations of the Charpy hammer is in Tab. 1. Graphical interpretation including static bar loading on a hydraulic press is then shown in fig. 4.

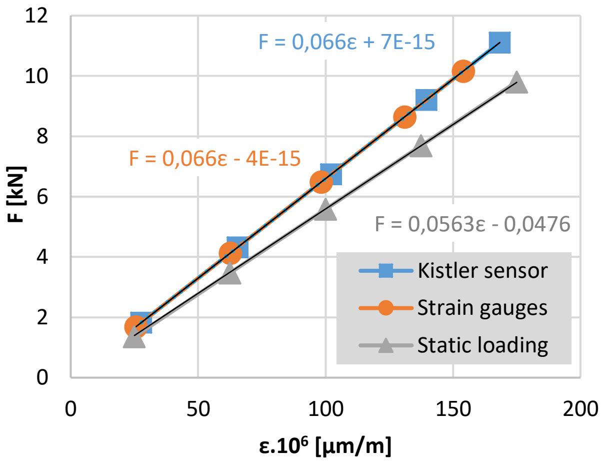

Figure 4. The dynamic force dependence on bar strain

The coordinates of force in dependence on strain are shown in Fig. 4. Linear trend line was fitted the plotted coordinates using the MS Excel software. It was found that in both cases, the measured values agree. Line gradient of both curves are almost the same. It is another proof that the coordinates have a linear character as follows from Hook's law. Additional verification of the results obtained is that the force is equal almost to zero under zero load value. This slight difference is due to a measuring mistake e.g. using a mathematical filtering. As follows from the results, there is no difference in the used measuring technique used while measuring the dynamic impact force.

Table 1. Measured results

Angle deviation of Charpy hammer	Kistler sensor		Strain gauges				Static loading	
	ε. 10⁶	F	U_{BD}	ε	σ	F	ε	F
[°]	[µm/m]	[kN]	[mV]	[µm/m]	[MPa]	[kN]	[µm/m]	[kN]
10	27.74	1.83	0.0090	25.63	5.38	1.69	25.0	1.36
20	65.48	4.32	0.0220	62.64	13.15	4.13	62.5	3.47
30	102.16	6.74	0.0345	98.29	20.64	6.48	100.0	5.58
40	139.60	9.21	0.0460	131.04	27.52	8.64	137.5	7.69
50	168.40	11.11	0.0541	154.07	32.36	10.16	175.0	9.81

It should be noted that the piezoelectric sensor is has been used for a short time within the modernization of measurement in the laboratory of high strain rate sat FME, BUT. This comparison also shows if the Kistler sensor is suitable for Taylor anvil test. As shown in Fig. 4, compared to existing methodology piezoelectric sensor is a suitable replacement in terms of simplification of measuring devices with the same level of the information minimally influenced by wave dispersions. The strain gauges are burdened with a delay and have low lifetime due to shock loading. The strain gauges are loaded with a delay increasing with their length as shown in fig.3. The duration of measurement recording by strain gauges is about 3 times greater than the duration of the recording by the Kistler sensor. For this reason, it would be appropriate to use as shortest strain gauges as possible.

4 CONCLUSIONS

The verification of impact force using the Charpy hammer helped verify the accuracy of measurements using strain gauges and piezoelectric sensors. Since the results of measurement by strain gauges match the Kistler sensor, force can be measured independently using only one method. It should be noted that the accuracy of measurement by strain gauges is influenced by many factors such as proper grounding of the power amplifier, noise and frequency discharges in the electrical network and many others. In contrast, the Kistler sensor allows fast measurements without complicated preparations and existing power conditions.

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