FZU, Czechia

PRISM

RESIDUAL STRESS MEASUREMENT REPORT

1720438

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RESIDUAL STRESS MEASUREMENT REPORT

Customer:	FZU, Czechia
Contact person:	Mr. Sanin Zulic
Date:	31. Mai 2017
Process number:	1720438
Order number:	-

1 SAMPLE DESCRIPTION AND NAME:

The residual stress has been measured at some shot peened sample.

2 MEASUREMENT POSITION AND DIRECTION

Following are measurement position and direction at the test sample (Measurement direction: SigXX = longitudinal direction, SigYY = cross direction).

Fig. 1: Overview test sample

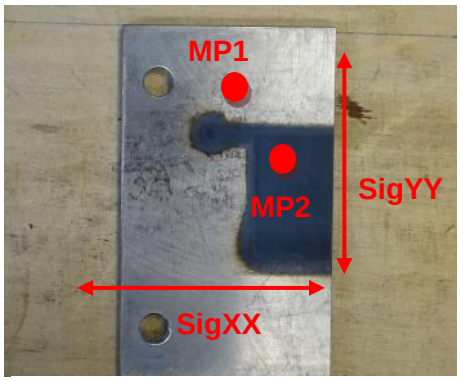


Fig. 2: Measurement position and direction

3 DEPTH PROFILE

Measurements were performed with the following (nominal) depth steps: 10, 20, 50, 100, 150, 200, 250, 300, 400, 500, 600 µm. The individual depth steps were generated with a special drill.

4 DRILLING PATTERN

Following the drilling pattern is shown

Fig. 3: Drilling pattern

5 MEASUREMENT PARAMETER AND DEVICE SETTINGS

PRISM	
Central unit	
PRISMS version	1.1.0
Camera settings	24°
Illumination settings	60°
Drilling parameter	
Drilling diameter	0,8mm (1/32)
Drill type	2-fluted
Drill coating	TICN
Rotation speed	50.000 rpm
Feed rate	0,01 mm/s
Sample	
Material	Ti
Young’s module	114000 MPa
Poisson’s ratio	0,34

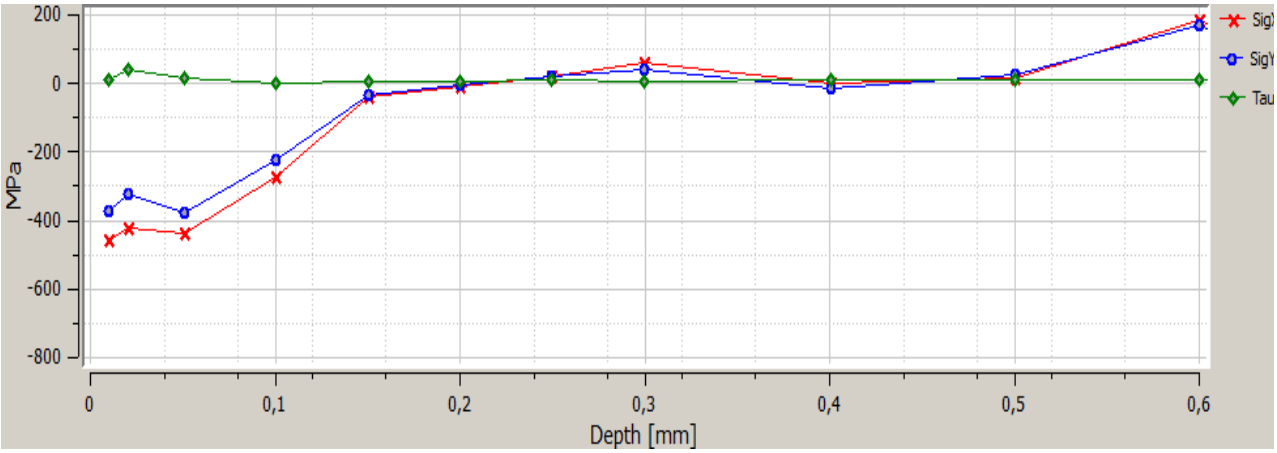
6 RESULTS

The results of the stress analysis were summarized in a table (Table 1, ff.) and the depth profiles were plotted (Graph. 1, ff.).

Table 1

MP1

Depth [µm]	SigXX [MPa]	SigYY [MPa]	TauXY [MPa]	Sig1 [MPa]	Sig2 [MPa]
10	-455	-371	11	-370	-457
21	-421	-322	42	-306	-436
51	-435	-375	16	-371	-439
100	-272	-225	-1	-225	-272
150	-37	-34	6	-29	-42
200	-7	-4	8	3	-14
250	21	23	9	31	13
300	61	40	5	62	39
401	1	-15	13	8	-23
501	17	28	11	34	10
600	186	172	11	192	165

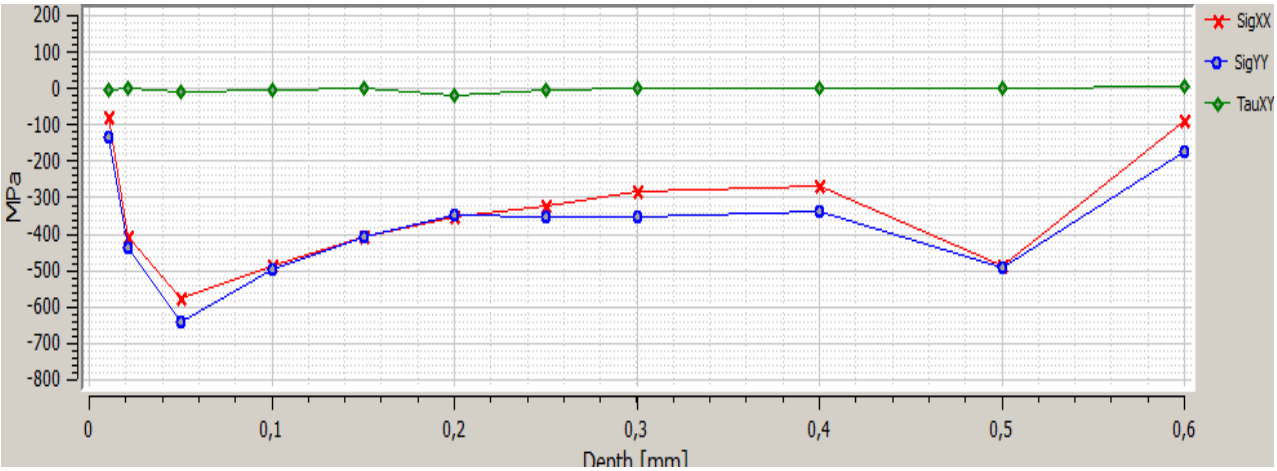


Graph 1: depth dependence of residual stress

Table 2

MP2

Depth [µm]	SigXX [MPa]	SigYY [MPa]	TauXY [MPa]	Sig1 [MPa]	Sig2 [MPa]
10	-79	-131	-3	-79	-131
21	-407	-435	0	-407	-435
51	-576	-639	-9	-575	-640
100	-489	-494	-5	-486	-498
150	-405	-407	-1	-404	-407
200	-350	-347	-19	-329	-368
250	-321	-351	-6	-320	-353
300	-280	-354	-1	-280	-354
401	-267	-339	3	-267	-339
501	-488	-491	-1	-487	-491
600	-89	-174	4	-89	-174



Graph 2: depth dependence of residual stress

ANNEX

The hole drilling technique is one of the most commonly used methods for stress measurement. By removing a volume of material, residual stresses are removed and the stress equilibrium in the part is changed. The stresses in the remaining material rebalance and the surface, especially near the hole, distorts slightly. In the traditional technique with strain gages, this surface distortion is measured as a change in electrical resistance.

Prism measures surface distortion optically using laser light (ESPI – Electronic Speckle Pattern Interferometry; see schematic in Figure 1. Images from before drilling are compared with those after each drilling increment. Every condition is described by a set of four images, each taken with the reference beam phase-shifted a different amount: 0°, 90°, 180° and 270°. The reference beam interferes with the object beam on the CCD, Figure 1. This allows measuring surface displacements as a phase shift. Illumination and observation directions can be adjusted by the user to accommodate a variety of measurement conditions. Thus, the sensitivity direction of the measurement can vary, Figure 2.

Data analysis includes all pixels in a ring-shaped area around the hole, described by the inner and outer integration radius. The area immediately next to the edge does not provide useful information because the drilling process always disturbs this part of the surface. The analysis area can be modified in the software; an inner radius of twice the hole radius and an outer radius 4 times the hole radius are typical.

The combination of all pixel intensities I_i yields a phase map Ω,

$$I_i(p,q) = I_{ref}(p,q) + I_{obj}(p,q) + 2\sqrt{I_{ref}(p,q) \cdot I_{obj}(p,q)} \cdot cos(phi(p,q))$$

$$\Omega = tan^{-1} \cdot \left(\frac{(I_1 - I_3)(I'_1 - I'_3) + (I_2 - I_4)(I'_2 - I'_4)}{(I_1 - I_3)(I'_2 - I'_4) - (I_2 - I_4)(I'_1 - I'_3)} \right)$$

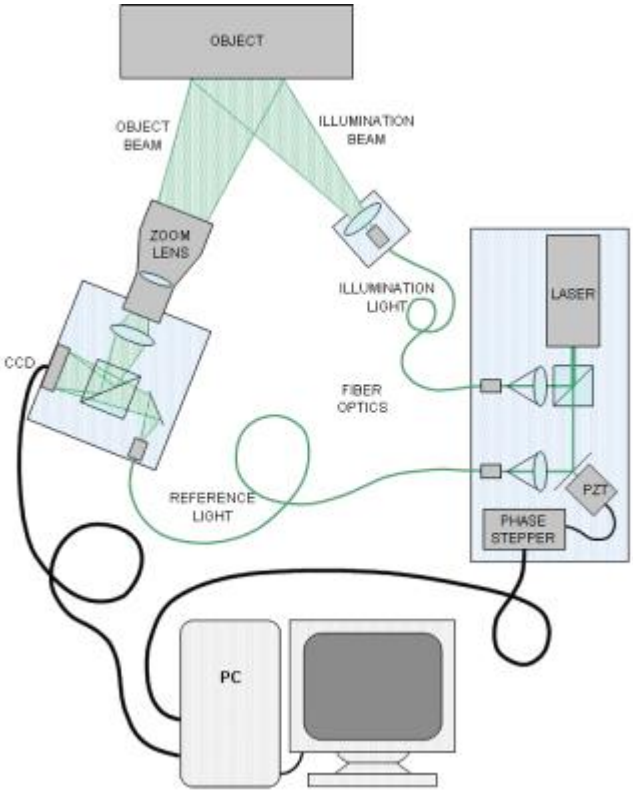


Fig. 1. *Prism schematic.*

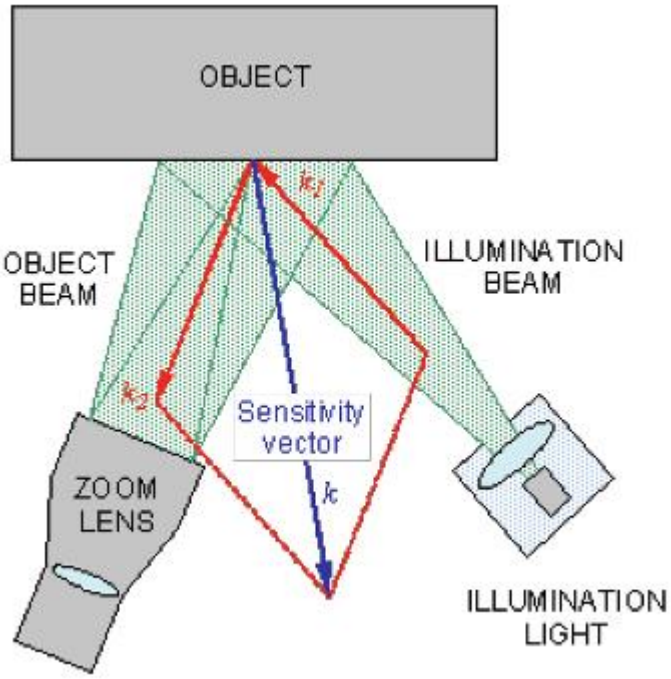


Fig. 2. *Illustration of the sensitivity vector.*

which is then treated with an unwrapping algorithm to produce the experimental displacement map. This map is fitted using model displacement maps for each of the three variables of the planar stress state. Together with the elastic material parameters, Young's modulus and Poisson's ratio, this generates the stress values. The fitting also considers three variables describing all possible types of rigid-body movements (to account for sample movement between the image sets). The stress profile calculation includes an option for Tikhonov regularization, which binds the individual depth values together and leads to a smoothing of the curve.

Prism typically is used with end mills from about 0,8 mm to about 3,2 mm (1/32" – 1/8") diameter. But the limitation for hole diameter is only that of the hardware; that is, the actual size of the drill bit, and the capability of the zoom lens to image the hole. The zooming function is affected by the distance between camera and sample.

The maximum useful hole depth is dependent on hole diameter. In fact, instead of separating depth and diameter, the parameter of interest is the depth to diameter ratio, h/d. It is generally considered that the maximum h/d ratio should not exceed 0.6. The reason for this is apparent; with increasing drilling depth the distortion of the surface decreases even if the stress level is constant. From a certain depth onward the specimen will not produce any noticeable change at the surface, which is where the displacement measurement is taking place. The numerical models developed for Prism support drilling between $0.1<h/d<0.6$.

A second hole/depth dependency is the state of stress, that is, for lower stress levels, a larger amount of material must be removed by the drill in order to produce a measurable amount of surface displacement. On the other hand, if stresses are large, even small drilling increments may produce good data. This also means that a smaller diameter bit may be used successfully for the same depth increment.

The end mills provided with the instrument produce a hole very close to cylindrical. The holes end in an inverted cone. For shallow depths the hole shape still may significantly deviate from the cylindrical shape assumed in the stress model. This may lead to a relatively poor fit of the stress state, making near-surface results less accurate. A possible remedy is to use a smaller diameter bit for cases where surface-near measurements are critical.

Type of drill, type of drill bit, the actuated stage and the setup of the components all affect the accuracy of hole diameter and depth and subsequently the accuracy of the result. In general, the drill system provided with Prism should produce diameter accuracies with less than 1% impact on stress results. Relative depth accuracy is also a function of the depth drilled since most error sources have absolute magnitudes (not relative to the depth value). Thus, shallow holes are affected more. In general, if a full error analysis is required, measurements will have to be made of hole depth and diameter, in the particular material of interest, and with the drilling equipment to be used.