MEASUREMENT OF SURFACE CHARACTERISTICS BY THE LOCAL PLASTIC DEFORMATION

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Abstract

The content of this article is comparing the results of measurement of residual stresses using the X-ray diffraction and Barkhausen noise.

These two processes are often used in academic research. Currently, they are no longer in use except for when the output control of real heavy-duty machine parts is required to be measured. Problem is, that these two methods works on different physical principles. The main motivation of this article is the possibility of comparing the results obtained using these two methods. On the samples, plastic deformations such as critical damage from pitting were found.

Keywords: X-ray diffraction, Barkhausen noise, plastic deformation, residua stresses

1. MOTIVATION OF EXPERIMENT

Surface condition is a critical variable for most machine parts, especially those that are highly dynamically loaded. The top layer of the material is a very dangerous place in terms of creating fatigue damage, since the initial development takes place mainly there. There are many influences that create the fatigue effect on the parts. Primarily these are surface residual stresses (along with the operating load), influence of microstructure, influence of morphology (roughness) after machining. Some of the most important influences are residual stresses. These are usually caused by technological condition of machining. High level of especially tensile stress can cause easy growing of fatigue microcracks. On the surface, formed defects are usual as well, such as pittings, cavitation, wear, etc. These defects usually means considerable fluctuations in the level of residual stresses. Two independent methods can be used for study: X-ray diffraction method and Barkhausen noise method. The main purpose of the experiment is to assess how these methods can capture the damage created by plastic deformation, and whether the results of these two methods are comparable.

2. SAMPLES

As the test material used was non-alloy quality structural steel C45. It is mainly used for machine parts such as shafts, gears, etc. The material is suitable for heat treatment and surface laser hardening. Three samples were made. Dimensions of samples were 25x50x20 mm. The samples were hardened at temperatures of 850 º C into oil. Sample 1 was tempered at 250° C for 2 hours and samples 2 and 3 were tempered at 560 ° C for 2 hours. On the samples were measured Vickers hardness. The surface was then prepared on metallographic grinding paper up to 1600. Polishing was not used due to prevent the formation Beilby layer, which could involve the results especially at measiring by X-ray diffraction. Simulation of defects was created using Brinell hardness test. On the sample was created three indentations. In samples 1 and 2, each formed one cratered indentation, 20 and 40 indentations force 3000 kg to the same place. The third sample was formed indentations reduced force to correspond to the sample 1.

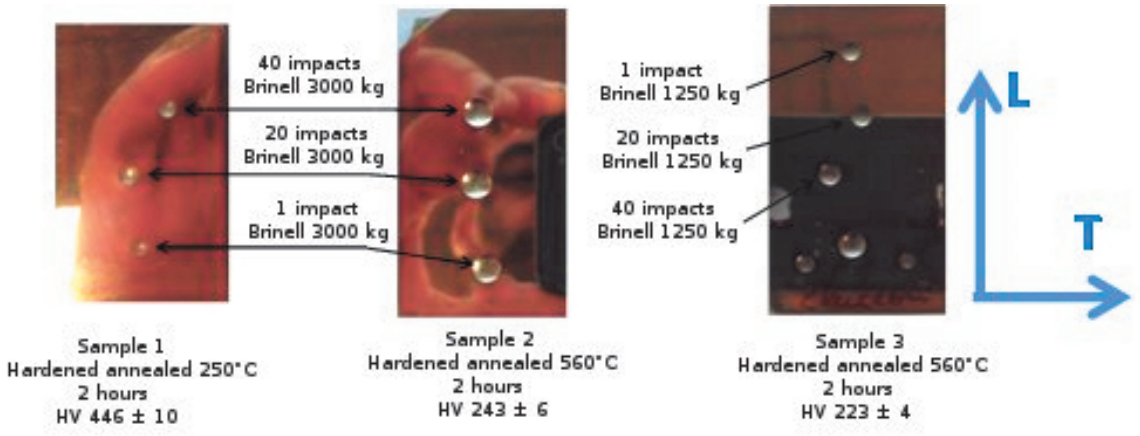

Fig. 1 Used samples

3. X-RAY DIFFRACTION

Measurements were performed on a diffractometer X'Pert Pro ω-arrangement. Due to the need of a close parallel primary beam illuminating the surface was used monocapilarry an inside diameter of 0.5 mm. To set monocapillary was used optical camera. Proper adjusting the monocapilary and the reticle is reflected in the optical image position θ = 0 ° (see figure).

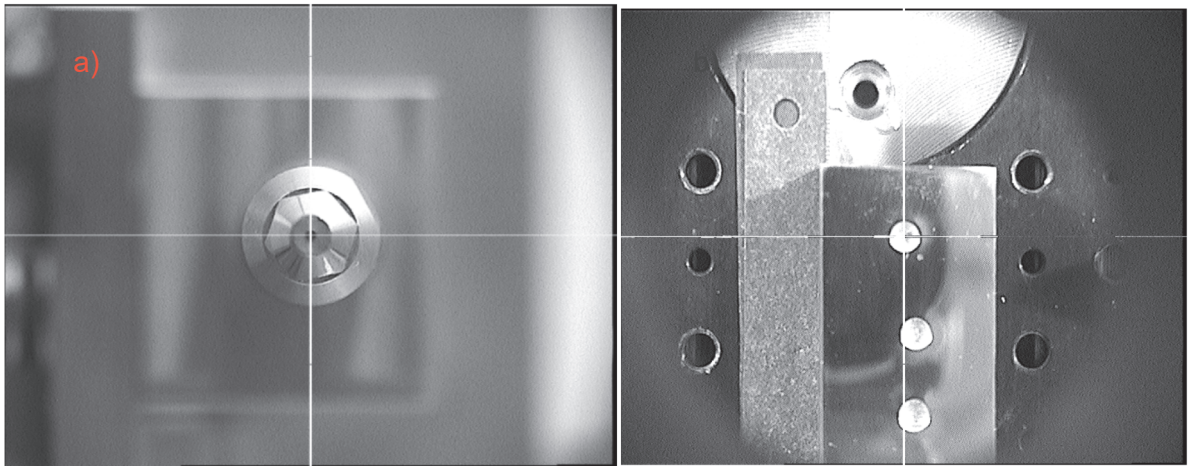

Fig. 2 a) optical image from a camera mounted on his shoulder detector at θ = 0 °; correct setting monocapillary a white crosshair position is reached at the cross in the middle of the hole 0.5 mm monocapillary. b) The image of the sample with indentations was caused by pressing the balls force 3000 kg and scanned by a camera placed on the shoulder of the detector. The white cross marks the position of the irradiated area.

It was used CrKα radiation and diffraction patterns were analyzed by {211} α-Fe. Each profile was measured Tilting corresponding values sin2ψ = 0; 0.12 ... 0.6 for positive and negative ψ. Step measurement was set to 0.25 ° 2θ and counting time 7 seconds. It was performed by numerical processing of the measured profiles (see figure) and can be calculated by dependence on the tilt-spacing specified value sin2ψ (see figure).

4. BARKHAUSEN NOISE

This method is based on magnetic characteristics of materials. These are explained by using specific substructure, called Weiss area's, which divide the grain and subgrain boundaries. They build small magnets

and are separated by and are called: Bloch walls have a thickness of only a few atomic planes. In ferromagnetic materials without the presence of an external magnetic field are these domains organized chaotically. Magnetizing by an external field causes a shift on each of these areas in the direction of magnetization. This process is not homogeneous, always takes place gradually as each area sequentially in this process involved. Thus, the seemingly smooth magnetization curve finding discontinuities (steps), measured as the Barkhausen noise. The surface condition of samples analyzed is the result set of the following technological operations: Mechanical grinding, polishing metallographic and indentation when the indenter occurs locally exceeding the yield strength, and therefore changes in the mechanical properties of the surface and thus redistribution " superimposed " macroscopic residual stress. These effects are presented by the change quantity called: magnetoelastic parameter when residual tensile stress grow, this parameter is increased, and vice versa. Level of the magnetoelastic parameter is also affected by other accompanying technological process, for example of hardening, which changes the values of magnetoelastic parameter too.

4.1 Experimental arrangement for measurement of Barkhausen noise

Measurement was performed on the analyzer MicroScan StresstechOy 600-1 allowing gauging except magnetoleastic parameter mp that corresponds to the intensity of the Barkhausen noise (so-called discontinuous magnetization), can analyze other characteristics of the hysteresis loop, e.g., the coercive force Hc, remanence br and permeability μ. In process of testing was used standard sensor S1-138-15-0. On the begin was set sinusoidal signal magnetizing voltage of 5 V sample 1, and 3.5 V, sample 2 and 3 by magnetization frequency 125 Hz. The results of each analysis points are the mean of 10 measurements. The depth of penetration of the excitation signal is dependent on the used frequency of the excitation signal and the material to be analyzed [1].

5. EVALUATION

These two methods work both on different physical principles. It can be only supposed that among measurements of magnetizing parameter mp and normal residual stresses ND is certain continuity. It can be assumed that the value of the magnetization parameter and the normal residual stress quantities has the normal (or more exactly binormal) distribution. Next will be calculated a Pearson correlation coefficient r.

$$r = \frac{\sum\left[(x_i - \bar{x})(y_i - \bar{y}\right]}{\sqrt{\sum(x_i - \bar{x})\sum(y_i - \bar{y})^2}} \quad (1)$$

Where x_i and y_i are the measured values. `x and `y are the means. This parameter can reach values between -1 and 1, while a negative value indicates an indirect proportion and positive the direct proportion. The value approaching to zero indicates probably no correlation between the measured variables.The correlation coefficient had to be verified by using t-test when the test the null hypothesis of independence.

$$t = \frac{r}{\sqrt{\frac{1-r^2}{n-2}}} \quad (2)$$

Where r is the correlation coefficient and n is the number of values. Testing criterion t is compared with t-quantiles of the distribution for the chosen significance level and the degrees of freedom v = n-2 on the level of significance α

If $t > t_{1-\alpha/2}$- correlation coefficient is apparently significant at the α level.

If $t < t_{1-\alpha/2}$ - The correlation coefficient is probably not significant at the α level. Hypothesis is neccersary to refuse.

Since area around the crater is due to the geometrical characteristics of the dispersion of values which was carried out so that the measured values were progressively removed, if is possible to find a match, at least in the deformed zone around the indentation.

Table 1 Sample 1, 1 indentation

distance from center [mm]	mpL	ND - direction L [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α	mpT	ND - direction T [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α
0	66	-507	-0.15	0.36	refuse	35	-116	-0.44	1.20	0.9
1	56	-22	-0.32	0.76	refuse	47	-283	-0.46	1.15	0.9
2	62	17	-0.14	0.28	refuse	53	-731	-0.76	2.31	0.95
3	78	-62	0.23	0.42	refuse	38	-858	-0.98	8.61	0.995
4	83	-214	-0.17	0.25	refuse	36	-612	-0.99	13.76	0.995
5	75	-223	-0.27	0.28	refuse	31	-428	-1.00	17.06	0.975
6	61	-261	-	-	-	28	-271	-	-	-
7	59	-156	-	-	-	28	-260	-	-	-

Table 2 Sample 1, 20 indentations

distance from center [mm]	mpL	ND - direction L [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α	mpT	ND - direction T [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α
0	99	-347	0.02	0.04	refuse	64	-314	-0.69	2.32	0.9875
1	100	-111	-0.53	1.40	0.8	83	-465	-0.75	2.53	0.95
2	99	-48	-0.51	1.18	0.8	95	-929	-0.94	5.35	0.995
3	113	-114	-0.24	0.43	refuse	71	-934	-0.99	12.84	0.995
4	131	-187	-0.13	0.19	refuse	66	-750	-1.00	29.04	0.995
5	141	-172	0.04	0.04	refuse	49	-486	-0.99	8.78	0.95
6	123	-113	-	-	-	40	-367	-	-	-
7	94	-166	-	-	-	35	-267	-	-	-

Table 3 Sample 1, 40 indentations

distance from center [mm]	mpL	ND - direction L [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α	mpT	ND - direction T [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α
0	75	-495	0.80	3.23	refuse	46	-317	-0.84	3.83	0.995
1	82	-286	0.68	2.10	refuse	91	-702	-0.84	3.42	0.9875
2	109	10	0.48	1.09	refuse	89	-1074	-0.96	6.83	0.995
3	128	-16	0.71	1.75	0.9	60	-828	-0.98	7.92	0.995
4	128	-152	0.60	1.05	0.8	50	-529	-0.89	2.76	0.9
5	110	-156	0.67	0.90	refuse	42	-416	-0.58	0.71	refuse
6	98	-150	-	-	-	40	-333	-	-	-
7	93	-217	-	-	-	41	-273	-	-	-

Table 4 Sample 2, 1 indentation

distance from center [mm]	mpL	ND - direction L [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α	mpT	ND - direction T [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α
0	48	-206	-0.24	0.60	refuse	49	-162	-0.48	1.34	refuse
1	39	-165	-0.43	1.06	0.8	33	-129	-0.60	1.67	0,8
2	37	-35	-0.74	2.23	0.95	29	-336	-0.59	1.46	0,8
3	52	20	-0.72	1.78	0.9	49	-407	-0.08	0.15	refuse
4	80	-80	-0.54	0.90	refuse	80	-473	0.54	0.92	refuse
5	87	-99	-0.60	0.75	refuse	47	-496	0.22	0.22	refuse
6	56	-130	-	-	-	51	-485	-	-	-
7	115	-183	-	-	-	48	-473	-	-	-

Table 5 Sample 2, 20 indentations

distance from center [mm]	mpL	ND - direction L [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α	mpT	ND - direction T [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α
0	56	-240	0.01	0.03	refuse	74	-214	-0.45	1.23	refuse
1	65	-242	-0.19	0.42	refuse	55	-289	-0.62	1.74	refuse
2	73	-122	-0.66	1.74	0.9	61	-310	-0.39	0.86	refuse
3	47	-40	-0.74	1.92	0.9	79	-469	0.18	0.32	refuse
4	51	-90	-0.57	0.98	refuse	89	-501	0.18	0.27	refuse
5	134	-128	-0.47	0.53	refuse	64	-505	0.79	1.30	refuse
6	165	-82	-	-	-	84	-417	-	-	-
7	189	-180	-	-	-	78	-368	-	-	-

Table 6 Sample 2, 40 indentations

distance from center [mm]	mpL	ND - direction L [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α	mpT	ND - direction T [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α
0	46	-278	-0.07	0.17	refuse	46	-292	-0.01	0.03	refuse
1	63	-239	-0.40	0.98	0.8	63	-408	0.43	1.08	0.8
2	60	-32	-0.79	2.54	0.95	60	-423	0.59	1.47	0.8
3	59	-37	-0.78	2.13	0.9	59	-518	0.81	2.43	0.95
4	44	-109	-0.81	1.95	0.9	44	-509	0.77	1.70	refuse
5	86	-117	-0.85	1.63	0.8	86	-475	0.69	0.95	refuse
6	120	-132	-	-	-	120	-483	-	-	-
7	135	-191	-	-	-	135	-379	-	-	-

Table 7 Sample 3, 1 indentation

distance from center [mm]	mpL	ND - direction L [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α	mpT	ND - direction T [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α
0	75	-495	0.80	3.23	refuse	52	-92	0.55	1.61	refuse
1	82	-286	0.68	2.10	refuse	56	-307	0.19	0.44	refuse
2	109	10	0.48	1.09	refuse	30	-460	-0.34	0.73	refuse
3	128	-16	0.71	1.75	0.9	26	-468	0.09	0.16	refuse
4	128	-152	-	-	-	21	-395	0.88	2.61	0,9
5	110	-156	-	-	-	22	-320	0.76	1.16	refuse
6	98	-	-	-	-	25	-313	-	-	-
7	93	-	-	-	-	26	-253	-	-	-

Table 8 Sample 3, 20 indentations

distance from center [mm]	mpL	ND - direction L [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α	mpT	ND - direction T [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α
0	27	-179	-0.25	0.65	refuse	45	-184	0.60	1.85	0.9
1	40	-167	-0.27	0.63	refuse	29	-304	0.34	0.81	refuse
2	74	-19	-0.26	0.55	refuse	30	-451	0.83	3.03	0.995
3	71	-110	-0.17	0.30	refuse	31	-534	0.87	3.11	0.975
4	95	-156	-	-	-	34	-465	0.90	3.00	0.95
5	105	-179	-	-	-	32	-426	0.99	6.40	0.95
6	98	-	-	-	-	39	-395	-	2	-
7	93	-	-	-	-	46	-341	-	1	-

Table 9 Sample 3. 40 indentations

distance from center [mm]	mpL	ND - direction L [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α	mpT	ND - direction T [MPa]	corellation coefficient r	coefficient of t-distribution	Level of significance α
0	29	-150	-0.4	0.88	refuse	37	-126	0.50	1.43	0.8
1	18	-169	-0.44	0.87	refuse	30	-312	0.62	1.76	0.9
2	30	29	-0.77	1.7	0.8	27	-498	0.95	5.97	0.995
3	42	-147	-0.98	5.7	0.9	29	-534	0.95	5.03	0.9875
4	46	-162	-	-	-	29	-478	0.98	6.62	0.9875
5	79	-201	-	-	-	36	-403	0.93	2.56	refuse
6	98	-	-	-	-	42	-353	-	-	-
7	93	-	-	-	-	44	-360	-	-	-

6. DISSCUSSION OF RESULTS

Test evaluation of residual stress by X-ray diffraction allows that the depth of penetration of the radiation is able to penetrate to a depth of the order of micron units while the magnetization layers usually penetrates into the lower depths of materials thus this parameter can deliver information via an integrated penetration larger cross-section of the sample with the result which is expected (response defects in the surface layers) may be lost in this way. By changing the parameters of the magnetization can affect these values somewhat but not always clearly say from the depths of exactly what information is coming from. Mutual comparison is very complicated. Due to the physical conditions of both methods can be considered that increasing levels of residual voltage means a reduction magnetoelastic parameter. From the tables of results is apparent that is possible to follow only a trend of development of the residual stresses level.

For X-ray diffraction there was a difference between the measured values of residual normal stress in the direction of L and T with T in the direction that was reported higher levels of pressure stress. This explanation is probably in the direction of the last grinding as being carried in the direction of T. Although conducted with maximum parsimony. Yet biasing constitute a significant problem since trends during all three samples were more or less unchanged. This trend was also reflected in the measurement magnetoelastic parameter of Barkhausen noise that the measured values in the direction T are generally lower than in the direction L. The difference is probably that the layer at the surface is degraded more by grinding which recorded X-ray diffraction while the latter method was i removed the value from higher depths unaffected. Brinell hardness measurements using methods based on the injection of hardened balls into the material prescribed force is created by a crater that is measured. It can be assumed in the mutual comparison of measurement of normal residual stresses in the direction T and the measurement of the magnetization parameter acetable good agreement with the sample No. 1. At the direction of T results were probably influenced by forces that formed the final sample polishing.

CONCLUSION

Comparison of the residual stress state also known as surface using X-ray diffraction methods and the Barkhausen noise seems to only create limited correlations. This is especially important due to the fact that the X-ray diffraction measurement is difficult and expensive. Another problem is that the measured sample or machined part must be placed on a location where dangerous radiation must not penetrate. Of course is a possibility to obtain a mobile apparatus for measurement especially in recent times. This is a very costly and for certification and operation is the subject necessary to be approved by the Office for Nuclear Safety as this is linked to many regulations. In contrast the apparatus for measurement of Barkhausen noise is easily mobile and issued no hazardous radiation. The measurement is also very fast and I can say that due to the cost of devices is also significantly less moreover. With this device it is easier to teach to less skilled workers. At present. This method has been used in automatic lines for rapid control of machined parts. X-ray diffraction is limited primarily to check for problems and accidents. Or in the manufacture of highly stressed components.

ACKNOWLEDGEMENTS

This sentence was created under the project NEXLIZ - CZ.1.07/2.3.00/30.0038. co-financed by the European social fund and the state budget Czech Republic.

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