Analysis of surface layer variations by photothermal means

G. Goch, J. Geerkens, M. Reick, B. Schmitz

► To cite this version:

G. Goch, J. Geerkens, M. Reick, B. Schmitz. Analysis of surface layer variations by photothermal means. Journal de Physique IV Proceedings, 1994, 04 (C7), pp.C7-319-C7-322. 10.1051/jp4:1994776 . jpa-00253305

HAL Id: jpa-00253305

<https://hal.science/jpa-00253305>

Submitted on 1 Jan 1994

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Analysis of surface layer variations by photothermal means

G. Goch*,**, J. Geerkens*, M. Reick* and B. Schmitz*

* *Institut für Lasertechnologien in der Medizin (ILM) an der Universität Ulm, Arbeitsgruppe Lasermesstechnik, Helmholtzstr. 12, 89081 Ulm, Germany*

** *Universität Ulm, Abteilung für Mess-, Regel- und Mikrotechnik (MRM), Bereich Messtechnik, Albert-Einstein-Allee 41, 89069 Ulm, Germany*

Abstract The geometrical and physical properties of the surface and the near-surface layers can be modified by a mechanical or a thermal impact. If these variations are coupled with a modification of the thermal properties, they become detectable by photothermal means. In order to perform some fundamental experiments, we chose the Vickers hardness test as a model for a slight and reproducible mechanical impact. The surroundings near the deformed areas were scanned; the optical beam deflection as well as the radiometric signal were measured and compared with the optical microscopic images.

1. INTRODUCTION

During any processing step the mechanical, physical or chemical impacts generate the state of the surface and near-surface layers. Since their properties influence the functional behaviour, the physical and mechanical parameters, in particular the induced mechanical and thermal inhomogeneities caused by an individual impact, should be known [1,2]. Schematically, figure 1 illustrates the variations of surface layers as induced by a mechanical load [3], ranging only to a depth of several ten micrometers. But, in spite of their minor volume, they determine decisively the function, reliability and quality of a given workpiece.

Fig. 1: Surface layers on a machined part [3]

From conventional machining it is known that residual workpiece stresses influence the geometry and the accuracy of a machined part. Other mechanical processing steps result in strain hardening, plastic deformation and compressive residual stress. The fatigue strength under dynamic load, the sensitivity to corrosion, the surface behaviour under wear, critical sliding and rolling loads and the suitability of a surface for coating may depend on a preceding machining process. Soft annealing, tensile workpiece stresses and phase transitions can be caused by thermal impacts. And, the electronic properties of semiconductors depend on the material

microstructure and on the distribution of chemical elements in the surface layers.

Until now, most of the variations of the physical surface properties, influenced by the machining processes, can neither be calculated nor estimated. Therefore, these properties have to be measured using non-destructive techniques with high spatial, especially depth resolution. Among others, the photothermal metrological techniques are effective methods to investigate the parameters changes of zones close to the boundary - in a non-destructive, contactless manner and with a sufficient depth resolution. Depending on the penetration depth of thermal waves, the thermal properties of the surface and near-surface layers contribute most to the photothermal signal. Thus, the surface properties, the variations and depth profiles of the thermal parameters are distinguished from the features of the base material [4,5].

2. EXPERIMENTAL CONFIGURATION

In this work we performed preliminary studies on mechanically processed samples. They prove that the photothermal sensing techniques are suitable methods to detect even little variations of the thermal properties caused by a mechanical processing step.

An argon laser beam, modulated by an acousto-optical device, is expanded, tightly focused and excites the sample's surface within a spot size of about 10 μm . Thus, experiments with a resolution in a microscopic scale can be realized.

The optical beam deflection caused by the temperature dependence of the refractive index is detected by the commercially available, compact setup 'Mirage MonoBloc' [6]. Within this stable optical unit, a low power HeNe probe laser is skimmed parallel to the sample's surface. One of the two deflection contributions - either parallel-transversal or perpendicular-normal with respect to the surface - can be measured by a four-quadrant diode. The outputs of two of the diodes are connected to the differential inputs of a lock-in amplifier. Then both, the in-phase (real part) and the quadrature (imaginary part) component or alternatively the amplitude and the phase delay (relative to the modulation signal) are measured.

By the radiometric setup, the variations of the surface temperature are monitored by a JT-cooled MCT detector.

In order to induce intentionally a change of material properties, we chose the Vickers hardness check. It is considered to be a defined, reproducible and easy-to-use method for a slight mechanical load and a little change of the geometrical structures, optical and thermal surface parameters. The samples were fixed to computer controlled X-Y stages for scanning them relative to the detectors and laser beams. The optical beam deflection and the radiometric measurements were carried out simultaneously. The results were compared with optical microscopic images.

3. RESULTS - THERMAL CHANGE DURING MATERIAL PROCESSING

We investigated experimentally ceramics (Silicon Nitride - WIDIANIT N2000) and hardmetal (Tungsten Carbide or Titan Carbide/Nitride alloyed with different amounts of Cobalt and Nickel - WC-Co TTI25, Cermet THM). Some of the physical values are summarized in table 1. The figures 2a-2c illustrate exemplarily one series of the obtained results. Here, a Vickers tip of 163 degrees and 500 N load (HV50) was pressed into a ceramic sample of Si_3N_4 (WIDIANIT N2000). The diamond tip penetrated about 12 μm into the material, deforming an area of $160 \times 160 \mu\text{m}^2$. An area of $800 \times 640 \mu\text{m}^2$ was scanned. As already mentioned, the photothermal results (2a,2b) must be compared with the optical microscopic image (2c). The latter reflects the optical surface properties. Scratches caused by the cutting and geometrical deformations caused by the Vickers indenter can be clearly resolved. Some deformations around the edges of the tip are invisible in this example. Other samples showed a slight, measurable curvature surrounding the marked area. But, determined by an autofocus system, the height of these deformations did not exceed 3 μm . Thus, a decisive geometrical influence on the photothermal signal in the surrounding of the Vickers indentation might be excluded. Contrasting to this, inside the Vickers tipped deepening such a spatial influence should be considered, where other optical and thermal

effects also affect the generation and penetration of the thermal waves. Therefore, this contribution is focused only on the surrounding of the indented surface.

In contrast to the optical results, the photothermal images show a remarkable variation at the areas surrounding the Vickers tipped surface, comprising both the amplitude (fig.2a) and the phase signal (fig.2b). These and other results indicate that due to the mechanical load the thermal flux into the sample is disturbed. The reason for this behaviour is not yet completely understood. Probably, there are subsurface hidden cracks (as illustrated in fig.2d), induced by the loading. Or, the variations of the thermal properties are correlated to the modification of the microcrystalline structures, caused by the mechanical load. The tracks starting near the rectangular corners support the first assumption, while the wide areas at the edges refer to the second one. But altogether, comparing these figures justifies the assumption that the physical properties of the material have been changed in the surroundings of the machined and deformed area. The mainly mechanical impacts correlate to the changes of thermal properties and, therefore, become detectable by photothermal means.

Fig.2a: Vickers tip - Optical Beam Deflection, Amplitude signal, Magnification: 80
Modulation frequency: 4.78 kHz
 Δ Amplitude: 25%

Fig.2b: Vickers tip - Radiometric measurement, Phase signal, Magnification: 80
Modulation frequency: 4.78 kHz
 Δ Phase: 12deg.

Fig.2c: Vickers tip - Optical image
Magnification: 160

Fig.2d: Cracks in ceramics induced by mechanical load

In order to check and to prove our assumptions we also determined the change of the thermal properties far and near the marked area. A considerable change of the thermal diffusivities, determined by the 'Zero-Crossing' method of Kuo et al. [7] was measured. The partly increasing, partly decreasing values probably indicate that different reasons - cracks and changes of the microcrystalline structures - yield those thermal effects.

Table 1: Change of the thermal diffusivities, caused by a mechanical load

Material	Silicon Nitride	WIDIANIT	TTI 25	THM
Thermal conductivity (in W/m*K) (1)	35	29	15,7	80
Density (in g/cm ³) (1)	3.3	3.26	7	14.9
Hardness HV30 (1)	1800	1400	1450	1580
Hardness HV50 (2)	-	-	1480	1670
T.D. near (in cm ² /s) (2)	0.136 - 0.155	0.178 - 0.216	0.133 - 0.138	0.258
T.D. outside (in cm ² /s) (2)	0.147	0.199	0.105	0.261

1: manufacturer or [1] 2: this work

T.D. outside: thermal diffusivity, no influence of the marked area

T.D. near: thermal diffusivity, near and influenced by the marked area, averaged value

4. CONCLUSIONS

Qualitatively, these results demonstrate that the photothermal techniques - the optical beam deflection and the radiometric method - can be used to investigate the influences on the surface and a subsurface layer due to a mechanical load, which is in principle unavoidable during material processing. Extensive work is still necessary to verify and improve these results. The photothermal techniques must be applied to different mechanically processed samples. In particular, the depth profiles of the thermal properties must be determined - qualitatively and quantitatively.

5. REFERENCES

- [1] Tönshoff H.K., Trumpold H., Brinksmeier E. and Wobker H.-G., *Annals of the CIRP* **38** 2 (1989) 699 - 708
- [2] Brinksmeier E., *Prozeß- und Werkstückqualität in der Feinbearbeitung*, Habilitationsschrift, Universität Hannover, 1990
- [3] v. Weingraber H. and Abou-Aly M., *Handbuch Technische Oberflächen*, Friedrich Vieweg & Sohn, Braunschweig, 1989
- [4] Munidasa M., Tian-Chi M., Mandelis A., Brown S.K. and Mannik L., *Materials Science and Engineering* **A159** (1992) 111-118
- [5] Tian Chi M., Munidasa M. and Mandelis A., *J. Appl. Phys.* **71** 12 (1992) 6029-6035
- [6] Phototherm Dr. Petry GmbH, Saarbrücken, FRG
- [7] Kuo P.K., et al., *Can. J. Phys.* **64** (1986) 1165-1171

This work was supported by a grant of the federal state of Baden-Württemberg, Germany, Nr. II 7532.294 -4/1