X-RAY DIFFRACTION ANALYSIS OF MACROSCOPIC RESIDUAL STRESSES IN SURFACE LAYERS OF STEELS AFTER GRINDING

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Keywords

X-ray diffraction, residual stress, grinding, steels, -splitting, cooling, Ranque-Hisch vortex tube, Doelle-Hauk method

Abstract

This study focuses on states of residual stress in steels which were subjected to grinding. Various cooling conditions during grinding were applied. The samples were analysed employing X-ray diffraction method. The obtained 2 (sin^2 dependences exibit -splitting and hence the method for evaluation of anisotropic states of residual stress proposed by Doelle and Hauk was used to determine the stress tensors. The influence of cooling process on macroscopic residual stress was studied.

Introduction

This study focuses on states of residual stress (RS) in steels which were subjected to grinding. Various cooling conditions during grinding were applied. The samples were analysed employing X-ray diffraction method. The obtained 2 (sin^2 dependences exibit -splitting and hence the method for evaluation of anisotropic states of RS proposed by Doelle and Hauk [1] was used to determine the stress tensors. The influence of cooling process on macroscopic RS was studied.

Samples under investigation

The measuring was carried out on five types of steels listed in Table 1. Because the -splitting is observed only in multiphase materials, even with a small amount of second phase, and because the level of RS is significantly affected by a carbon content, which influences the microscopic behaviour of the material, the chemical composition of studied materials is listed below.

Square-shaped samples of dimensions 50×50×6 mm^3 were ground on a face grinding machine BPH 320 A with a wheel made of aluminium oxide (corundum). The samples were fixed on a magnetic table. Grinding conditions were as follows: the wheel speed was set to 35 m/s, tangential speed of table drift was 10 m.min^{-1}, axial table drift was 1 mm per stroke, thickness of removed layer reached 0.02 mm. The grinding wheel was trued up after each sample in order to maintain constant grinding conditions. Prior to machinig, all samples were subjected to fine grinding to ensure the same initial conditions.

Annealed (stress-releaved) samples were at disposal so that necessary unstressed lattice plane spacings of all five types of steels could be obtained.

Conditions of cooling

The result of mechanical surface treatments with a tangential component like milling, turning or grinding is plastical deformation in the near-surface region. This produces residual stresses due to the greater elastic relaxation of this region compared to the bulk. Various cooling techniques are applied during grinding in order to conduct the heat away from the surface and therefore to supress the origin of tensile stress in materials. Both gaseous and liquid cooling mediums are common. In the experiment, Cimtech A31F was used as cooling liquid, the amount of incoming liquid on the samples was 5 l per minute. The source of cooling air was Ranque-Hilsch vortex tube, four temperatures of air were chosen: 0 °C, –10 °C, –20 °C, –28 °C. For comparison, one sample was ground without cooling.

The Ranque-Hilsch vortex tube is a device without moving mechanical parts that separates a flow of compressed gas into a hot stream and a cold stream. Compressed air is ejected tangentially through a generator into the vortex spin chamber. The air stream revolves at up to 1 million rotations per minute toward the hot end where

Table 1. Chemical composition of materials.

Symbol	Name	Chemical composition, % weight						
		C	Mn	Mo	Cr	V	Ni	Si
12 050	Carbon steel for surface coating	0.42-0.5	0.5-0.8	-	0-0.25	-	0-0.3	0.17-0.37
14 220	Mn-Cr steel for cementation	0.14-0.19	1.1-1.4	-	0.8-1.1	-	-	0.17-0.37
17 135	Heat-resistant Cr-Mo-V steel	0.17-0.23	0.5-1	0.8-1.2	10-12.5	0.2-0.35	0.3-0.8	0.25-0.6
19 313	Low-alloy Mn-Cr-V steel	0.8-0.9	1.75-2.1	-	0.2-0.4	0.1-0.2	0-0.35	0.15-0.35
19 852	Hig-speed Mo-W-Co steel	0.8-0.9	0-0.45	4.5-5.5	3.8-4.6	1.5-2.2	-	0-0.45

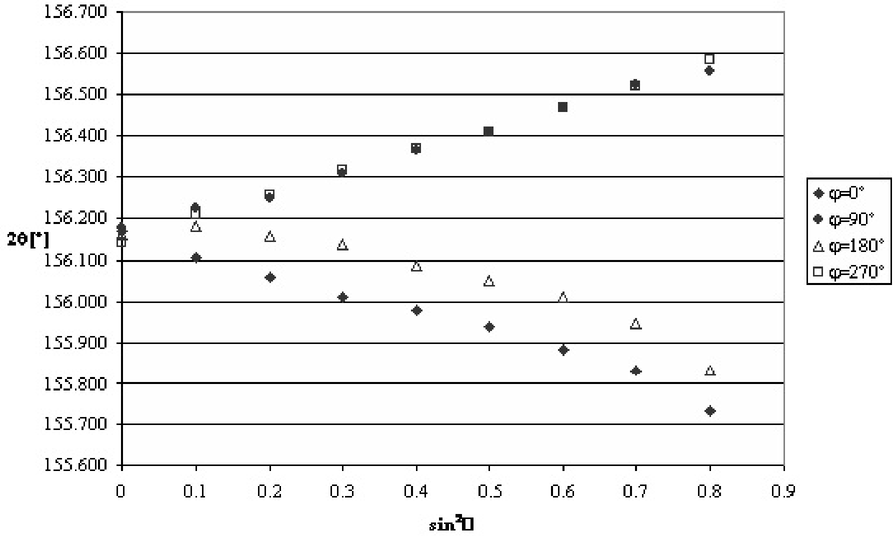

Figure 1.: The plot of 2 (sin^2) for 14 220 steel cooled with Ranque-Hilsch vortex tube,

some leaves the tube through the control valve. The remaining air, which is still spinning, is forced back through the centre of this outer vortex. The inner stream gives off kinetic energy in the form of heat to the outer stream and exits the vortex tube as cold air. Differences as large as +180K and –70K from the temperature of the inlet gas can be obtained from a suitably designed tube driven by air at the pressure of 1100 kPa.

Experimental procedure

The X-ray diffraction technique is a widely used tool for measurement of RS based on a change of the lattice parameter. The position shift of peaks of X-ray diffraction patterns reflects the lattice plane spacing change and hence the macroscopic RS. Due to the limitations of X-ray penetration depth, the X-ray diffraction technique can only be used for surface layers. For depth profiling of RS below the surface, electrolytic polishing should be performed.

The 2 sin^2 dependences for (211) diffraction planes were investigated with -diffractometer and CrK radiation (wavelength = 0.228965 nm). The direction of the measured strain is defined by the azimuth angle and the tilt angle . Measuring was carried out in the grinding direction (= 0°, 180°) and in the transverse direction (= 90°, 270°) corresponding with positive (= 0°, 90°) and negative (= 180°, 270°) tilt. The obtained 2 sin^2 dependences exibit -splitting for grinding direction as shown in Figure 1. The penetration depth of used radiation into -Fe for sin^2 = 0,4 is approx. 4 m [4].

-splitting

Investigation of surfaces of steels after grinding led to so called -splitting. Evaluation of experimental data from measuring in positive and negative tilt (rotating specimen by 180°) corresponds to different values of RS, which would mean that the stresses obtained when the beam of incident X-rays is in the grinding direction differ from those obtained when the beam of incident X-rays impinged the sample surface at the direction opposite to the grinding, even if the geometric alignment between the incident X-rays and the sample is maintained. Various explanations of -splitting have been put forward. One of the most widely used interpretations of this phenomenon is based on inhomogenities of the distribution of the Burgers vector of dislocations with strong density gradients from the surface. The other explanation takes into account the occurrence of shear components in the surface layers which are considered as a consequence of anisotropy, gradient or coupled stress effects on the residual strains at the surface.

A method to evaluate strain tensor was proposed by H. Doelle and V. Hauk [1]. The lattice plane spacing versus sin^2 distributions is measured in three azimuths = 0°, 45°, 90° and the average strain a$_+$ = 0.5($_{>0°}$+ $_{<0°}$) and the deviation from this average strain a$_-$ = 0.5($_{>0°}$- $_{<0°}$) are calculated. The complete strain tensor can be evaluated by differentiating the obtained dependences. If the X-ray elastic constants are known, the stress tensor components can be gained by using the Hooke law.

Conclusions

Following conclusions could be drawn from the obtained results:

An anisotropic state of macroscopic residual stresses was found on the all investigated surfaces, i.e. all dependences 2 sin^2 show -splitting in grinding direction regardless of method of cooling.

The values of shear residual stress do not exceed 60 MPa and they are affected neither by temperature of cooling nor by its way. This finding corresponds with the commonly observed fact that the shear stresses are consequences of the geometry of machining.

Cooling with liquid leads to distinctively higher compressive residual stresses in comparison with cooling using cold air from Ranque-Hilsch vortex tube.

Absolute value of stress components $_{11}$ in vast majority of samples is always smaller than the stress component $_{22}$.

The condition that the values of stress components $_{13}$ and $_{33}$ at the surface are equal to zero is fulfilled because the values of calculated stress tensors are averages over the penetration depth of applied radiation.

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Analysis of residual stress of nickel superalloy Inconel 718 after electro discharge machiningg

ANALÝZA ZBYTKOVÉ NAPJATOSTI VYSOKOPEVNOSTNÍ SLITINY INCONEL 718 PO ELEKTROEROZIVNÍM OBRÁBĚNÍ

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Keywords
Macroscopic residual stress, EDM - electro discharge machining, milling, X–ray diffraction, Inconel 718

Abstract

The aim of this paper is to provide a comparison of residual stress states in the surface layers of nickel superalloy Inconel 718 which were investigated employing X-ray difraction analysis (XRA) and electric etching method. Two parameters of the surface layer integrity were studied: polished.section. for determination of the affected layers of cutting area and phase changes, and surface roughness (Ra) obtained after each method of machining. The measurement was carried out on samples machined by EDM in following modes: finishing using graphite and copper electrodes leading to requested surface of high quality i.e. Ra 0,55 m, and stocking using graphite and copper electrodes. EDM was compared to classical milling technology both down-cut and up-cut.

1. Zbytková napětí a nekonvenční technologie obrábění

Protože se libovolná interakce s materiálem realizuje přes jeho volný povrch, může stav povrchových vrstev součástí ovlivnit rozhodujícím způsobem užitkové vlastnosti celého objemu. Jedním z nejvýznamnějších faktorů, který musí být v této souvislosti uvažován, je distribuce zbytkových napětí doprovázejících každý technologický proces, při němž dochází k nerovnoměrné plastické deformaci.

Zbytková napjatost v povrchových vrstvách řezné plochy je důsledkem kombinovaného účinku mechanických a tepelných příčin. Působí-li mechanické zatížení při nízkých teplotách, dochází v tenké povrchové vrstvě k plastickým deformacím a ve vrstvách pod ní k deformaci pružné. Po odlehčení se pružně deformovaná část snaží vrátit do svého původního stavu a při tom působí tlakem na vrstvu plasticky deformovanou. Tím vzniká ve zpevněné povrchové vrstvě napětí tlakové a ve vrstvách spodních tahové. Zároveň s plastickou deformací je povrchová vrstva obrobené plochy vystavena účinku tepla vznikajícího při obrábění. Plasticky deformovaná ohřátá povrchová vrstva se snaží při ochlazování zmenšit svůj objem, čemuž brání spodní studenější vrstvy; tak u povrchu vznikají tahy a hlouběji tlaky. Účinek plastické deformace a teploty na směr a velikost zbytkových napětí je tedy opačný. Při těch způsobech obrábění, kdy dominuje velké mechanické zatížení povrchu (při menší teplotě) bude pravděpodobně převažovat vliv plastické deformace a povrch zůstane napjatý tlakově. Při vysoké teplotě a malé zatěžující síle vzniknou naopak v povrchové vrstvě tahy.

Druh a velikost zbytkových napětí v povrchových vrstvách je vždy funkcí obráběného materiálu, způsobu a podmínek obrábění. Charakter zbytkových napětí v povrchové vrstvě obrobku má vliv na jeho provozní vlastnosti. Tlaková napětí zvyšují mez únavy a zlepšují odolnost povrchu obrobku proti opotřebení. Tahová napětí naopak mez únavy snižují a usnadňují rozrušení povrchových vrstev troucích se ploch.

Studium vlivu pracovních podmínek na druh a velikost zbytkových napětí v povrchových vrstvách obrobku je proto jedním z podkladů pro optimalizaci obráběcího procesu z hlediska kvality obrobku, a to zejména u součástí aplikovaných v obtížných provozních podmínkách.

Rentgenografický difrakční výzkum zbytkové napjatosti řezné plochy po nekonvenčních technologiích obrábění materiálu dosud nebyl systematicky prováděn. Přitom právě takové “nástroje” obrábění jako je elektroerozivní obrábění (EDM- electro discharge machining) [2] umožňují řešit úlohy na kvalitativně vyšší úrovni než klasické způsoby opracování kovů. K základním přednostem progresivních metod úběru materiálu pomocí