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Multi-Parameter Analysis of Surface Finish in Electro-Discharge Machining of Tool Steels

The paper presents a multi- parameter analysis of surface finish imparted to tool-steel plates by electro-discharge machining (EDM) is presented. The interrelationship between surface texture parameters and process parameters is emphasized. An increased number of parameters is studied including amplitude, spacing, hybrid and fractal parameters,, as well. The correlation of these parameters with the machining conditions is investigated. Observed characteristics become more pronounced, when intensifying machining conditions. Close correlation exists between certain surface finish parameters and EDM input variables and single and multiple statistical regression models are developed.

1. Introduction

Among the various non-conventional processes electro-discharge machining (EDM) is the most widely and successfully applied for the machining of various workpiece materials. The material is removed by means of repetitive spark discharges that cause local melting and/or evaporation of the workpiece material and the resulted surface is characterized by overlapping craters and features indicative of the intense thermal impact involved.

Surface integrity changes (including surface topography) induced by EDMachining have been reported in numerous research publications. Of major interest is, however, the correlation of the surface topography parameters with the machining conditions towards the advanced control and optimization of the EDM process. 2D or 3D profilometry combined with regression analysis is a promising tool for this purpose together with the application of neural networks and/or Taguchi optimization.

The present work is a follow-up of a research outlined above with additional emphasis directed towards the multi-parameter analysis of the EDMed surface texture interrelationship to process parameters. Based on industrial demand, as well as on ISO 4287:1997 [4] mostly, an increased number of texture parameters was studied including amplitude, spacing, hybrid, as well as fractal parameters. Statistical regression models were developed, when possible, to express the correlation of the machining conditions with the imparted surface finish characteristics.

2. Experimental

EDMachining was performed on a HOSTEK SH-38GP (ZNC-P type) electro-discharge machine-tool with working voltage of 30V and open circuit voltage of 100V. Experiments were conducted in a typical oil dielectric (BP250) with electrolytic copper being used as the tool electrode (anode).

The pulse current, i_e and the pulse-on time, t_p considered being the main operational parameters varied over a range from roughing to finishing, namely: i_e: 5, 10, 20, 30 A, - t_e: 100, 300, 500 μsec, thus resulting in 12 discrete pulse energies.

Specimens in the form of square plates of dimensions 70mm x 70mm x 10 mm were used as workpieces (cathode).

The test materials were three grades of quality tool steel, namely: a modified AISI P20 type prehardened mould steel (Impax Supreme), an AISI D2 type cold work tool steel (Sverker 21) and a premium AISI H13 type hot work tool steel (Orvar Supreme) produced by Uddeholm S.A. Impax Supreme is a premium quality vacuum degassed Cr-Ni-Mo alloyed steel mainly used for injection moulds and extrusion dies for thermoplastics. Sverker 21 is a high C, high Cr tool steel alloyed with Mo and V; it is recommended for tools requiring high wear resistance, combined with moderate toughness. Orvar Supreme is Cr-Mo-V alloyed steel mainly used for die casting dies, forging tools and extrusion tooling. For comparison purposes, reference is also made to plain carbon steel (Ck60) specimens machined with the same conditions.

The numerous surface roughness parameters used for the description of an engineered surface are normally categorized into three groups, according to its functionality, namely: amplitude, spacing and hybrid parameters. The parameters selected for the present study represent all three groups mentioned and read as follows:

Amplitude parameters

Arithmetic: - arithmetic average R_a of the profile
- maximum height of the profile, R_t (R_{max})

Statistical: - skewness of the profile amplitude distribution, R_{sk}
- kurtosis of the profile amplitude distribution, R_{ku}

Spacing parameters
- mean spacing of the asperities, R_{sm}

Hybrid parameters
- real or developed length of the profile ratio, R_{lr}
- quadratic mean profile inclination, R_{DelQ}

- bearing or Abbott curve parameter at 20 per cent of the profile height, $R_{tp20\%}$
Fractal dimension, D.

The multi-parameter surface texture analysis was performed using a Rank Taylor-Hobson Surtronic 3+ profilometer equipped with the Talyprof software. The cut-off length was selected at 0.8 mm, whilst 40 measurements were conducted on every specimen at random directions, as it is known that EDMachining generates geometrically isotropic textures.

3. RESULTS and DISCUSSION

The results obtained were plotted in the following diagrams which illustrate the variation of the corresponding surface texture parameters with the pulse energy, W_e. This is calculated through the formula: $W_e=V_e \cdot i_e \cdot t_e$ with the assumptions of: i) square form of pulses and ii) standard working voltage V_e (30 V in this case).
Statistical regression models were formulated for the correlation of the surface parameters with the machining conditions.

3.1 Arithmetic amplitude parameters

Arithmetic average roughness (R_a) is by far the most commonly used parameter in surface finish measurement and for general quality control. Despite its inherent limitations, is easy to measure and offers a good overall description of height characteristics of a surface profile. For EDMed surfaces the variation of R_a with process operational parameters follows well-known patterns. It increases when the pulse energy increases, with a gradually lower rate, see Fig. 1. Note that for medium and high pulse energies ($W_e \geq 150$ mJ), EDMed surfaces of all three tool steels of the present study are systematically rougher than the corresponding ones of Ck 60. Moreover, for low pulse energies Orvar specimens exhibit the lowest roughness of all three tool steels; this difference becomes negligible for high pulse energies.
The variation of maximum roughness, R_t with pulse energy W_e is illustrated in Fig. 2. Note that R_t parameter is very sensitive to the high peaks or deep scratches, therefore differences in the values measured for the three steels for a certain energy level are evident.

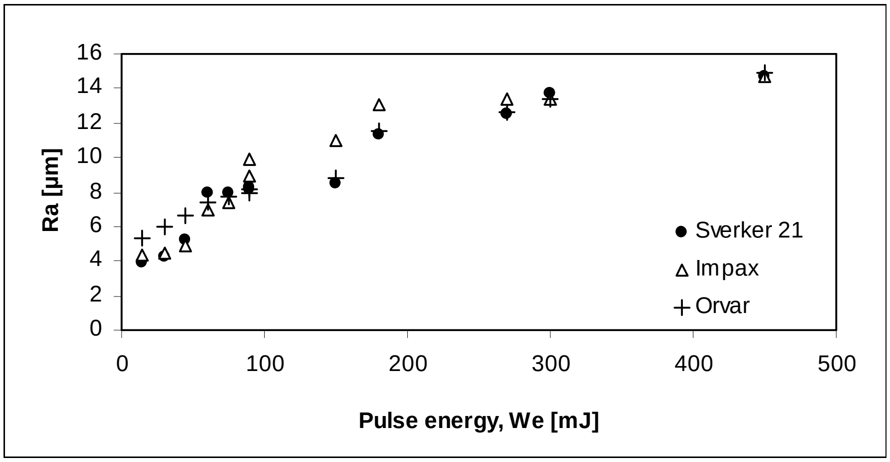

Figure 1: Variation of average roughness, R_a with pulse energy W_e.

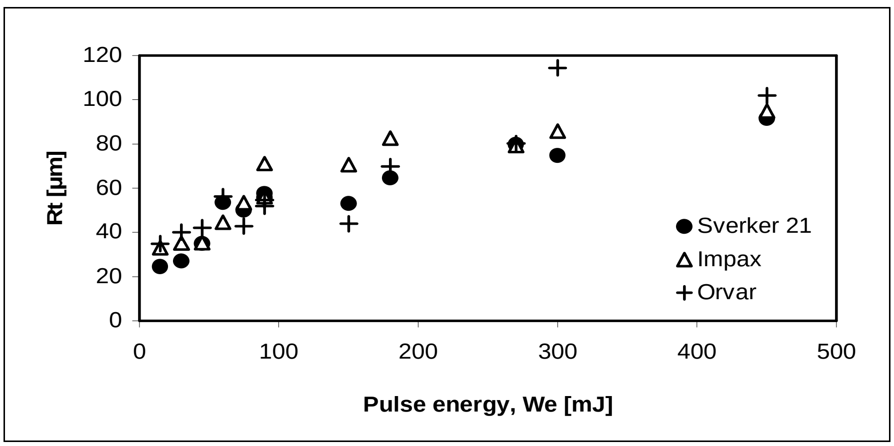

Figure 2: Variation of maximum roughness, R_t with pulse energy W_e.

3.2. Statistical amplitude parameters

Skewness parameter (R_{sk}) is typically used to measure the symmetry of the profile about the mean line and is sensitive to deep valleys or high peaks. The variation of skewness of EDMed surfaces with pulse energy is illustrated in Fig. 3; in general, it appears uncorrelated to the pulse energy. Judging from the measured skewness values, the EDMed profiles are revealed to be "empty" of material as indicated from the positive values, excluding some low pulse energies; at higher energies skewness is stabilized.

Kurtosis (R_{sk}) typically describes the sharpness of the probability density of the profile. Measured values of this parameter are in the range of around or a little over 3, see Fig. 4 indicating normally distributed high peaks and low valleys.

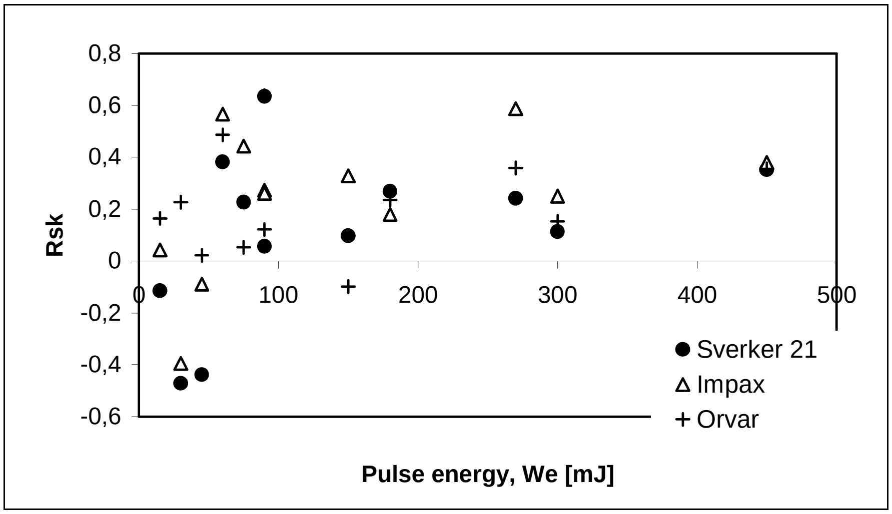

Figure 3: Skewness of the heights distribution (R_{sk}) versus pulse energy W_e.

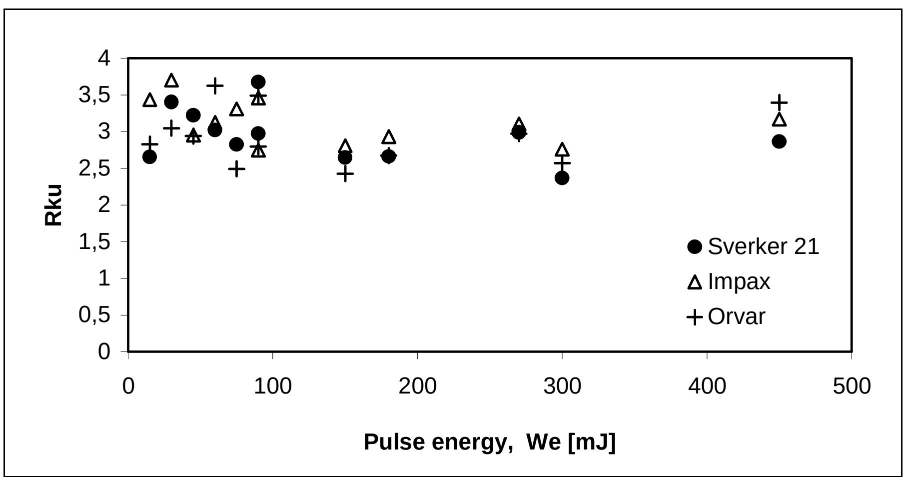

Figure 4: Kurtosis of the heights distribution, (R_{sk}) versus pulse energy W_e.

4. Conclusions

Summarizing the main observations of the present paper on the multi parameter analysis of surface finish imparted to tool steel (Sverker 21, Orvar and Impax) plates by electro-discharge machining the following conclusions may be drawn:

(a) EDMed surfaces are revealed to be in view of topography "empty", "open", "steep" and random in shape whilst the parameters selected express quantitatively in a satisfying manner these features. Observed characteristics become more profound, when intensifying the machining conditions.

(b) Close correlation was revealed between certain surface texture parameters and EDMachining conditions. Obtained statistical multiple regression models are characterized, in most of the cases, by very high correlation coefficients.

(c) Material properties do not exert significant influence on the characteristic features of the resulted EDMed surfaces. For certain pulse energy, measured surface roughness parameters were almost identical for all three tool steels tested, as well as their trends proved to be similar over the whole range of pulse energy variation.

References

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