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FINITE ELEMENT ANALYSIS OF CHANGING OF STRESS CONDITION CAUSED BY DIAMOND BURNISHING

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Abstract. *The article is aspected to the finite element modelling of stress in subsurface layer of aluminium alloy workpiece during diamond burnishing process. This cold forming process is a simple, cost-effective finishing method that can be used to improve surface integrity and provide compressive residual stress. Available with these, durability and quality enhancement of the components can be reached, but improperly chosen burnishing parameters can distort the efficiency of the plastic deformation process. In order to optimize this, a 2D FEM model is created including the real surface integrity of the workpiece which was measured with AltiSurf 520 surface roughness measuring device. The method is simulated using DEFORM-2D software, corresponding to the numerical values of burnishing parameters implemented in practice as well, thereby allowing a comparative analysis with the results of X-ray diffraction measurement.*

Keywords: *finite element modelling; diamond burnishing; surface integrity; plastic deformation.*

1. Introduction

As a result of the development of engineering technology, new opportunities and methods are constantly being developed to examine individual material structure changes. However, most of these are impossible to implement on a low budget, which is why it is important to study the individual procedures at a theoretical level, for example using the finite element method, which has already been dealt with in numerous publications in many machining fields [1-5]. Moreover, in industrial practice, the quality requirements of parts subjected to fatigue include the value and distribution of the residual stress near the surface, which can sometimes only be measured by destructive testing, so FEM is also an ideal solution in this case.

Several researchers have worked on modelling surface hardening processes, Yen et al. successfully established 2D and 3D models of roller burnishing and even though the 3D model shown more realistic surface deformation, the refined 2D model seems to predict the residual stresses better than the 3D model [6]. In the work of Amini et al., the 3D model of ball burnishing process was created in ANSYS considering the topography of the initial surface. 3D surface parameters and residual stresses (in axial and tangential directions) were analysed and the publication also pointed out that the friction coefficient between the tool and workpiece in the modelling is not negligible [7]. Felho and Varga also taken into account the original surface roughness [8], such as Borysenko et al., indeed, in their examination the diamond tool was scanned and used for the FEM simulation in Advant Edge [9]. The study of Balland et al. shows the diversity of applicable programs as they used ABAQUS to investigate the topology of surface with periodic irregularities stressed by rolling contact [10]. In another work on the same topic [11], they draw attention to the importance of meshing during the simulation, not only from the point of view of cost in computing time.

In this paper a 2D FEM model for ball burnishing process is established to examine the effect of it on the changing of stress conditions. The apply of this method makes it possible to reduce some or all the high costs of experimental testing.

2. Implementation of surface burnishing

When external cylindrical surfaces are burnished, plastic deformation occurs as a result of the interaction between the forming element, i.e. the static contact between the tool and the workpiece, during the sliding friction (Fig. 1). No chips, sparks or dust are produced during machining, and the need for coolant is minimal or even eliminated, so environmentally friendly and cost-effective machining can be realized [11-13].

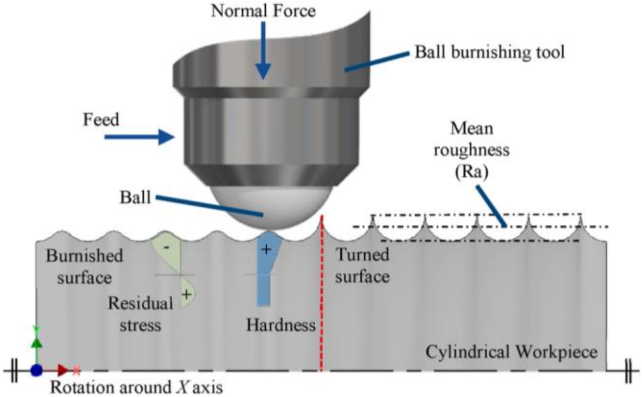


Figure 1. Schematic illustration of burnishing treatment [14]

The purpose of its application is to improve the quality of the surface and increase service life of the component, which is achieved by increasing the hardness of the sub-surface layer and reducing surface roughness [15, 16].

In this experiment the burnishing operation was realized on Optimum OPTIturn L-series 440 flatbed CNC lathe with 3.5 mm radius PCD tool, applying F = 20 N burnishing force, f = 0.001 mm/rec burnishing feed and v = 15 m/min burnishing speed and the kinematic viscosity of the applied manual dosing oil was $\nu = 70\ mm^2/s$. The surface of the workpiece was pre-machined by finishing turning set at $f_1 = 0.2$ than $f_2 = 0.15$ mm/rev.
In addition, before and after burnishing, measuring process of residual stress was implemented on an X-ray diffraction measuring machine type Stresstech Xstress 3000 G3R, which realizes non-destruction test.

3. Simulation of burnishing process

Finite element model of diamond burnishing treatment was simulated by DEFORM FE code, creating a 2D model as it has faster runtime, smaller model sizes and simpler boundary conditions than 3D versions.
The burnishing tool was modelled as a rigid sphere with 3.5 mm radius and the surface of the workpiece is based on the physical surface. Before burnishing, the real workpiece was measured on a 4 mm long distance with Altisurf 520 topography measuring device and the surface points were imported to the code. Since the results of the preliminary simulations show that the procedure is effective up to 0.15-0.17 mm below the surface, I have set the thickness of the workpiece to 0.2 mm to further simplify the model.
A critical point in finite element modelling is the decomposition of the workpiece into mesh elements, since the size distribution of these is a key determinant of the accuracy of the simulation results. With the reduced test thickness, I was able to achieve an edge length of 0.02 mm for the four-node mesh elements used near the surface, with sufficient computation time. The tool and the meshed workpiece are illustrated in Figure 2.

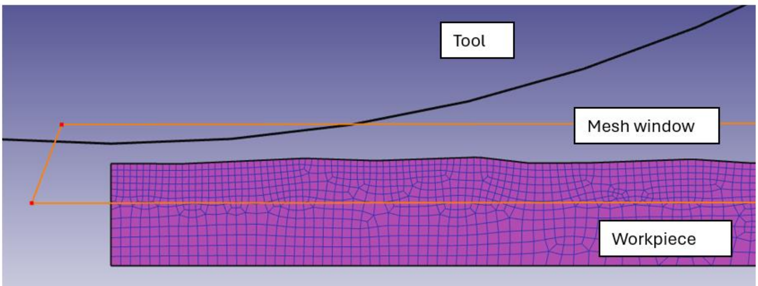


Figure 2. A section of 2D FEM model of burnishing

As a result of the burnishing force exerted by the tool, small plastic deformations are created on and near the surface of the workpiece. To describe these small deformations, the points of the flow curve taken experimentally must be approximated by a function in the finite element space. In the simulations, "power law" relation provided by the program was used to define the yield stress with deformation, which is described by formula (1), where $\bar{\sigma}$ is the flow stress.

$$\bar{\sigma} = c\bar{\varepsilon}^{n}\dot{\bar{\varepsilon}}^{m} + y \tag{1}$$

, where:

c	material constant,	c = 121,228
$\bar{\varepsilon}$	effective plastic strain,	
$\dot{\bar{\varepsilon}}$	effective strain rate,	
n	strain exponent,	n = 0,266076
m	strain rate exponent,	m = 1,12487
y	initial value	y = 50,0003 MPa

The kinematics of the tool was modelled after the real kinematics of the of the process, according to Stöckmann and Putz [17], Rodriguez et al. [18], Felho and Varga [19]. In the simulation workpiece was fixed at the bottom and sides, firstly the tool is moved down vertically until it reaches the precalculated indentation depth [20], then moved to the initial position. Next, the tool is horizontally moved with the displacement value of the burnishing feed and loads again the surface of the workpiece. This cycle should be repeated at least 8 times [15, 17, 19], this simulation has been built accordingly as well.

4. Results and discussion

Configuration shown in Fig. 3 was used to evaluation of the simulation, where the first contact between the tool and the workpiece can be seen. Since, the procedure was simplified to two-dimensions, it is not possible to interpret stress in the tangential direction, only axial stresses (Stress – X) can be examined.

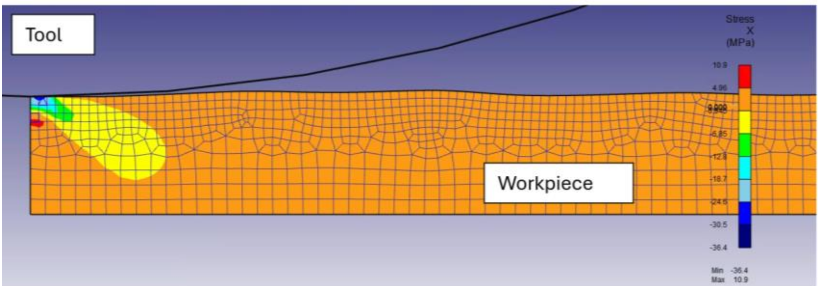
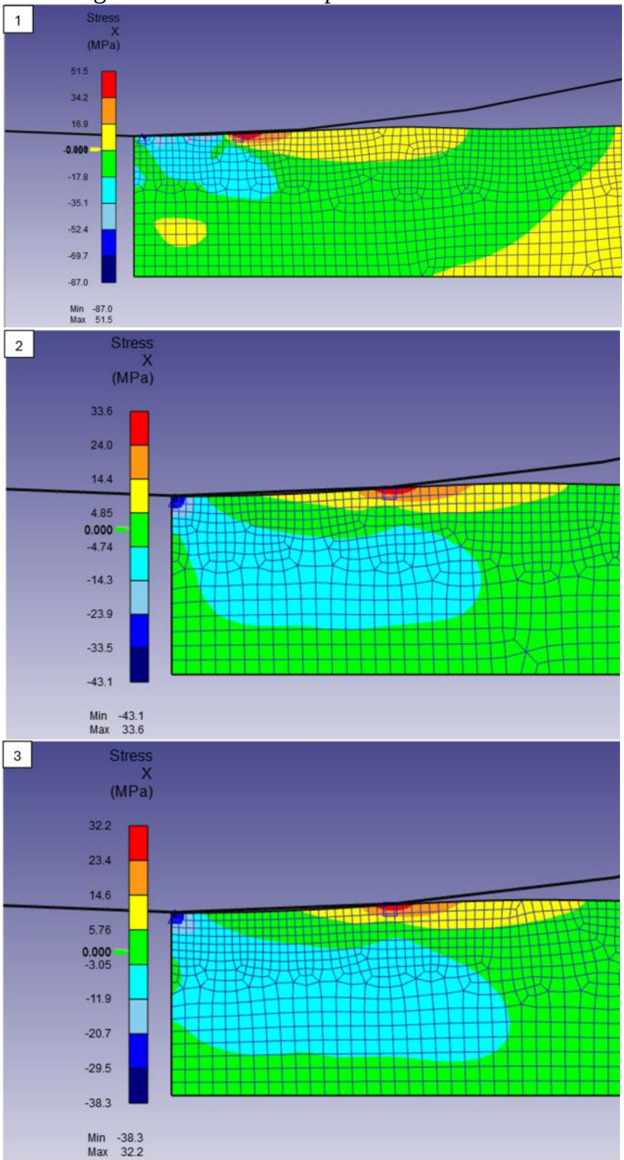
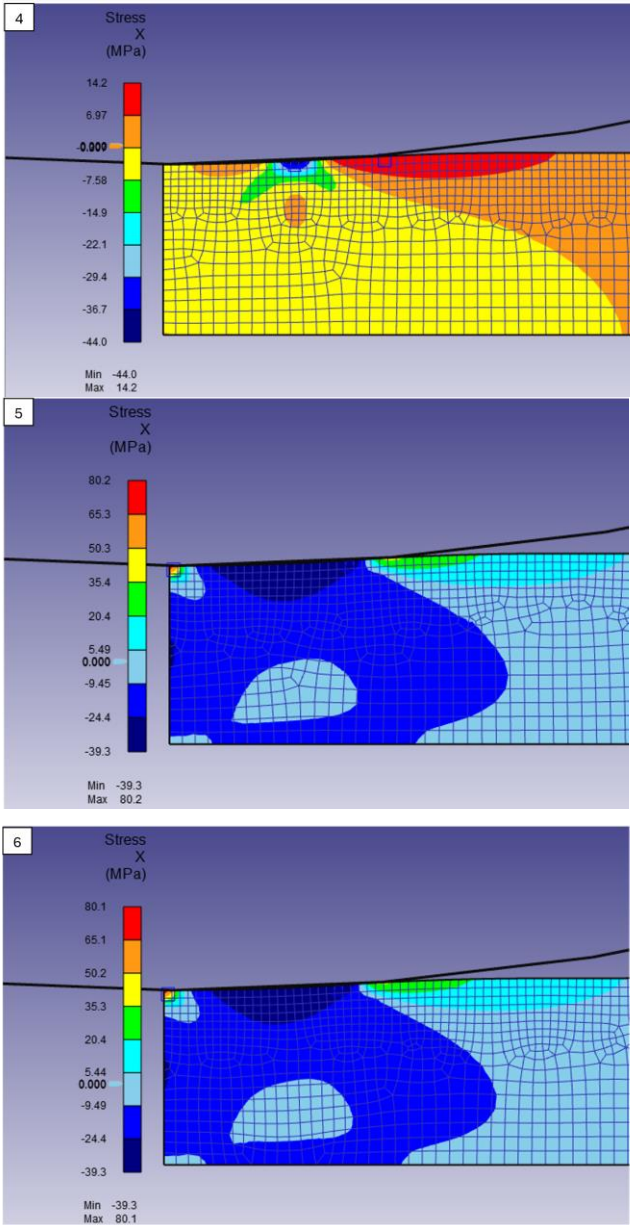


Figure 3. Changing of stress conditions during the first contact

As it was mentioned, the process of "loading-unloading-displacement" was repeated for 8 times and Fig. 4. shows the distribution of the residual stress for each full loading step according to the 0.001 mm step over distance.




4
Stress
X
(MPa)
14.2
6.97
0.000
-7.58
-14.9
-22.1
-29.4
-36.7
-44.0
Min -44.0
Max 14.2
5
Stress
X
(MPa)
80.2
65.3
50.3
35.4
20.4
5.49
0.000
-9.45
-24.4
-39.3
Min -39.3
Max 80.2
6
Stress
X
(MPa)
80.1
65.1
50.2
35.3
20.4
5.44
0.000
-9.49
-24.4
-39.3
Min -39.3
Max 80.1

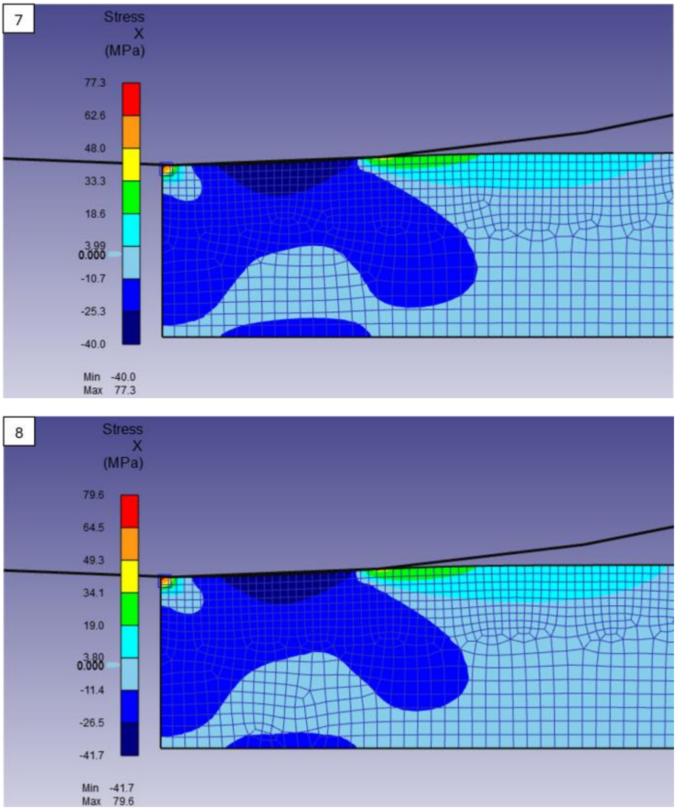


Figure 4. Changing of stress conditions during the first contact

The results of X-ray diffraction measurement showed that the burnished surface has between (-88.6) -(-138.6) MPa compressive residual stress. Compared these values with the FEM simulation results, where this range is between (-38.3) – (-87.0) MPa, it can be observed that these values match only in the case of first tool indentation. One of the possible explanations for this could be that a denser mesh necessary to set and/or the material quality of the workpiece under test is not selected from the FE program library (Al-6061-O, COLD), but is based on the real value by examining the real yield strength.

The physical stress measurement does not provide information on how the residual stress is distributed; this phenomenon can be available at the simulation. Accordingly, as the burnishing progresses, the compressive residual stress distribution increases, however, its value changes unfavourably, it relaxes excessively, which leads to the conclusion that the value of the burnishing feed rate is too low. This is significant because by increasing this parameter setting, time and cost can be saved both in terms of concrete machining and simulation calculation.

Based on this, my future plans definitely include the creation of a more realistic model to study the effect of the process on the stress conditions at increased feed rate.

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СКІНЧЕННО-ЕЛЕМЕНТНИЙ АНАЛІЗ ЗМІНИ НАПРУЖЕНОГО СТАНУ ПОВЕРХНІ, ВИКЛИКАНОГО АЛМАЗНИМ ВИГЛАДЖУВАННЯМ

Анотація. *Статтю присвячено скінченно-елементному моделюванню напружень у підповерхневому шарі заготовки з алюмінієвого сплаву в процесі алмазного вигладжування. Цей процес холодного формоутворення є простим, економічно ефективним методом обробки, який можна використовувати для покращення цілісності поверхні та забезпечення залишкових напружень стиснення. З ними можна досягти довговічності та підвищення якості компонентів, але неправильно підібрані параметри вигладжування можуть спотворити ефективність процесу пластичної деформації. Для того, щоб оптимізувати це, створюється 2D FEM-модель, що включає реальну цілісність поверхні заготовки, яка була виміряна за допомогою приладу для вимірювання шорсткості поверхні AltiSurf 520. Метод моделюється за допомогою програмного забезпечення DEFORM-2D, що відповідає реалізованим на практиці числовим значенням параметрів вигладжування, що дозволяє проводити порівняльний аналіз з результатами рентгенівських дифракційних вимірювань. Результати рентгенівського дифракційного вимірювання показали, що полірована поверхня має від (-88,6) до (-138,6) МПа компресійне залишкове напруження. Порівнюючи ці значення з результатами моделювання МСЕ, де цей діапазон знаходиться в межах (-38,3) –(-87,0) МПа, можна помітити, що ці значення збігаються лише у випадку першого відступу інструменту. Одне з можливих пояснень цього може полягати в тому, що більш щільна сітка, необхідна для встановлення та/або якості матеріалу випробовуваної заготовки, не вибирається з бібліотеки програми FE (Al-6061-O, COLD), а базується на реальному значенні шляхом вивчення реальної межі текучості. Вимірювання фізичного напруження не дає інформації про те, як розподіляється залишкове напруження; Це явище може бути доступне при моделюванні. Відповідно, у міру вигладжування збільшується розподіл залишкових напружень стисненні, однак його величина змінюється несприятливо, надмірно зменшується, що призводить до висновку про занадто низьку величину швидкості подачі вигладжування. Це важливо, оскільки, збільшуючи цей параметр, можна заощадити час і кошти як з точки зору механічної обробки, так і з точки зору імітаційного розрахунку.*

Ключові слова: *скінченно-елементне моделювання; алмазне вигладжування; цілісність поверхні; пластична деформація.*