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COMPARISON OF THE STRESS INTENSITY OF METALLIC AND NON-METALLIC MATERIALS DURING FLAT GRINDING

Abstract: *The article compares the stress and strain state of some metallic and non-metallic materials during flat grinding. Given the same grinding conditions for all tests, it was determined that the concrete sample experienced the least stress, while the tungsten sample experienced the most stress. At the same time, compression and tension deformations are minimal after grinding tungsten and copper alloy, and maximal after grinding window plate glass.*

Key words: *grinding, properties, volumetric strain, pressure, von Mises stress.*

Language: *English*

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1. Introduction

Final machining in various industries is difficult because of the strict requirements of the product drawing. Contact machining leads to the generation of force and temperature loads in the cutting zone, which predetermines errors (decreased quality of the machined surface, deviation of actual dimensions and geometry from the specified ones) of the part, depending on the degree of material deformation [1-2]. The stress state of various materials after flat grinding usually varies depending on their physical and mechanical properties, such as hardness, ductility, and thermal conductivity [3-4]. Generally, harder materials such as ceramics and hardened steel tend to create higher residual tensile stresses on the surface due to the impact of the abrasive, which can lead to the formation of microcracks or surface cracking [5-10]. Softer or more ductile materials, such as aluminum or copper alloys, often have lower residual stresses and can be subjected to compressive stresses that increase the material's fatigue resistance. Thermal effects during grinding, such as thermal expansion and temperature gradients, also significantly affect the residual stress profile, and rapid cooling can lead to tensile stresses. Therefore, understanding these differences is crucial for optimizing the grinding parameters to minimize the negative effects of stresses and improve the durability and performance of the machined parts.

2. Materials and methods

The work of Chemezov, D., et al. “Application of the finite element method for qualitative assessment of the stress-strain state of a steel workpiece during flat grinding” presents an assessment of the stress-strain state of a steel workpiece during preliminary surface grinding. This paper proposes a comparison of the stress and strain of certain metallic and non-metallic materials under flat grinding conditions. The following materials were used for the study: 1010 steel, high-strength alloy steel, cast iron, tungsten, 6063-T83 aluminum, UNS C10800 copper alloy, concrete, and window plate glass. A silicon carbide grinding wheel was used as an abrasive tool in all the experimental series. The conditions for flat grinding without cooling were the same for all eight tests: the grinding depth was 0.1 mm, the feed rate of the grinding wheel was 5 m/min, and the rotational speed of the grinding wheel was 1800 rpm.

The properties of the materials are presented in the Tables 1-9.

Table 1. Properties of silicon carbide.

Parameter	Value or function
Density, kg/m^3	$2977.514+0.05100882\times T-2.291028\times10^{-4}\times T^2+2.976431\times10^{-7}\times T^3-1.917209\times10^{-10}\times T^4+4.77098\times10^{-14}\times T^5$
Young's modulus, Pa	4.8×10^{11}
Poisson's ratio	0.01
Thermal conductivity, W/(m×K)	$191.9216-0.3261784\times T+2.739462\times10^{-4}\times T^2-7.70926\times10^{-8}\times T^3$
Resistivity, Ω×m	$e^{-1.433037\times10^{-8}\times T^3+5.315569\times10^{-5}\times T^2-6.632958\times10^{-2}\times T+2.214811\times10}$
Coefficient of thermal expansion, 1/K	$-3.233018\times10^{-6}+4.191361\times10^{-8}\times T-1.031589\times10^{-10}\times T^2+1.268211\times10^{-13}\times T^3-7.579153\times10^{-17}\times T^4+1.759919\times10^{-20}\times T^5$
Heat capacity at constant pressure, J/(kg×K)	$772.40824+0.431390902\times T-2.09759359\times10^{-5}\times T^2$
Electrical conductivity, S/m	$\frac{1}{e^{-1.433037\times10^{-8}\times T^3+5.315569\times10^{-5}\times T^2-6.632958\times10^{-2}\times T+2.214811\times10}}$
Tangent coefficient of thermal expansion, 1/K	0.0000045
Thermal strain	$-8.788949\times10^{-4}+2.53851\times10^{-6}\times T+1.512679\times10^{-9}\times T^2-2.031494\times10^{-13}\times T^3-4.305492\times10^{-17}\times T^4$
Yield stress, Pa	$4.444901\times10^8+46441.18\times T$
Molar heat capacity, J/(mol×K)	$30.9708676+0.0172972669\times T-8.41061822\times10^{-7}\times T^2$
Thermal diffusivity, m^2/s	$1.731704\times10^{-4}+4.400109\times10^{-8}\times T-1.111516\times10^{-10}\times T^2+2.784253\times10^{-14}\times T^3$
Normal total emissivity	$0.8314646-3.618495\times10^{-5}\times T+1.212255\times10^{-7}\times T^2-7.911016\times10^{-11}\times T^3$

Table 2. Properties of 1010 steel.

Parameter	Value or function
Density, kg/m^3	$7910.967-0.100271\times T-3.511597\times10^{-4}\times T^2+1.470685\times10^{-7}\times T^3$
Young's modulus, Pa	$2.109875\times10^{11}+3.572844\times10^{7}\times T-106319.6\times T^2$
Poisson's ratio	$0.2712267+7.030261\times10^{-5}\times T-3.856929\times10^{-8}\times T^2+1.246582\times10^{-11}\times T^3$
Thermal conductivity, W/(m×K)	$76.84794-0.03185824\times T-4.196927\times10^{-5}\times T^2+2.819746\times10^{-8}\times T^3$
Resistivity, Ω×m	$1.323461\times10^{-6}-5.259924\times10^{-9}\times T+7.937115\times10^{-12}\times T^2-3.047727\times10^{-15}\times T^3$
Coefficient of thermal expansion, 1/K	$6.78762\times10^{-6}+2.878178\times10^{-8}\times T-7.594277\times10^{-11}\times T^2+1.43191\times10^{-13}\times T^3-1.357067\times10^{-16}\times T^4+4.830576\times10^{-20}\times T^5$
Heat capacity at constant pressure, J/(kg×K)	$105.664493+1.79406866\times T-0.00275295527\times T^2+1.76845672\times10^{-6}\times T^3$
Electrical conductivity, S/m	$\frac{1}{5.447716\times10^{-16}\times T^3-8.034806\times10^{-14}\times T^2+4.780562\times10^{-10}\times T+1.038288\times10^{-8}}$
Tangent coefficient of thermal expansion, 1/K	$-7.251939\times10^{-6}+6.376279\times10^{-8}\times T-4.206483\times10^{-11}\times T^2$
Thermal strain	$-0.00234185521+4.083948\times10^{-6}\times T+1.512293\times10^{-8}\times T^2-6.083782\times10^{-12}\times T^3$
Bulk modulus, N/m^2	$1.842649\times10^{11}-2.509462\times10^{7}\times T-28588.37\times T^2$
Shear modulus, N/m^2	$8.301552\times10^{10}+9184755\times T-38834.5\times T^2$
Thermal diffusivity, m^2/s	$-9.7503837\times10^{-5}+2.606505\times10^{-7}\times T-1.594388\times10^{-10}\times T^2$

Table 3. Properties of high-strength alloy steel.

Parameter	Value or function
Density, kg/m^3	7850
Young's modulus, Pa	2×10^{11}
Poisson's ratio	0.3
Relative permeability	1
Heat capacity at constant pressure, J/(kg×K)	475
Thermal conductivity, W/(m×K)	44.5
Electrical conductivity, S/m	4.032×10^{6}
Relative permittivity	1
Coefficient of thermal expansion, 1/K	12.3×10^{-6}
Murnaghan third-order elastic moduli (l), N/m^2	-3×10^{11}
Murnaghan third-order elastic moduli (m), N/m^2	-6.2×10^{11}
Murnaghan third-order elastic moduli (n), N/m^2	-7.2×10^{11}
Lamé parameter (λ), N/m^2	1.15×10^{11}
Lamé parameter (μ), N/m^2	7.69×10^{10}

Table 4. Properties of cast iron.

Parameter	Value or function
Density, kg/m^3	7000
Young's modulus, Pa	1.4×10^{11}
Poisson's ratio	0.25
Coefficient of thermal expansion, 1/K	1.1×10^{-5}
Heat capacity at constant pressure, J/(kg×K)	420
Thermal conductivity, W/(m×K)	50

Table 5. Properties of tungsten.

Parameter	Value or function
Density, kg/m^3	17800
Young's modulus, Pa	3.6×10^{11}
Poisson's ratio	0.28
Coefficient of thermal expansion, 1/K	4.5×10^{-6}
Heat capacity at constant pressure, J/(kg×K)	132
Thermal conductivity, W/(m×K)	175
Murnaghan third-order elastic moduli (l), N/m^2	-4.7×10^{11}
Murnaghan third-order elastic moduli (m), N/m^2	-7.9×10^{11}
Murnaghan third-order elastic moduli (n), N/m^2	-1.1×10^{12}
Lamé parameter (λ), N/m^2	1.79×10^{11}
Lamé parameter (μ), N/m^2	1.41×10^{11}

Table 6. Properties of 6063-T83 aluminum.

Parameter	Value or function
Density, kg/m^3	2700
Young's modulus, Pa	6.9×10^{10}
Poisson's ratio	0.33
Relative permeability	1
Electrical conductivity, S/m	3.03×10^{7}
Coefficient of thermal expansion, 1/K	23.4×10^{-6}
Heat capacity at constant pressure, J/(kg×K)	900
Relative permittivity	1
Thermal conductivity, W/(m×K)	201

Table 7. Properties of UNS C10800.

Parameter	Value or function
Density, kg/m^3	$9038.962-0.3593546\times T-9.31574\times10^{-5}\times T^2$
Young's modulus, Pa	$1.396274\times10^{11}-5077626\times T-191131.5\times T^2+290.7333\times T^3-0.2058552\times T^4+5.385261\times10^{-5}\times T^5$
Poisson's ratio	$0.339846+2.405498\times10^{-5}\times T$
Coefficient of thermal expansion, 1/K	$1.83456\times10^{-5}-1.577095\times10^{-9}\times T+1.908643\times10^{-12}\times T^2$
Heat capacity at constant pressure, J/(kg×K)	$342.764033+0.133834821\times T+5.53525209\times10^{-5}\times T^2-1.97122089\times10^{-7}\times T^3+1.1407471\times10^{-10}\times T^4$
Tangent coefficient of thermal expansion, 1/K	$1.104756\times10^{-5}+2.743089\times10^{-8}\times T-3.159431\times10^{-11}\times T^2+1.370433\times10^{-14}\times T^3$
Thermal strain	$-0.004359242+1.427188\times10^{-5}\times T+3.639858\times10^{-9}\times T^2$
Bulk modulus, N/m^2	$1.459784\times10^{11}+4948257\times T-132451.5\times T^2+114.0737\times T^3+0.02475104\times T^4-9.178407\times10^{-5}\times T^5+3.51125\times10^{-8}\times T^6$
Shear modulus, N/m^2	$5.208306\times10^{10}-2585817\times T-71978.63\times T^2+110.2355\times T^3-0.07807297\times T^4+2.043615\times10^{-5}\times T^5$

Table 8. Properties of concrete.

Parameter	Value or function
Density, kg/m^3	2300
Young's modulus, Pa	2.5×10^{10}
Poisson's ratio	0.2
Coefficient of thermal expansion, 1/K	1×10^{-5}
Thermal conductivity, W/(m×K)	1.8
Heat capacity at constant pressure, J/(kg×K)	880

Table 9. Properties of window plate glass.

Parameter	Value or function
Density, kg/m^3	2500
Young's modulus, Pa	7×10^{10}
Poisson's ratio	0.17
Resistivity, Ω×m	$e^{1.565110\times10^{-9}\times T^4-2.797400\times10^{-6}\times T^3+1.991606\times10^{-3}\times T^2-7.059541\times10^{-1}\times T+1.289865\times10^2}$
Electrical conductivity, S/m	$\frac{1}{e^{1.565110\times10^{-9}\times T^4-2.797400\times10^{-6}\times T^3+1.991606\times10^{-3}\times T^2-7.059541\times10^{-1}\times T+1.289865\times10^2}}$
Surface emissivity	$-0.3610674+0.003928677\times T-4.052381\times10^{-6}\times T^2+1.515553\times10^{-9}\times T^3-1.291322\times10^{-13}\times T^4$

3. Results and discussion

The Table 10 shows the calculated ranges of von Mises stress, pressure, and volumetric strain of the materials.

The von Mises stress during flat grinding of non-metallic materials is lower than for metallic materials. The minimum calculated value of the equivalent stress in the cutting zone was 1.6×10^7 N/m^2. This value is determined during flat grinding of concrete. For structural steels of varying strength, the von Mises stress value is an order of magnitude higher than for accepted non-ferrous metal alloys. As strength increases, stress in steel decreases under abrasive treatment conditions. The maximum calculated value of von Mises stress (1.68×10^8 N/m^2) was determined during flat grinding of the tungsten (transition metal).

Table 10. Summary table of the results of calculating the stress-strain state of materials during flat grinding.

Material	von Mises stress, N/m^2	Pressure, N/m^2	Volumetric strain
1010 steel	$4.88\times10^4…1.11\times10^8$	$-2.99\times10^6…9.74\times10^7$	$-5.81\times10^{-4}…1.78\times10^{-5}$
High-strength alloy steel	$4.75\times10^4…1.05\times10^8$	$-2.91\times10^6…9.48\times10^7$	$-5.69\times10^{-4}…1.75\times10^{-5}$
Cast iron	$3.31\times10^4…8.05\times10^7$	$-1.98\times10^6…6.39\times10^7$	$-6.85\times10^{-4}…2.12\times10^{-5}$
Tungsten	$7.16\times10^4…1.68\times10^8$	$-4.35\times10^6…1.43\times10^8$	$-5.24\times10^{-4}…1.6\times10^{-5}$
6063-T83 aluminum	$2.03\times10^4…3.91\times10^7$	$-1.24\times10^6…3.94\times10^7$	$-5.83\times10^{-4}…1.84\times10^{-5}$
UNS C10800	$3.72\times10^4…6.84\times10^7$	$-2.25\times10^6…7.17\times10^7$	$-5.16\times10^{-4}…1.62\times10^{-5}$
Concrete	$6.57\times10^3…1.6\times10^7$	$-3.72\times10^5…1.15\times10^7$	$-8.27\times10^{-4}…2.68\times10^{-5}$
Window plate glass	$1.77\times10^4…4.55\times10^7$	$-9.51\times10^5…2.97\times10^7$	$-8.41\times10^{-4}…2.69\times10^{-5}$

The pressure in the material characterizes the value of compressive or tensile forces. Positive and negative pressure values in the table are interpreted as compressive and tensile loads, respectively. The compressive load in the cutting zone prevails. As with von Mises stress, the maximum grinding pressure is observed in tungsten, and the minimum pressure is observed in concrete.

Volumetric strain is the ratio of the change in the volume of a material to its original volume. The coefficient characterizes how much the material deforms under load. Positive values of the coefficient indicate an increase in volume, while negative values indicate a decrease in volume. Window plate glass and tungsten are the most and least deformed, respectively, due to their increased brittleness and hardness.

4. Conclusion

A comparative analysis of the experimental results showed that the non-metallic materials under study (concrete and window plate glass) are less stressed during preliminary grinding than the metallic materials. The minimum calculated von Mises stress value was determined during concrete grinding, and the maximum value was determined during tungsten grinding. A similar conclusion can be drawn based on the resulting pressure in the material, which characterizes not only the type of deformation (compression and tensile), but also the direction of the cutting forces that affect the accuracy of the dimensions and geometric shape of the workpiece. It has also been noted that the volume of the window plate glass workpiece changes to a greater extent (based on the calculated value of the coefficient of volumetric strain), which may result in cracks and chips during flat grinding. Tungsten and copper alloy demonstrate a minimal difference between the initial volume of the workpiece and the volume after preliminary abrasive treatment.

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