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Warm Compaction: FEM Analysis of Stress and Deformation States of Compacting Dies with Rectangular Profile of Various Aspect Ratio

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Abstract

The deformation under radial pressure of rectangular dies for metal powder compaction has been investigated by FEM. The explored variables have been: aspect ratio of die profile, ratio between diagonal of the profile and die height, insert and ring thickness, radius at die corners, interference, different insert materials, i. e. conventional HSS, HSS from powders, cemented carbide (10% Co). The analyses have ascertained the unwanted appearance of tensile normal stress on brittle materials, also "at rest", and even some dramatic changes of stress patterns as the die height increases with respect to the rectangular profile dimensions. Different materials behave differently, mainly due to difference of thermal expansion coefficients. Profile changes occur when the dies are heated up to the temperature required for warm compaction. The deformation patterns depend on compaction temperature and thermal expansion coefficients.

Keywords : FEM analysis, powder compaction, dies, shrink-fitting, warm compaction

1. Work programme

Following a research line focused on dies for metal powder compaction [1], stress and deformation states of rectangular-profile dies have been investigated. A simple scheme of die set investigated by FEM is shown in Fig. 1. The profile of the die cavity may be defined by the length of sides, a and b, with $a \le b$. Each profile is identified by the ratio between sides ζ, being $\zeta = b/a$ the aspect ratio of the die profile. The following values have been considered: a = 10 mm, ζ = 1, 2, 4, 8 and 16. d_c indicates the outer diameter of the insert. To follow the line already applied in previous studies, and to simplify the symbolism, the diagonal of each rectangle is supposed assimilable to the inner diameter of a circular insert. In this way, the ratio between inner and outer dimension of any insert may be represented by the ratio α' (primed, in this study, to make a distinction with respect to α, ratio between true diameters for the case of circular profiles). At the beginning, it has been established: α' = 0.80, 0.625 and 0.4, whereas the radiuses at the corners have been imposed as follows: $r_1/a = 0.01, 0.02, 0.04, 0.1$. As to the rings, at the beginning it has been established $\beta = 0.3$ and 0.4, being $\beta = d_c/D$, ratio between their inner and outer diameters. Just for example, some typical geometrical characteristics of the investigated nuclei are reported in Table 1.

2. Tension states

FEM analysis showed that the three-dimensional structure presents a triaxial stress state in the body. Only for effect of shrink fitting, the Cartesian components of tension, along the x and y axes, are compressive. The stress along the z axis is compressive just at the radius of the nucleus, but is tensile for a large extent of the sides. The tensile stresses vanish near the upper face of the insert. At constant interference, the tension, along the z-axis, increases considerably with the increase of die height, and afterwards

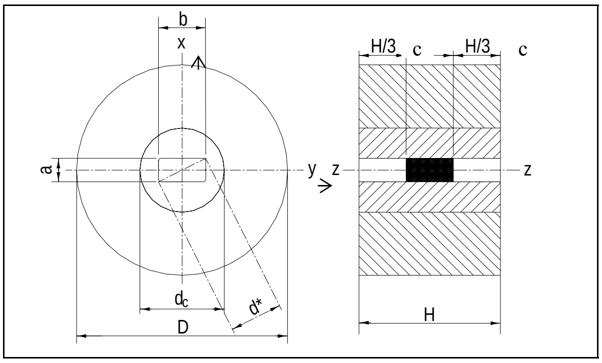

Fig. 1. Scheme of the die set investigated by FEM. The line zz represents the compaction axis.

Table 1. Geometrical characteristics of the investigated nuclei

ζ ratio	side b, mm	diagonal d*, mm	d_c, mm, ($\alpha' = 0.80$)	d_c, mm, ($\alpha' = 0.625$)	d_c, mm, ($\alpha' = 0.40$)
1	10	14.14	17.678	22.627	35.355
2	20	22.36	27.951	35.778	55.902
3	40	41.23	51.539	65.970	103.08
4	80	80.62	100.78	129.00	201.56
5	16	160.3	200.39	256.50	400.78

tends to a constant value. The appearance of tensions along the z-axis derives from the pressure exerted by the ring, which causes an axial extension of the fibres of the nucleus. The fibres in the neighbourhood of the radius between the sides tend to lengthen more, in comparison with the other, in particular with those of the elongated sides of the rectangular profile. The latter fibres are less deformed than those at the nucleus-ring interface. The variation among local elongations generates a compressive state of stress on the radius zone, balanced by a tensile state of stress on the sides of the inner die profile. An increase of the interference enhances this differential behaviour. Very small fillets at die corners act as powerful, and dangerous, stress raisers. If the radius between sides increases the previous effects diminish. The highest stresses on dies for warm compaction are present when the dies are kept at room temperature. When the insert is loaded by inner pressure and interference, in the zone where the inner pressure is applied, both tensile and compressive σ_z decrease. In the remainder of the nucleus the effect of shrink fitting predominates.

In general, the Von Mises' maximum equivalent stress, always appearing on the radius area, decreases when the radius increases, due to the attenuation of notch effect, or passing from carbide to high speed steel, as a consequence of lower stiffness, while it increases when α' increases, i.e. when the ratio between the diagonal of the rectangle (die profile) and the common diameter, d_c, increases, or if the die height increases, namely when passing from "short" dies to "long" dies, or when the greater side of the die rectangular profile increases, or, finally, when the thickness of ring decreases. In case of carbide inserts the most critical stress states always occur at rest. As already shown for circular profile die, the "fading" of interference at warm compaction temperature, deriving from the difference between coefficients of thermal expansion implies very high stresses at room temperature.

3. Deformation of the profiles of the dies

The inner (maximum) pressure, $p = 200$ MPa has been assumed acting on all the central height h = H/3.

In the industrial practice a hollow rough-shaped insert is shrink fitted and the grinding of the profile is usually performed after shrink fitting and cooling. For this reason, any profile deformation due to the interference vanishes (or, better, should not be considered). Therefore, the displacements are calculated by taking into account only the effect of the inner pressure.

Differently from the stress calculations, the presence of radiuses at the corners affects the displacements only in a negligible measure, if they are small. This fact can be easily explained if we realize that the displacements depend on the global rigidity of the die and that this characteristic is not much influenced by small geometry variations.

The dimensionless mid-line displacements of the rectangle sides may be seen as synthetic parameters apt to indicate the profile deformations. They generally decrease as the parameters α', β and H/d* decrease, with higher values and wider range of variability at $z = 0$ rather than at $z = h$.

The higher displacement for square profiles at $z = 0$ is ~ 0.0008d*; the lower one is ~ 0.0003d*. The moderately elongated rectangular profiles present the same trends, with increased and unequal displacements.

4. Concluding remarks

A FEM approach enabled to draw an exhaustive series of data on the stress state and on the deformed profiles of rectangular dies for metal powder compaction. The results of the investigation confirmed a typical empirical attitude: to minimise the stress level and the elastic yielding of dies subject to radial pressure the die set should be as rigid as possible. A high rigidity can be obtained either increasing the outer dimensions of the die set or using a high elastic modulus, such as cemented carbide, for the insert. In the less favourable conditions (very elongated die cavity and limitations on the total allowable radial thickness), the loss of precision due to radial displacement of die under pressure can even reach IT12 tolerance level. If this is the case, to limit the loss of precision of PM parts, a suitably "distorted" die profile is unavoidable. A comparison between carbide insert and HSS steel inserts indicates that at equal geometry of die the displacements of the inner profile of hard metal inserts are always lower (in absolute value) than the corresponding displacements of HSS inserts. The difference increases as the α' ratio increases. The deformed profile of any rectangular die depends also on the ratio H/d*. The working temperature affects the displacement under pressure. The interference does not affect the displacements on compaction. The changes of die profile during powder compaction sensibly modify the clearance between die and punches, following a course that depends on the aspect ratio of the profile and on part height.

5. Reference

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