Centrifugal Induction Coating of Metallic Powders

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Abstract

Principal peculiarities of technology for applying coatings of metallic powders on internal surfaces of hollow cylindrical parts by centrifugal method with induction heating from internal surface of part are examined. It is shown that most effective checking and regulating method of sintered powder layer is monitoring the high-frequency current generator power upon contactless pickup indications of external surface temperature of rotating part.

Keywords : metal powder, centrifugal induction sintering, high-frequency current, thermal conduction

1. Introduction.

The process of induction centrifugal sintering is one of the most productive methods for applying a powder coatings. It is possible to apply coatings on internal, external and face surfaces by induction centrifugal sintering. Recently, more wide application in technology of centrifugal sintering finds heating by high-frequency current from the direction of an internal surface of the part (fig. 1).

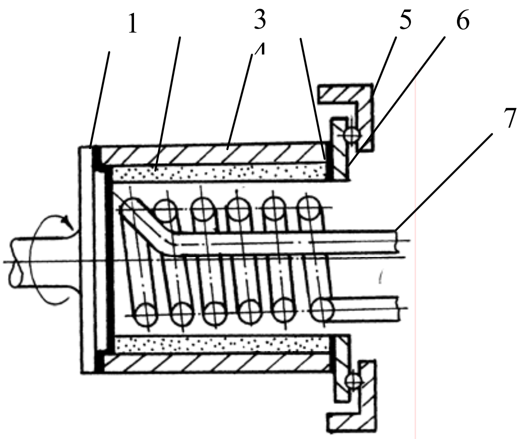

Fig. 1. The elementary diagram of centrifugal sintering of coatings from metal powders with use internal high-frequency inductor: 1 - the spindle of equipment for induction centrifugal sintering; 2 - powder material; 3 - part; 4 - linear; 5 - support; 6 - supporting disk; 7 - inductor

The following basic advantages are inherent to such kind of heating: high efficiency, low power consumption of process, minimal zone of thermal influence on the part, etc.

2. The Main Assumptions

An analysis of the main features of Centrifugical Induction Sintering (CIS) shows that the most important stage of the process is the isothermic heating at the temperature of sintering which is the determinant of physical and mechanical properties and service characteristics of produced two - layer parts. The main task on this stage is the supporting required average temperature of powder layer (sintering temperature) during required time (sintering time). At the same time the thermal regimes during previous stages of heating have no visible influence on the sintering kinetics and powder adhesion to the substrate.

As a rule the powder thickness is less than the substrate thickness or the curvature radius of substrate surface. So, the free inner surface of powder and the end faces of two layer cylinder can be counted as thermoisolated . Hence, the thermal resistance of powder layer can be neglected, and the temperature distribution on the thickness of powder can be calculated as uniform and equal to the temperature of inner surface of the substrate. Since from the defined Fourie Number ($F_0 \approx 0{,}305$) occurs a quasistationary regime of thermoconductivity when temperature distribution of substrate does not vary by shape but the temperature in each point grows in time with a constant relative velocity. When the inner surface of cylindrical perform reaches the sintering temperature of powdered material, this temperature bolsters up constantly by power control of heating source (ligh-frequency generator). On this case temperature distribution in the thickness of preform uniform and power produced by inner sources is equal to the heat flux from outer surface of preform which is conditioned by convective and radiant heat exchange with an environment. Temperature control on the inner surface of rotating preform during CIS process is very complicated task which rational solution is possible only at experimental level. So, usually the temperature of outer surface is controlled by non-contact pyrometry methods. This, to support assigned temperature of powder layer on the stage of sintering it is required to define temperature drop with preform thickness by a solution of stationary task of thermoconductivity for hollow cylinder with inner source of heat. This as in practice a thickness of cylinder is much less than its diameter and temperature drop is rather small (less 1 K), dependence of thermoconductivity from temperature can be neglected.

3. Mathematical Statement and Solution of a Stationary Problem of a Thermal Conduction

Formulation and solution of a stationary thermoconductivity task. Based on above – mentioned the one dimensional temperature field in a preform is described by the differential equation (1):

$$\frac{\lambda}{R}\frac{d}{dR}\left(R\frac{dT}{dR}\right)+q_v=0 \qquad (1)$$

Where T - temperature, K; R - radial coordinate, m; q_v - a specific power of interior heat sours, W/m^3; λ - a thermal conductivity a perform material at powder sintering temperature of dust *(Ts), W* / (mK).

If on an interior cylinder surface the heat exchange is absent ($\lambda=\lambda_1$), and on an outside surface ($R=R_2$) temperature $T=T_2$, then the boundary conditions look like:

$$\left.\frac{dT}{dR}\right|_{R=R_1}=0 \qquad (2)$$

$$T\big|_{R=R_2}=T_2 \qquad (3)$$

If to take into account lack of heat exchange on an interior surface of preform, a density of a thermal flow from an outside surface of preforms a result of share convective and radiation heat exchange

$$-\lambda\left.\frac{dT}{dR}\right|_{R=R_2}=\alpha\left(T_2-T_0\right)+\varepsilon\sigma T^4 \qquad (4)$$

We have received a relation linking temperatures of interior and outside surfaces of perform in process of powder sintering:

$$T_1=T_2-\frac{1}{\lambda}\cdot\frac{\alpha\left(T_2-T_0\right)+\varepsilon\sigma T_2^4}{\frac{R_1}{R_2}-e^{-\frac{2(R_2-R_1)}{\Delta}}}\times$$
$$\times\left\{R_1\ell n\frac{R_2}{R_1}-\frac{\Delta}{2}\left[1-e^{-\frac{2(R_2-R_1)}{\Delta}}\right]\right\} \qquad (5)$$

The expression (5) represents an algebraic biquadratic equation be relative T_2 for set values T_1. The precise solution of it can be found known methods, for example, a method of Decartes - Euler [2].

The comparison of theoretical, calculated and experimental data for the process of centrifugal induction sintering of a same-fluxing Fe-Cr-B-Si alloy PR-H4G2R4S2F on an interior surface of a bushing from mild carbon steel 20 has shown, that the error of calculation for temperature drop $\Delta T=T_2-T$ with an increasing the relative coordinate $\xi=\frac{R_2-R}{R_2-R_1}$ does not exceed 4%.

Thus from above – mentioned investigation follows, that for induction heating, with standard frequencies 66 kHz, 440 kHz and above usual at induction sintering of powder on inner surface of a bushing, the bushing outside surface temperature must be equal to the powder sintering temperature Ts.

At the heating with standard frequencies 8 kHz and below the outside surface temperature of bushing could be equal to value calculated with expressions (5), accepting T_1=Ts.

4. Summary

As a result the peculiarities of an induction centrifugal sintering of powder coatings on inner surfaces of hollow cylindrical performs with induction heating by other inductor it is shown that the most rational to establish sintering temperature of powder by pyrometric control of outside perform temperature and output power of the high frequency generator. Simple enough algebraic expressions for calculation of powder sintering temperature on the basis of measuring temperature of an outside surface of perform are obtain. This expressions take into account an influence both convective and radiant heat transfer, thermophysical and electrophysical properties of preforms, its dimensions, velocity of rotation and frequency of used induction generator. It is established theoretically and experimentally that at frequencies 66 kHz and above the temperature of outside surface of preform in practically imported cases exceeds the powder temperature no more than on 22 K, and the error of calculation under the obtained expressions does not exceed 4%.

5. References

1. Sluhotshky A.E., Ryskin C.E. Inductors for Induction heating – Leningrad: Energy, 1974

2. Korn G.A., Korn T.M. Mathematical handbook for scientists and engineers. Definitions, theorems and formulas for reference and review. –New York Toronto London: Me GRAW - HILL BOOK COMPANY INC, 1961.