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TEMPERATURE OF NiCrBSi POWDER PARTICLES DETONATION SPRAYED – THEORY AND PRACTICE

TEMPERATURA PROSZKU NiCrBSi NATRYSKIWANEGO DETONACYJNIE –TEORIA I PRAKTYKA

The article compared the results of theoretical calculations with results of actual temperature measurements of detonation sprayed NiCrBSi powder heated by the impact of the detonation products stream. Theoretical distributions of temperature in the powder particle were calculated by the Finite Element Method FEM, using the COSMOS/M program algorithm. In the absence of the heat transfer equations in the solid state being in movement, which is influenced by dynamic heat wave, the conduction mechanism described by Fourier's law was adopted. Experimental temperature measurements as a function of the acceleration path length were conducted using an own construction two-channel pyrometric system. The obtained data confirmed good agreement between the results obtained using FEM calculations method and results of experimental measurements using the pyrometric devices.

Keywords: NiCrBSi powder, detonation spraying, Finite Element Method, pyrometric system

W artykule porównano wyniki obliczeń teoretycznych z wynikami rzeczywistych pomiarów temperatury proszku NiCrBSi natryskiwanego detonacyjnie nagrzewanego na skutek oddziaływania strumienia produktów detonacji. Teoretyczny rozkłady temperatury w cząstce proszku obliczano metodą elementów skończonych MES, wykorzystując algorytm programu COSMOS/M. Z braku równań opisujących wymianę ciepła w ciele stałym będącym w ruchu, na które oddziałuje dynamicznie fala cieplna, przyjęto mechanizm przewodzenia opisany prawem Fouriera. Doświadczalne pomiary temperatury w funkcji długości drogi przyśpieszenia prowadzono wykorzystując dwukanałowy układ pirometryczny własnej konstrukcji. Uzyskane dane potwierdziły dobrą zgodność pomiędzy wynikami otrzymanymi przy zastosowaniu obliczeń metodą MES, a wynikami pomiarów doświadczalnych wykorzystujących pomiary pirometryczne.

1. Introduction

The use of technologies that employ blasting explosives and the energy of explosion of gas mixtures mainly for the forming of the metal surface layer has been known for many years [1, 2, 3]. These methods allow to obtain the collision speed up to 2500 m/s, and the temperature of joined materials are close to room temperature [4, 5, 6]. The limitation of the wider use of these methods for creating the materials surface layer properties is a significant volumetric deformation of the workpiece.

In order to eliminate the adverse phenomenon indicated above, while achieving the impact speed in the range of 600÷1000 m/s, the studies have been focused on the use of combustion energy of gaseous explosive mixtures with the highest overall speed – the detonation speed. The starting point for the creation and development of the detonation spraying process were studies of processes of detonation combustion in pipes. One of the most important parameters, of the two-phase metallization stream forming, consisting of the detonation products of gaseous explosive mixtures and the powder, is temperature. While the temperature of the detonation products decreases as a function of time (or traveled distance used interchangeably), temperature of the powder increases, reaches a maximum and then decreases. Selection of a suitable powder temperature as well as its velocity, crucially influences the properties of the obtained layer, such as adhesion, porosity, wear resistance, stresses in the layer and in the substrate-coating zone, as well as the morphology of the coating itself. Therefore, for each type of powder should be selected parameters individually including the powder temperature. The paper presents results of empirical measurements of the stream nickel-based powder temperature and compared with theoretical calculations.

2. Methods of stream temperature measurements

Experimental measurements of the detonation stream temperature were performed for the NiCrBSi powder with chemical composition: Ni – 70%, Cr – 16%, Si – 4%, B – 4%, C – 2%. Granulation of the powder was 25÷45 μm and the hardness 700HV.

The morphology of the powder (Fig. 1) was examined on Nikon Eclipse LV150 microscope.

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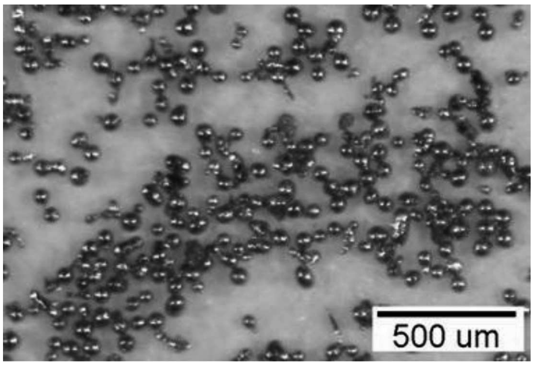

Fig. 1. The morphology of the NiCrBSi powder used for studies

Propane-butane with oxygen was selected as the detonation gas mixture. The oxygen pressure supplied to the device statically, was kept constant at 0.048 MPa and the propane-butane pressure was 0.01 MPa. The nitrogen pressure used to feed the powder in front of the detonation wave was 0.0005 MPa. The gas pressure was chosen experimentally and the selection criterion was adopted as coating adhesion defined in terms of bending.

The system shown in Fig. 2 was used for the temperature measurement.

The measuring system allowed to:

- Temperature measurement of a particles stream 1200÷3000 K;
- Recording the temperature changes in time of 1÷2 ms;
- Elimination of scaling individual optical channels, each time after each measurement. This was caused by the movement of the device as a result of strong vibrations.

Used system consists of a filter letting through radiation with a predetermined length and a specially designed silicon filter, which allows diffraction of the incident radiation.

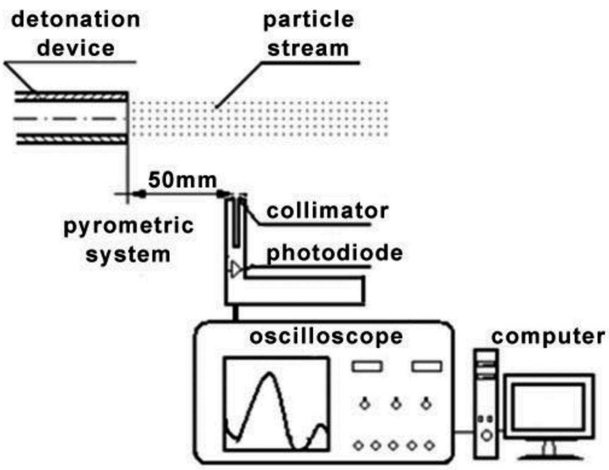

Fig. 2. System for measuring the stream temperature [7]

Recording and archiving of output signals were performed using a four-channel digital oscilloscope Tektronix TDS type – 460. The correctness of used solutions was tested experimentally.

Measurements have shown that the use of the described system does not register the light pulses in the trials carried out only for the gaseous detonation products. Positive results (lack of gases light) were also found in the samples studied at the different frequencies of the process, as well as the different composition of the operating propane-butane with oxygen gas mixture.

Temperature measurements as a function of the acceleration path length were conducted with the use of different barrel length in the range from 110 mm to 710 mm.

Samples with sprayed coatings were made from steel C45 hardened and tempered to a hardness of 28÷32 HRC and then polished (Ra=0.32 μm).

3. Results of NiCrBSi stream temperature measurements

Example results of the NiCrBSi temperature measurements are shown in Fig. 3.

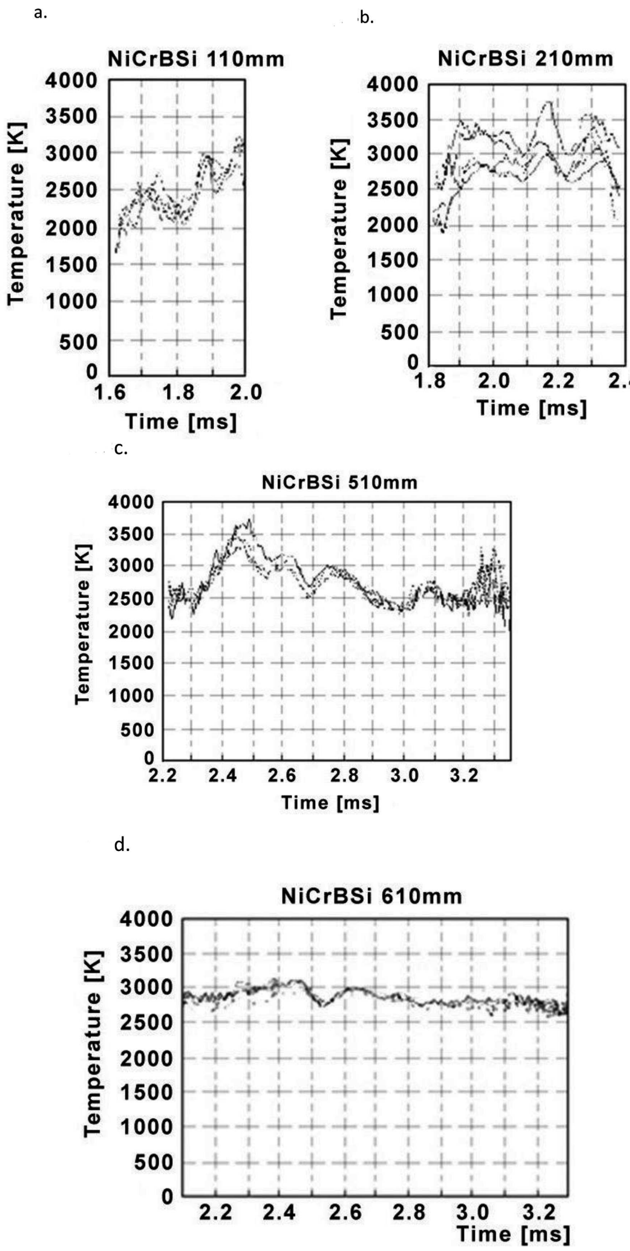

Fig. 3. Temperature of the NiCrBSi powder stream as a function of time measured for the barrel length: a) 160, b) 210, c) 510 and d) 610 mm

From the presented data of the temperature measurements (Fig. 3) it can be seen, that in the range of studied lengths, detonation stream, consisting of NiCrBSi powder, heats up to a maximum value and then cools down. In all received graphs here can be seen very high repeatability of temperature for studied acceleration path length which proves its high thermal stability. Average, the temperature dispersion is no higher than 100÷150 K. It is understandable that for the individual measurements. One can observe higher deviation up to ±300 K. However for adopted number of tests, they do not change the trends of thermal phenomena in the stream. Larger deviations from the average values are observed for the shorter acceleration path length. This may indicate that the process of stream forming has not been completed, caused by the impact of the shock wave on the dispensed powder. In this case, there is an outflow of the stream at the stage of its formation, in which powder particles of different grain size are mixed together in a piecemeal manner, powder particles with different grain size. Lack of order is caused by that the finest particles, which are heating quickly and are recorded by the pyrometer as the particles with the highest temperature, are found along the entire length of the stream, causing large spreads of measured temperatures. In contrast to this phenomenon, with a long acceleration path, there is a clear segregation of powder in the stream depending on the particle size. At the time, in front of the pyrometer slot, are exposed powder particles with a very similar granulation and hence a similar surface temperature. The result is a high compatibility of NiCrBSi powder temperature particles as a function of process time registered by the measuring device.

It is not excluded occurrence of varied powder temperatures for shorter distances, for which the acceleration takes place. This may be caused by unstable parameters of gases detonation.

Interesting data was obtained by making a statement of the results of temperature measurements as a function of the barrel length (Fig. 4). When the spraying parameters were used, the clear maximum temperature was obtained for the NiCrBSi powder in the tested range.

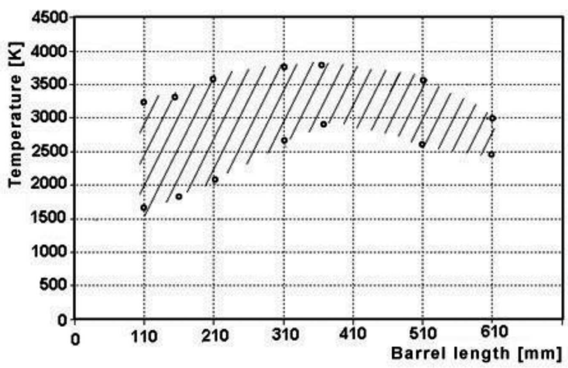

Fig. 4. Temperature changes for a NiCrBSi powder stream as a function of the barrel length [7]

The highest stream temperature was observed for the barrel length in the range of 310 to 410 mm (Fig. 4).

4. Model of gases stream impact on Ni powder particles

Due to the lack of literature data about values of physical constants for the NiCrBSi powder spraying, the calculation of the impact of the gas stream on the Ni powder wes considered.

Because of the high dispersion of the physical constants values given in the literature for the individual powders, the values assumed for the analysis are given in TABLE 1.

TABLE 1

The values of physical constants for Ni powder

Parameter	Unit	Ni powder
Initial temperature	K	293.15
Specific heat	J/(kg K)	444 [8]
Density	kg/m^3	8900 [8]
Heat transfer coefficient at the phase boundary (gaseous and solid)	W/(m^2 K)	10÷100 [9] *100**
Melting temperature	K	*1728** [8]
Coefficient of thermal conductivity	W/(m K)	164 for 100 K 90.7 for 300 K 65.6 for 600 K 76.2 for 1200 K [8] *80**

* Values used in the calculation

Due to the fact that the data available in the literature is characterized by the large differences of values and therefore does not facilitate the decision on what value level of parameters should be adopted for the calculations. To check the influence of this parameter on the calculations characteristics, calculations were performed for the extreme values of heat transfer coefficient, i.e. 10 and 100 W/(m^{2}K). Nickel powder particle was analyzed with a diameter of 45 μm. Initial temperature was T_o =293.15 K and the ambient temperature T_∞ =3273.15 K.

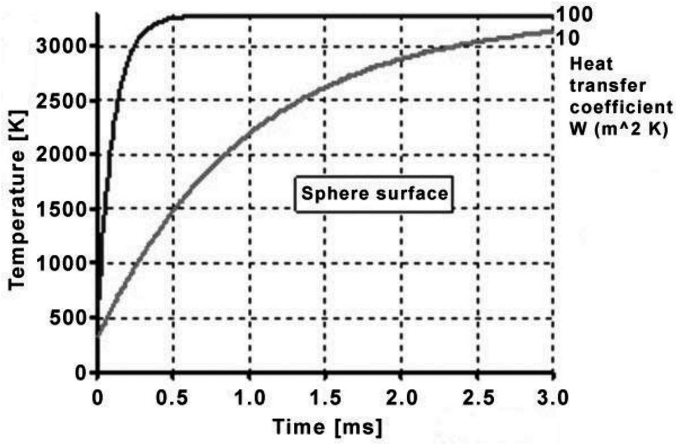

Fig. 5. Effect of heat transfer coefficient on the value of temperature calculation on the surface of a sphere (Ni) with a diameter of 45 μm

The obtained calculations show, that the value of heat transfer coefficient has a significant effect on the temperature on the surface of the particle. It was found, that with the increase of this factor equalization of the particle surface temperature to the value of the ambient temperature is more rapid. For the assumed value of 100 W/(m^{2}K) surface particle was heated to the temperature 3273.15 K after approximately 0.6 ms, while for the assumed value of the heat transfer coefficient 10 W/(m^{2}K) after the same time, the temperature reached

1643.15 K. The time required to heat the powder particles in this case was about 3.5 ms (Fig. 5).

The results of calculations for two different powder diameters are shown in Fig. 6. Submitted temperature changes, as a function of heating time for the two powder diameters 25 and 45 μm, were calculated using the heat transfer coefficient of 100 W/(m^{2}K). Based on the calculation results, it was found that the temperature equalization on the surface of powder with a diameter of 25 μm to a temperature of the detonation gaseous products was reached after about 0.3 ms, whereas for a powder diameter of 45 μm at approximately 0.5 ms. At the same time there were conducted calculations of temperature distribution inside the particle with a diameter of 25 μm, which showed that the powder temperature is almost identical on the surface, along the radius until its center (Fig. 7).

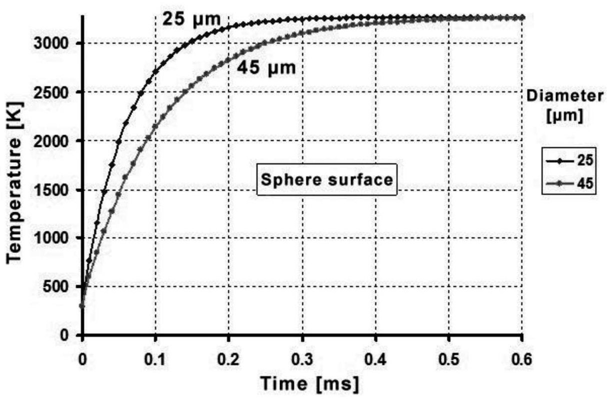

Fig. 6. Effect of heating time on the value of the calculated temperature on the surface of nickel powder with a diameter of 25 and 45 μm

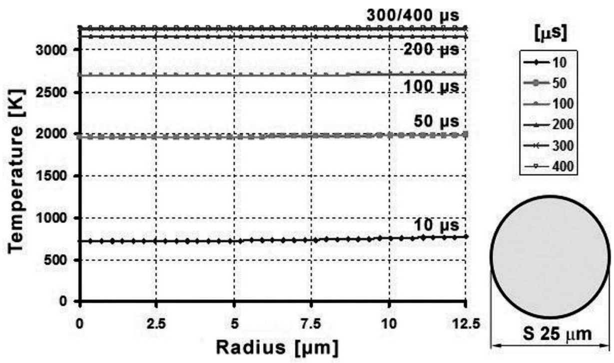

Fig. 7. The temperature distribution along the radius of nickel powder with a diameter of 25 μm after 10, 50, 100, 200, 300 and 400 μs

5. Conclusion

Performed calculations for the assumed boundary conditions have shown that heating of the particles surface temperature depends primarily on the ambient temperature (temperature of the gaseous detonation products) and adopted for the calculation value of the heat transfer coefficient.

Changing the value of this coefficient factor from 10 W/(m^{2}K) to 100 W/(m^{2}K) causes that the calculated theoretical time needed to heat the powder surface extends approximately 6 times, i.e. from about 0.5 ms to over 3.0 ms.

Adopted to the calculation constant heat transfer coefficient showed that the heating time of the powder (spherical) with a diameter in the range of 25 μm and 45 μm does not affect in such a decisive manner on surface heating time. Maximum duration of surface heating to the ambient temperature (temperature of gaseous detonation products T_∞ =3273K) is about 0.5 ms. It is worth to mention, that calculations show that the powder temperature is almost identical on its surface and inside, which indicates the intensive heat transfer from the surface of the powder into the material which is characterized by a thermal conductivity. Due to the size of individual powder particles, calculated results appear to be possible especially for smaller diameters.

From a comparison of the obtained graphs for the experimental measurements and calculations using the FEM method, results their high compatibility. Calculations have shown that a powder with a diameter of 25 and 45 μm heats up to the temperature of 3273.15 K (maximum temperature adopted for the calculations) after about 0.6 ms and then the temperature reaches a constant value. Similar results were obtained for the empirical measurements which show that the stream temperature, measured at a distance of 110 mm from the initial place, is contained within the range of 1600÷3200 K. Because the time when the stream arrives at the measuring point is above 1.6 ms (see Fig. 3a) can be assumed that the process of the particles surface heating calculated theoretically already occurred. The difference between the values calculated theoretically and measured experimentally is only 73 K which is 2%, which can be considered as a very satisfactory result. When analyzing the differences between the two obtained results should also be in mind that the adopted data rates and material constants relate to static conditions. In the literature, there is lack of any data such as the value of heat transfer coefficient at the phase boundary (gaseous and solid) in the case of solid state being in movement.

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