INFLUENCE OF HOT FORMING PARAMETERS ON THE STRUCTURE AND PROPERTIES OF THE ALLOY INCONEL 625

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The study presents the effect of hot deformation parameters on the structure and properties of Inconel 625 alloy. It was found that increasing the hot deformation temperature combined with impact loading allows for the production of a compact with low residual porosity and high mechanical properties. Based on the research results, the optimal conditions for the consolidation of the powder material were determined. It was noted that impact loading enables the formation of juvenile surfaces between particles, which enhances adhesion strength after hot deformation.

Keywords: hot deformation, powder metallurgy, nickel-based alloys, mechanical properties

Introduction. Ukraine is among the few countries in the world with a complete cycle of aircraft production. Therefore, the development of new materials and technologies for manufacturing components capable of operating under high-temperature conditions is one of the key challenges today. Numerous studies have shown that hot forging of pre-atomized powders [1–3] enables the production of high-density semifinished products suitable for subsequent machining. A significant advantage of this approach over high-temperature sintering and hot pressing is the formation of a material with an inherited fine-grained structure.

The aim of this study is to investigate the effect of hot forging process parameters on the structure and properties of pre-atomized Inconel 625 alloy.

Materials and Method of Investigation. Inconel 625 alloy powder was produced by atomization with a particle size of 20–80 μm. Since Inconel 625 powder is not suitable for cold pressing, the billets for hot deformation were prepared by encapsulating the powder in a steel container with an inner diameter of 36 mm and a wall thickness of 4 mm. The steel container was sealed at both ends with steel caps no less than 1 mm thick and hermetically compacted in a steel container under a pressure of 450 MPa. Forging of the prepared samples was performed in a semi-closed die on a FB-1732 screw press. Hot deformation was carried out at temperatures of 950, 1050, 1150, and 1220 °C.

Results and Discussion. Fig. 1 shows the microstructures of the samples after different forging regimes. Analysis of the microstructures of the heat-resistant Inconel 625 alloy reveals that after hot deformation at 950 °C, in addition to the matrix (a solid solution of chromium in nickel, Fig. 1a, area 1), a $Ni_xCr_yMo_z$-type phase is observed, which contributes to the strengthening of the base alloy (Fig. 1a, area 2). The structure also shows residual porosity (Fig. 1a, area 3), which is approximately 6.5% according to image analysis of the polished cross-section using JMicroVision software. Raising the deformation temperature to 1050 °C reduces the residual porosity to 2% (Fig. 1b, areas 1, 2). Among the observed pores are both spherical and flat ones. Spherical pores are less than 1 μm in size, while flat pores—classified as two-dimensional features—can reach several microns in length. Flat pores are typically located along the particle boundaries; at this temperature, most boundaries undergo recrystallization. Further increasing the deformation temperature to 1220 °C does not significantly reduce porosity any further, with the remaining porosity being below 1%.

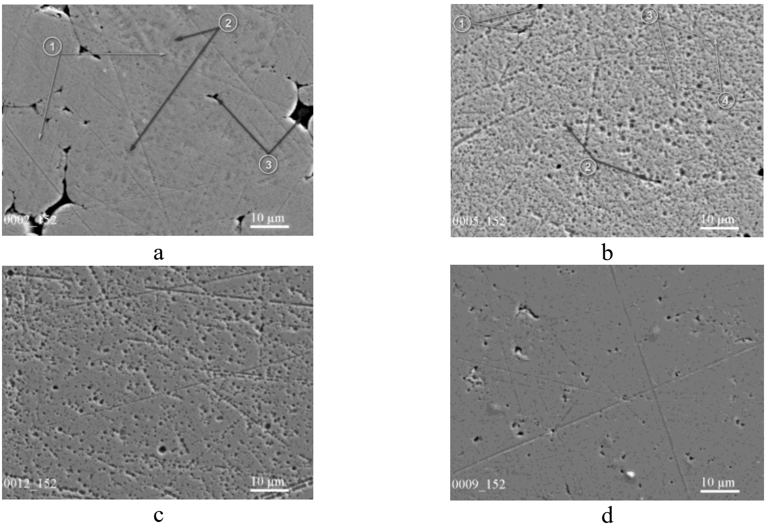


Fig. 1. Microstructure of Inconel 625 powder alloy after hot forging at deformation temperature: a - 950 °C, b - 1050 °C, c - 1150 °C, d - 1220 °C.

Fig. 2 presents the phase composition results. As can be seen, changing the deformation temperature does not alter the phase composition. Two phases are clearly distinguishable in the microstructures: the dark matrix γ-phase (solid solution of chromium in nickel) and the bright phase enriched in niobium and molybdenum. Table 1 provides micro-X-ray spectral analysis data for the material deformed at 1220 °C (Fig. 2d), with the elemental distribution in the phases shown.

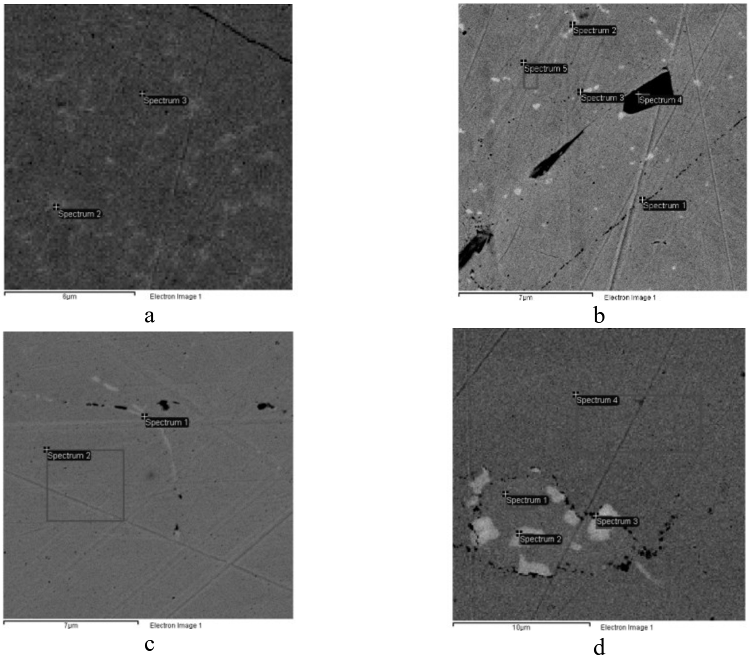
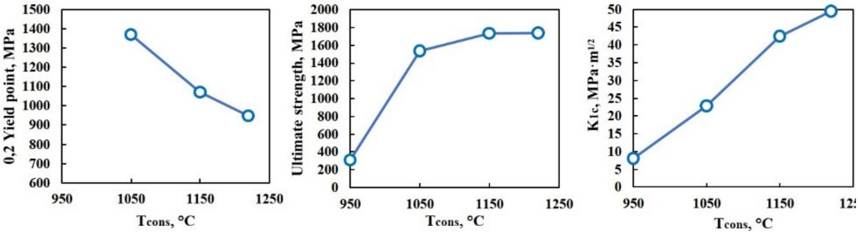


Fig. 2. Local phase analysis of Inconel 625 powder alloy after hot forging at deformation temperature: a - 950 °C, b - 1050 °C, c - 1150 °C, d - 1220 °C.

Table 1. EDS analysis of the microstructure of the sample forged at 1220 °C (Fig. 2d)

Spectrum №	Element content							
	C	N	Si	Cr	Ni	Nb	Mo	W
1	4.84	–	–	18.54	63.36	2.87	6.54	3.86
2	7.88	2.43	1.18	13.45	29.39	24.72	14.70	6.25
3	7.64	2.34	1.21	10.31	28.10	27.26	11.09	12.04
4	4.66	–	0.24	18.40	63.84	3.89	8.96	–

Fig. 3 displays the mechanical testing results. As the deformation temperature increases, the yield point decreases, while the ultimate strength and fracture toughness of the alloy increase. Notably, in the 1150–1220 °C range, the values for yield strength and strain to failure stabilize at a sufficiently high level, averaging around 1600 MPa. This suggests that the temperature range of 1150–1220 °C is optimal for ensuring stable mechanical properties in the hot-deformed alloy.



a b c

Fig. 3. Dependence of mechanical properties on forging temperature:
a – yield point; b – ultimate strength; c – fracture toughness.

Conclusions. The study shows that the optimal consolidation conditions for Inconel 625 alloy, achieving a near fully dense structure and strong particle bonding, are within the 1150–1220 °C range. After forging, the material demonstrates high strength (approx. 1600 MPa) and fracture toughness (approx. 50 $MPa \cdot m^{1/2}$) at room temperature. The phase composition remains unchanged and corresponds to that of the atomized powder material.

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