climate operations, tempering after sub-zero cooling is mandatory, as it allows for the restoration and even enhancement of the material's performance characteristics.

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CORE-SHELL PRECIPITATES IN A "SUPEALLOY-CERAMICS" COMPOSITE PRODUCED BY LASER MELTING

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A composite based on Ni-rich superalloy "Inconel-718" with adding ceramic particles, designed for high-temperature erosion applications, was produced via an integrated technology including Spark Plasma Sintering (SPS) followed by laser surface melting.

The starting material was a powder mixture consisting of the nickel-based superalloy Inconel 718 and ceramic powders (TiC, NbC, TiB_2) taken in equal proportions. The total ceramic volume fraction was 20%. Sintering was carried out on an "HP D 10SD" (FCT System) unit under the following conditions: vacuum of 5 Pa, heating rate of 100 $K \cdot min^{-1}$, sintering temperature of 1000 °C, holding time of 10 min, and maximum applied pressure of 50 MPa. The SPS process produced discs 30 mm in diameter and 5 mm thick. After SPS, one side of each disc was double-scanned with a fiber laser beam (1064 nm wavelength) using a "TruFiber 400" laser system (TRUMPF). The laser parameters were: power 300 W, scanning speed 7 $mm \cdot s^{-1}$, beam diameter 1.3 mm, focal distance 20 mm, and 30% track overlap. Processing was performed in air.

As a result, a dense structure was formed, consisting of a (Ni,Cr)-rich matrix, a fragmented eutectic network along dendrite boundaries, and equiaxed ceramic inclusions of angular shape uniformly distributed throughout the material (Fig. 1a). Many of these inclusions exhibited a heterogeneous "core–shell" morphology with a dark core and a lighter shell. Energy-dispersive X-ray spectroscopy (EDX) was used to determine the interphase distribution of chemical elements.

The elemental distribution indicates that the equiaxed ceramic inclusions (formed as a result of adding ceramic powders to Incone) possess a heterogeneous core–shell structure. The shell is enriched in niobium and boron, whereas the core contains elevated amounts of aluminum, oxygen, and titanium. Niobium and boron are also present in the eutectic inclusions. This distribution suggests that laser melting caused the dissolution of both the Inconel matrix and the ceramic particles, enriching the melt with elements originating from the

ceramics (Nb, Ti, B, and C). During solidification, titanium reacted with atmospheric oxygen and with aluminum present in Inconel, forming a complex oxide $(Ti,Al)_xO_y$. These oxide particles crystallized first in spherical form due to surface tension forces acting at the inclusion–liquid interface. These oxide spheres then served as substrates for the crystallization of niobium carboborides, producing the observed core–shell inclusions.

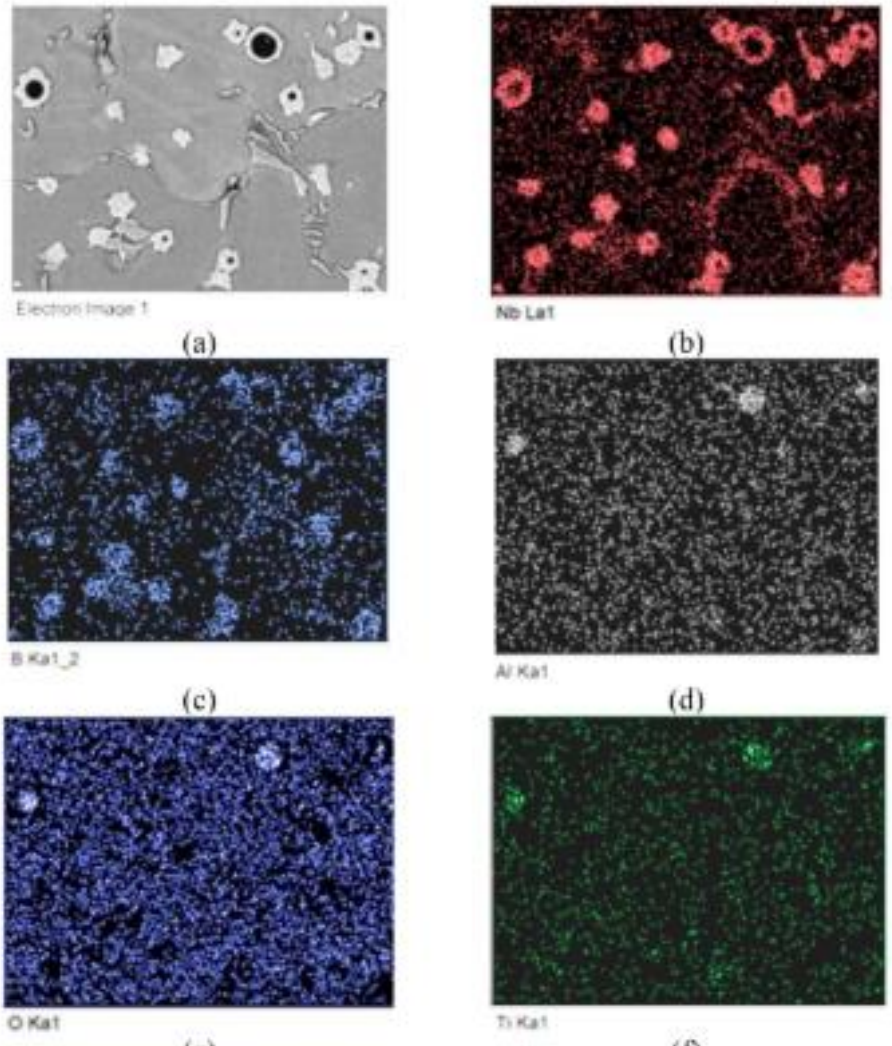


Figure 1. (a) Microstructure of the composite. Corresponding EDX maps of the distribution of (b) Nb, (c) B, (d) Al, (e) O, and (f) Ti

As the size of the oxide core increased, the thickness of the carboboride shell decreased. This is explained by the larger surface area of the growing core and the limited availability of Nb, B, and C atoms in the surrounding melt that

could participate in shell formation. The presence of boron in both the shell and the eutectic inclusions indicates that these phases formed due to the dissolution of TiB_2 particles and subsequent boron enrichment of the melt. Therefore, it can be inferred that the temperature in the laser-affected zone exceeded the melting point of titanium diboride (~3200 °C).

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