Shock wave loading of Nickel based superalloy and micro-structural features of the compacts

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Abstract. Explosive shock wave loading has been employed to consolidate micro-sized nickel based IN718 superalloy powder. Cylindrical geometry configuring the various critical parameters with optimized detonation pressure has been used to consolidate the powder with desirable means. The thrust on the work is to compact the powder nearer to theoretical density having almost negligible density gradient and without melting the core of the specimen. XRD study indicates that the crystal structure of the post compacts remains the same. Shock wave loading deformed the particles as has been inferred from SEM. The variation in particle size has been measured from Laser Diffraction based Particle Size Analyzer (LDPSA). It is found that this is a rapid fast technique to produce larger and crack free compacts of metal powders without their melting and with less particle size variation.

1. Introduction

It is the concern of every powder metallurgist to compact the powder with efficient and desirable means. For the years shock waves have been employed for the rapid solidification of the hard metal powders which are otherwise difficult to compact using conventional techniques such as hydraulic and iso-static pressure techniques [1]. SWC is a possible alternative for densification and synthesis of micro-sized composites. Experimentalists produce these shock waves through powerful electric discharges; supersonic movement of bodies; gas gun and Laser facility; explosive detonation etc. The main advantage of the explosive shock wave loading to the materials is its rapid time processing and controlled detonation pressure, which directly transmits shock wave to the material [2]. The shock processing of materials utilizes the intense deposition of shock energy preferentially on the particle surface, which gets deformed often melted and re-solidified producing inter-particle bonding without melting the core of the specimen [3]. This paper describes the shock consolidation of IN 718 alloy powder to produce specific dimensional compacts for selected applications. It is well known that IN 718 alloy is a Ni-Cr based superalloy and is widely used in Aerospace industry- cryogenic storage, gas turbines, jet engines, compressor wheels and related applications in critical components such as blades, discs, rocket motors, space crafts, and nuclear reactors etc; due to its very high temperature and corrosion resistant properties.

The work reported here is a part of an extensive program is being undertaken to produce materials of unique industrial applications. The first part of the study comprises the theory and experimental work on shock consolidation of the superalloy powder with maximum compaction and negligible melting using explosive whereas second part provides the information on crystallographic parameters,
grain sizes, micro-structure and morphological analysis of post-compacts. Useful information has been obtained on the controlling parameters to produce compacts for desired applications.

2. Experimental
The various critical parameters such as type of explosive, powder container material and thickness, type of confinement etc., have been optimized keeping in frame of required compacts. Therefore, an explosive mixture (AN/TNT/Al::50/42/8) with moderate detonation velocity (5.8km/s) has been used. The schematic arrangement of the geometry used in the experiment has been illustrated in Figure 1. The cylindrical compaction system shown in figure is a metallic tube made of mild steel. The cylindrical ampoule is placed in a cylindrical plastic container made of PVC having wooden plug at the bottom. The space between the metallic tube and plastic container is filled with the explosive. A wooden plug having an electric detonator and booster covers the plastic container from the top. In order to carry out the experiment, the explosive filled compaction cylinder is placed in an earth pit for easy recovery of the compacted specimen. Figure 1 shows various components of the trial assembly. When the explosive loaded assembly is detonated from the top, an axi-symmetric shock compresses the superalloy powder producing a pressure of about 9.42GPa. Significant in-homogeneity of the structural properties along the ampoule has been observed.

![Figure 1. Cross-sectional layout of the configuration used for the consolidation experiment and various trial components.](image)

XRD technique was used for the elementary phase analysis of the pre and post-compacts. The device used was XPERT-PRO X-Ray Diffractometer with a step-angle equal to 0.02° and step-time of 10.33 sec at room temperature. The X-ray beam of Kα lines of Cu with wavelength 1.54Å impinged on the powder sample to get the required XRD pattern. The glancing angle was varied from 30° to 80°(2θ). The particle sizes of the pre and post compacts were determined with Laser Diffraction based Particle Size Analyzer (LDPSA) and correlated to Microscope intercept method. The device used for the particle size distribution was Malvern Mastersizer S-2000. For microstructure analysis of the compacts and to account for the inter-particle melting/bonding SEM technique was adopted and the device used was JEOL JSM6100 system at 15kV.

3. Results and Discussion
Figure 2 corresponds to the X-ray pattern for pre and post shock compacted specimens, respectively. The sharp diffraction peaks indicates pure crystalline structure and after being indexed using ASTM standards, satisfy fcc structure. This means that the crystal phase/structure of the post-compacted specimens remained the same even after the shock-loading. It can be observed from the diffraction pattern that the FWHM values for the post-compacted specimens are increased suggesting a particle size reduction [4].
The particles size has been validated by using Laser diffraction based particle size analyzer. It has been observed that average particle size for IN718 superalloy powder is close to 105μm. The particle size varies from 30.53μm to 390.80μm. The volume or Mass Moment Mean diameter of the specimen before shock loading was found to be 105μm. The reduction in particle size after shock-loading has been validated by the scanning electron microscopy technique discussed as follows.

Figure 3 represents the SEM images of the pre and post-compacted specimens. The particle are smooth spherical in shape and have the size close to 120μm. The value is in agreement with that of measured by laser diffraction method. After shock-loading, the particle size has been reduced to 70 μm. The particles are welded and interlocked together under the extensive shock energy which preferentially deposits on the particle surfaces resulting into melting and hence responsible for bonding mechanism. The heat generated at the particle boundaries during compaction and consequential microstructure features produced depend on the interparticle friction and local deformation mechanism. The apparent white etched spots in the micrographs at the interparticle regions attributes to a little melting which has been identified by several investigators that produced due to rapid- solidification shrinkage which also responsible for the bonding mechanism[5].

Figure 4 shows surface morphology of pre and post-compacted specimen. It can be seen from the micro-structure that dendritic behavior of the compacted specimens remains the same even after the intensive shock loading.

Density of the compacted specimen was calculated to be close to 97% of the theoretical value.
Conclusions
Uniform compacts of the superalloy IN718 without the presence of any fracture/micro-voids have been obtained by using explosive having moderate detonation velocity. Cylindrical geometry with optimized critical parameters provided a density 97\% of theoretical value. The particle sizes for the compacted specimen were found to be reduced by explosive shock wave loading with a small variation (105-77\,\mu\text{m}). Shock wave loading deformed the particles micro-structure as has been inferred from SEM but the crystalline structure remained the same (fcc). The technique is now being used to produce denser compacts to achieve tremendous mechanical properties.

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References
[1] Thathani N N, Mutz A H and Vreeland T 1989 Acta Metall. 37 897-908
[2] Alba-Baena N G, Salas W and Murr L E 2008 Mater. Charact. 59 1152-60
[3] Hokamoto K, Prummer R A, Knitter R and Taira K 2007 J.Matter. Sci. 43 684-88
[4] Cullity B D 1956 Elements of XRD (USA- Addison Wesley Publishing Co.)
[5] Wang S L, Mayers M A and Szecket A 1988 J. Material. Sci. 23 1786-1804