High Strain Rate Behavior of Harmonic Structure Designed Pure Nickel: Mechanical Characterization Microstructure Analysis and 3D Modelisation

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Abstract : The development of new architecture metallic alloys with controlled microstructures is one of the strategic ways for designing materials with high innovation potential and, particularly, with improved mechanical properties as required for structural materials. Indeed, unlike conventional counterparts, metallic materials having so-called harmonic structure displays strength and ductility synergy. The latter occurs due to a unique microstructure design: a coarse grain structure surrounded by a 3D continuous network of ultra-fine grain known as “core” and “shell,” respectively. In the present study, pure harmonic-structured (HS) Nickel samples were processed via controlled mechanical milling and followed by spark plasma sintering (SPS). The present work aims at characterizing the mechanical properties of HS pure Nickel under room temperature dynamic loading through a Split Hopkinson Pressure Bar (SHPB) test and the underlying microstructure evolution. A stopper ring was used to maintain the strain at a fixed value of about 20%. Five samples (named B1 to B5) were impacted using different striker bar velocities from 14 m/s to 28 m/s, yielding strain rate in the range 4000-7000 s-1. Results were considered until a 10% deformation value, which is the deformation threshold for the constant strain rate assumption. The non-deformed (INIT – post-SPS process) and post-SHPB microstructure (B1 to B5) were investigated by EBSD. It was observed that while the strain rate is increased, the average grain size within the core decreases. An in-depth analysis of grains and grain boundaries was made to highlight the thermal (such as dynamic recrystallization) or mechanical (such as grains fragmentation by dislocation) contribution within the “core” and “shell.” One of the most widely used methods for determining the dynamic behavior of materials is the SHPB technique developed by Kolsky. A 3D simulation of the SHPB test was created through ABAQUS in dynamic explicit. This 3D simulation allows taking into account all modes of vibration. An inverse approach was used to identify the material parameters from the equation of Johnson-Cook (JC) by minimizing the difference between the numerical and experimental data. The JC’s parameters were identified using B1 and B5 samples configurations. Predictively, identified parameters of JC’s equation shows good result for the other sample configuration. Furthermore, mean rise of temperature within the harmonic Nickel sample can be obtained through ABAQUS and show an elevation of about 35°C for all fives samples. At this temperature, a thermal mechanism cannot be activated. Therefore, grains fragmentation within the core is mainly due to mechanical phenomena for a fixed final strain of 20%.

Keywords : 3D simulation, fragmentation, harmonic structure, high strain rate, Johnson-cook model, microstructure
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