MECHANICAL AND THERMAL RESPONSE OF SHOCK-CONSOLIDATED MAR-M 200

Marc A. Meyers, S. L. Wang, and B. B. Gupta

Center For Explosives Technology Research
New Mexico Institute of Mining and Technology
Socorro, New Mexico, U.S.A.

Consolidation of rapidly solidified Mar-M 200 powder was carried out successfully for the axi-symmetric and plane-wave (using contact explosives with normal incidence) geometries. However, cracking produced by reflected waves remains a major problem and considerable development work will be required until this major problem can be eliminated. The ambient temperature ultimate compressive strength of the consolidated powder is approximately 2200 MPa. The changes in micro-indentation hardness and microstructure as a function of isochronal anneals of one hour between 600 and 1200 °C are presented. Aging the compact to optimum hardness (850 °C/1 hour) raised the ultimate compressive strength to 2550 MPa.

1. INTRODUCTION

Shock-wave compaction seems to be a technique with considerable potential in the consolidation of ceramic and metal powders (1,2). Good candidate alloys for this technique are the rapidly-solidified powders, which exhibit unique mechanical properties; indeed Cohen et alii (3) suggested dynamic compaction as a possible means of producing bulk parts from these minute powders (approximately 0.1 mm diameter). Meyers et alii (4) showed recently that rapidly-solidified powders could be consolidated by explosives. This paper describes the continuation of this research; more detailed mechanical tests were performed and post-explosionem aging treatments were conducted with the objective of increasing the ambient temperature mechanical strength.

2. EXPERIMENTAL TECHNIQUES

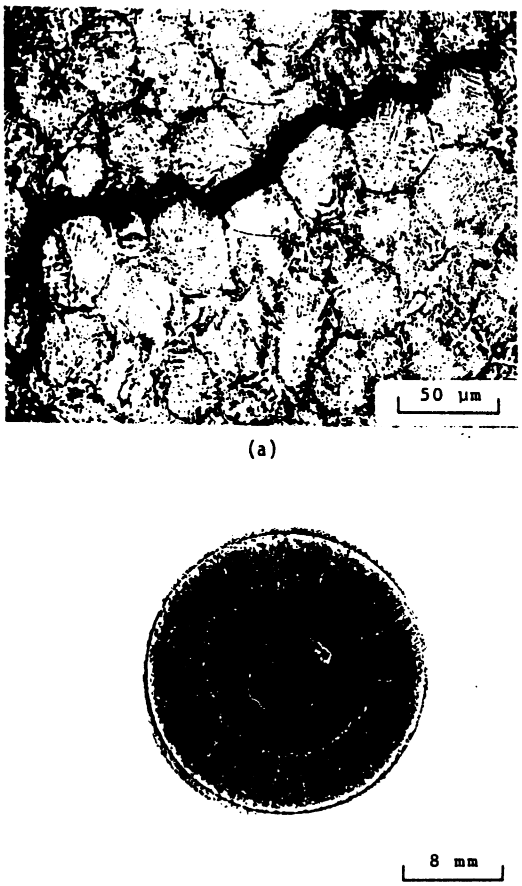
MAR-M 200, a nickel base superalloy prepared by the Pratt and Whitney RSR (Rapid Solidification Rate) process, was used in the present investigation; the powder is described by Patterson et alii (5). It exhibited a microdendritic structure. Compaction was performed using the axi-symmetric (described in [4]) and the plane-wave configurations. In the plane-wave configuration an explosive cylinder (C-4) was placed on the top of a steel block containing, in its interior, the powder. The interior cavity of the steel block containing the powder was evacuated prior to the detonation of the explosive. The techniques for the metallographic characterization (optical, scanning and transmission electron microscopy) are described in greater detail by Meyers et alii (4) and Gupta (6). Compression tests were carried out using cylindrical specimens with a diameter of 6 mm and length of 12 mm placed between two parallel plates in a MTS 810 testing machine; castor oil was used as lubricant between specimen and plates.

3. RESULTS AND DISCUSSION

The main problem in shock-wave consolidation is cracking produced by tensile relief waves. Although high strength levels and unique microstructures are achieved, completely satisfactory tailoring of the waves has not, to the authors' knowledge, been achieved yet. The recent National Materials Advisory Board (National Academy of Sciences) report (2) addresses this problem. In most axi-symmetric systems tested, cracking was observed. Figure 1 (a) shows radial and tangential cracks in the cross-section of a consolidated cylinder. Figure 1 (b) shows that these cracks propagate in an inter-particle mode. Cracking was also prevalent for the plane-wave geometry. Nevertheless, specimens large enough for mechanical testing and metallography could be obtained.

The substructure generated by shock-wave consolidation is described in detail in (4). Essentially it consists of interparticle melt regions, high deformation regions, and shock-deformed regions. The interior of the particles are subjected to uniaxial strain shock waves. The substructure that results from this consists of deformation twins and bands; Figure 2 shows a typical region. The exteriors of the particles, on the other hand, experience considerable residual plastic strain. This is accompanied by considerable heat evolution leading to recovery, recrystallization and even melting. Figure 3 shows a region that has become microcrystalline as a result of plastic deformation. Figure 4 shows the boundary between two particles (dark line through micrograph); it is probable that it consists of an oxide layer, since the particles were exposed to air.

The shock-consolidated specimens were aged at various temperatures; MAR-M 200 is an age-hardening alloy and the objective of the aging treatment was to foster the synergistic effects of precipitation and shock-wave strengthening. Figure 5 shows the substructure that was observed after aging for one hour at 600 °C. Deformation



(a)

(b)

Figure 1 : (a) Cross-section of consolidated cylinder showing radial and tangential cracks; (b) Microstructure of consolidated powder showing inter-particle cracking

twins can be seen in bright field; dark field renders them more obvious. No obvious change in substructure can be seen. After 800 °C/1 hour the dislocations arrays are slightly different, as shown in Figure 6, with a uniform distribution being replaced by "patches". No precipitation is evident although it cannot be ruled out. Aging for one hour at 900 °C and above produces gamma-prime precipitation. After 1150 °C/1 hour one can see in Figure 7 the cuboidal precipitants that have grown to a size of approximately 0.5 µm. The diffraction pattern shows no evidence of cold work any longer. The hardness is, as expected, affected by aging; it increases up to 850 °C and then decreases, as evidenced in Figure 8. If

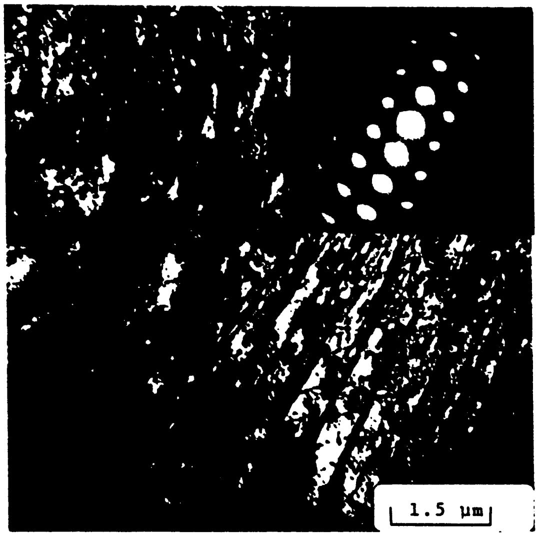


Figure 2 : Transmission electron micrograph of deformation twins generated by shock-consolidation

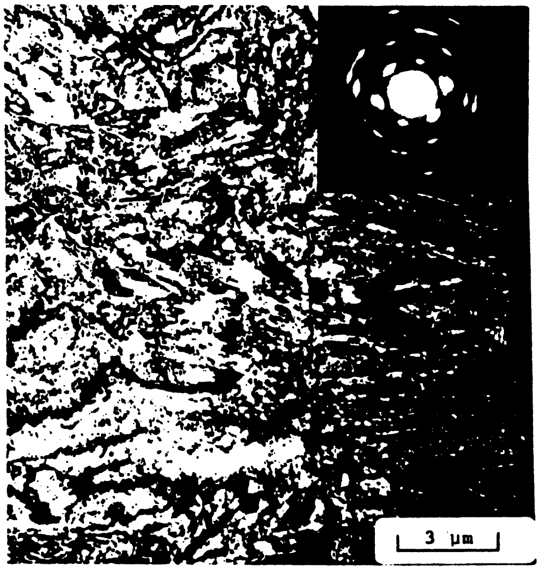


Figure 3 : Microcrystalline region generated by intense deformation close to particle surface (TEM)

Figure 4 : Interface between two particles; notice heavily deformed regions (TEM)

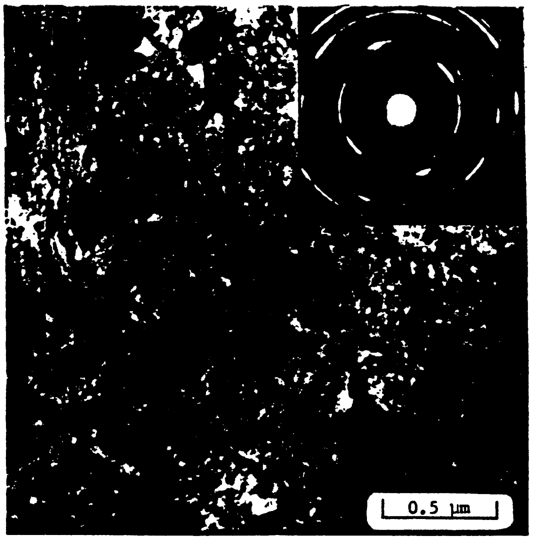


Figure 6 : Substructure resulting from aging at 800 °C/1 hour (TEM)

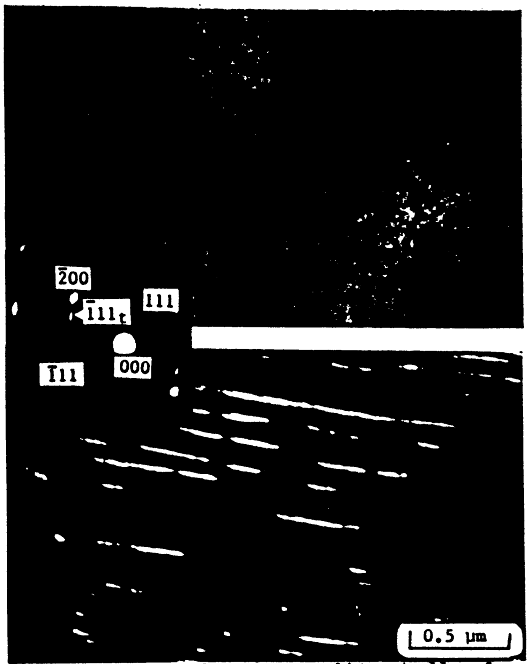


Figure 5 : Aging of shock-consolidated alloy for one hour at 600 °C; notice deformation twins identified by dark field of $\bar{1}11_t$ reflection

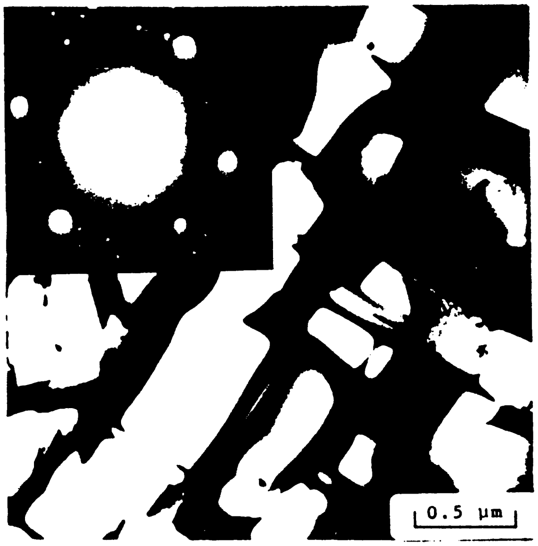


Figure 7 : Profuse gamma-prime precipitation after aging at 1150 °C/1 hour (TEM)

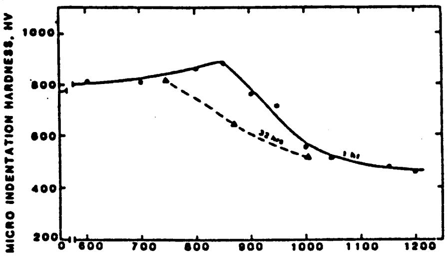


Figure 8 : Effect of aging on hardness of shock-consolidated material

aging is conducted for 32 hours (the aging time recommended for MAR-M 200) the temperature for maximum hardness is decreased; this is a consequence of the greater time for precipitate growth.

The compressive strength (at ambient temperature) was determined in the post-explosionem condition and after aging. Compression specimens were used because one could not obtain specimens large enough for tensile testing due to cracking. Figure 9 shows the true stress-true strain curves. The compressive ultimate strength in the post-explosionem condition (two specimens shown) is approximately 1950 MPa; this is about twice the strength of the as-cast alloy. Aging increases the yield stress and introduces work hardening into the structure; this is a beneficial effect.

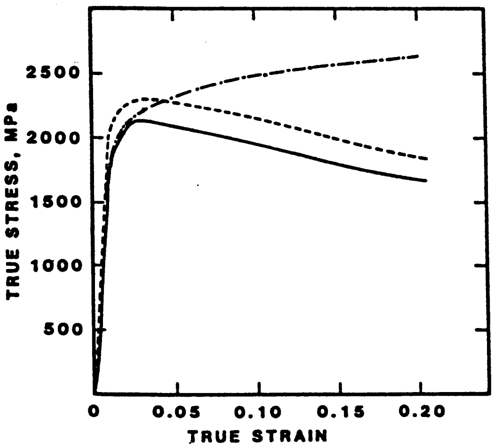


Figure 9 : True stress-true strain curves (in compression) for material in shock-consolidated condition (——,---) and in peak-hardness aged condition (-·-·-·-)

ACKNOWLEDGEMENTS

The alloy was kindly supplied by Mr. A. R. Cox of Pratt and Whitney Government Products Division. This research was partially funded by National Science Foundation Grant DMR 81-15127 and by the Research and Development Division of New Mexico Tech.

REFERENCES

[1] Prummer, R., Powder Compaction, T.Z. Blazynski (ed.), Explosive Welding, Forming and Compaction (Applied Science Publishers, London, 1983).
[2] Dynamic Compaction of Metal and Ceramic Powders, NMAB-394, National Materials Advisory Board (National Academy Press, Washington, 1983).
[3] Cohen, M., Kear, B. H., and Mehrabian, R., (eds.), Proc. Second Intl. Conf. on Rapid Solidification Processing (Claytors Publishing Div., Baton Rouge, 1982).
[4] Meyers, M. A., Gupta, B. B., and Murr, L. E., J. of Metals, 33, No. 10, (1981) 21-26.
[5] Patterson II, R. J., Cox, A. R., and van Reuth, E. C., J. of Metals, 32, No. 9, (1980) 34-39.
[6] Gupta, B. B., Shock-Wave Consolidation of MAR-M 200 Powder, M Sc Thesis, New Mexico Institute of Mining and Technology, 1982.