Conditions for Shear Band Formation in Tungsten Alloys

H. Couque, N. Eches

► To cite this version:

H. Couque, N. Eches. Conditions for Shear Band Formation in Tungsten Alloys. Journal de Physique IV Proceedings, 1997, 07 (C3), pp.C3-403-C3-408. 10.1051/jp4:1997370 . jpa-00255527

HAL Id: jpa-00255527

<https://hal.science/jpa-00255527>

Submitted on 1 Jan 1997

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Conditions for Shear Band Formation in Tungsten Alloys

H. Couque and N. Eches

GIAT industries, Division des Systèmes d'Armes et de Munitions, 7 route de Guerry, 18000 Bourges, France

Abstract. Local loading conditions associated with shear banding formation in laboratory tungsten alloy specimens are examined. The specimens consist of compression specimens of large length to diameter ratio made of 91W-6Ni-3Co swaged tungsten alloys tested with the Hopkinson pressure bar and symmetric Taylor techniques. Experimental and numerical results provide insights on the effect of the hydrostatic pressure on shear band formation in tungsten alloys.

Résumé. Les conditions locales de chargement liées aux observations expérimentales de bandes de cisaillement des alliages de tungstène sont examinées. Ces bandes ont été observées avec des échantillons de compression dynamique à grand rapport de longueur sur diamètre composés d'alliages corroyés de tungstène 91W-6Ni-3Co. Les échantillons ont été testés à l'aide des techniques aux barres d'Hopkinson et de Taylor symétrique. Les résultats expérimentaux et numériques révèlent le rôle de la pression hydrostatique sur la formation de bandes de cisaillement dans les alliages de tungstène.

1. INTRODUCTION

Previous studies indicate relationships between ballistic performances and the critical deformation in compression characterizing shear band formation for depleted uranium and tungsten alloys (1,2,3). The lower critical deformation of the depleted uranium alloys favors crater formation of smaller diameter during the penetration process. A possible way to improve the ballistic performances of tungsten alloys is to lower this critical deformation. Such investigations require knowledge of the local loading conditions associated with the initiation and propagation of shear bands and of the influence of the microstructure on the shear band formation. If data are available on the influence of the microstructure (3), there are few information describing stress states during the initiation and propagation of shear bands. As well, information are needed on the influence of loading variables typical of penetration events such as pressure and strain rate on shear band formation.

The objective of the present paper is to focus on the local loading conditions associated with shear bands observed in laboratory tungsten alloy specimens. These shear bands were observed under significant hydrostatic pressure and under large stress state variation with the use of dynamic compression specimens of large length to diameter ratio. These tests consist in Hopkinson pressure bar and symmetric Taylor tests conducted with 91W-6Ni-3Co swaged tungsten alloys. Hopkinson pressure bar tests was conducted at 4900 s⁻¹ with specimen of length to diameter ratio equal to 2 (3). Taylor tests involved specimens of length to diameter ratio equal to 4 impacted at speeds ranging from 200 to 300 m s⁻¹. The numerical simulations were conducted with the hydrocode AUTODYN-2D (4) implemented with a Johnson and Cook constitutive model.

2. EXPERIMENTAL PROCEDURE

Dynamic uniaxial constant strain rate compression data of a 25% swaged 91W-6Ni-3Co alloy from Teledyne was used (3). These data were generated with a Hopkinson pressure bar system using specimens 6.3 mm in diameter and 12.7 mm in length. No lubricant was applied to the loading interfaces. The pressure bar system consists in 2410 MPa maraging pressure bars 12.7 mm in diameter. The test conducted with an incident stress pulse of 80 percent of the bar yield material providing a strain rate of 4900 s⁻¹ and a specimen global strain of 0.4 is discussed.

Taylor testing was generated to provide material behavior in dynamic compression with large variation in the stress state. The alloy employed is a 25% swaged 91W-6Ni-3Co alloy provided by Cime Bocuze of GIAT industries of similar microstructure and high strain rate compression properties that the pressure bar material. Taylor testing was performed using the symmetric loading approach introduced by Erlich et al (5). This approach has the primary advantage to eliminate friction at the loading interfaces therefore facilitating numerical simulations. The symmetric Taylor tests implicate two specimens 9 mm in diameter and 35 mm in length loaded with a newly developed system at GIAT industries Bourges Center

(4). The loading system involves a 25 mm caliber gas gun to launch, at velocities ranging from 200 to 300 m s⁻¹, one Taylor specimen guided with a Teflon sabot against a second Taylor specimen located at the gun muzzle and positioned with another Teflon sabot. The two Teflon sabots are identical and provide guidance up to impact without interfering with the loading phase.

3. NUMERICAL PROCEDURE

Numerical simulations were conducted with the Lagrange processor of the finite difference finite element hydrocode AUTODYN-2D (4). For the Hopkinson pressure bars tests, incident and transmitted bars were simulated to reproduce the Pochhammer-Chree oscillations. The bar mesh was refined at the specimen loading interfaces to match the specimen mesh size. Precisely, the specimen mesh is composed of square elements 450 µm in size. To simulate accurately the specimen dry loading interfaces, a friction of 0.5 was used based on the work of Bertholf et al. (7). This work reports hydrocode simulations of Hopkinson pressure bar tests of an aluminum alloy involving loading interfaces from lubricated to bonded conditions. Taylor simulations were conducted with a numerical model simulating the Taylor specimens, the Teflon sabots and the steel gun. The mesh of the Taylor specimens is composed of square elements varying in size from 500 µm for the elastically loaded region to 250 µm in the plastically loaded region. High strain rate and temperature dependence was taken into account using a Johnson and Cook constitutive model. The model, calibrated to reproduce experimental data at 23°C at a strain rate of 1 and 5000 s⁻¹, and at 600°C at a strain rate of 1 s⁻¹, expresses the equivalent stress in MPa as:

$$\sigma = (1948 + 600 \varepsilon_p^{1.62})(1 + 0.03 \ln \dot{\varepsilon})(1 - \{(T - 300)/(T_m - 300)\}^{0.94})$$

with ε_p the equivalent plastic strain, $\dot{\varepsilon}$ the strain rate, T the test temperature in Kelvin and T_m the melting temperature of the Ni-Co-W matrix equal to 1750°C.

4. RESULTS

The simulations of the Taylor tests conducted at launched velocities of 200 and 300 m s⁻¹ reproduce final diameters and lengths by +2% and -4%, respectively. For the compression test, the typical bulging of the high length to diameter ratio compression specimen is simulated. Minimum and maximum diameters of the bulged region were reproduced within +2%.

Sections of the Hopkinson pressure bar specimen and of the Taylor specimen launched at 300 m/s reveal shear band formation, see Figure 1. These shear bands involve highly deformed tungsten particles with shear strain exceeding several hundred percent. No shear bands were observed for the Taylor test conducted at 200 m s⁻¹.

The effective plastic strain of the two specimens exhibiting shear bands is compared in Figure 3. The shear localization paths within the intense shear stress zone are shown. For the Hopkinson pressure bar specimen, the shear band path is located between one region exhibiting little plastic deformation, corresponding to the specimen loading sides and a plastically deformed region involving deformation reaching 0.5. Such features are confirmed through the observation of the deformed microstructure, see Figure 1a, where the loading side zone reveals an unchanged microstructure consisting of the elongated tungsten particles of the swaged alloy (4). In another hand, the Taylor specimen reveals large plastic deformation on both sides of the shear localization path with a maximum deformation of 0.8 for the loading side zone. Both specimens reveal that local deformation of at least 0.5 is necessary to trigger shear banding.

Pressures and temperatures reached along the shear localization paths are shown in Figure 3 for reference material points indicated in Figure 2. In the case of the Hopkinson pressure bar specimen, high pressures up to 2000 MPa with an effective local plastic strain up to 0.50 characterized the onset of shear localization, points H1 and H2. For the Taylor specimen, shear localization occurs at an effective plastic strain of about 0.55 and under low pressures, i.e. starting under no confinement at -200 MPa (points T1 and T2) and propagating at pressures reaching 500 MPa (point T3). Temperatures at the onset of localization are similar for both specimens which is about 480°C for the Hopkinson pressure bar specimen and are ranging from 400 to 600°C for the Taylor specimen.

The Taylor specimen stress state is characterized by a tensile hoop stress associated to a two-dimensional compressive state of stress while the Hopkinson pressure bar specimen exhibits a three-dimensional compressive stress state with a hoop stress of about -1000 MPa. For the Taylor specimen, strain rates exceeding 10⁵s⁻¹ are reached up to a deformation of 0.1 and then attained 5000 to 6000s⁻¹.

a1) INCIDENT SIDE

a2) DETAIL A

b1)

b2)

Figure 1. Shear bands observed with Hopkinson pressure bar specimen (a1, a2) and Taylor specimen (b1, b2).

a)

b)

Figure 2. Equivalent plastic strain distribution in the Hopkinson pressure bar specimen (a) and Taylor specimen (b). The Hopkinson incident pressure bar side is on the left.

Figure 3. Pressure and temperature histories of material points located near the shear band paths for the Hopkinson pressure bar specimen (a1, a2) and Taylor specimen (b1, b2). The material point locations are indicated in Figure 2.

5. DISCUSSION

To provide insights on the influence of pressure and plastic deformation on the formation of shear bands in tungsten alloys, these results are compared to high strain rate tensile (8) and torsional data (9). Torsional data at a strain rate of 3000 s^{-1} indicate low fracture strain of the order of 0.12 and is associated to tungsten/tungsten interfacial failure. Tensile data at a strain rate of 1500 s^{-1} reveal that damage initiation (necking) occurs at strain of 0.05. Again, tungsten/tungsten interfacial failures characterized damage initiation of the tensile specimen, precluding the generation of local shear bands (8).

Figure 4. Pressure and effective plastic strain histories of the tensile, torsional, compressive and Taylor specimen failure zones.

Figure 4 shows the loading path of the failure zones of the tensile, torsional, compression specimens. Pressure as low as 500 MPa, appears to be sufficient to preclude tungsten/tungsten interfacial failure, therefore allowing large plastic deformation. These results clearly imply that the compression mode of loading is required to evaluate shear localization capabilities of tungsten alloys. While recognizing that pressures reached in terminal ballistic ranged from 1500 to 15000 MPa, dynamic compression and Taylor testing are mean to generate accurate low pressure data to support damage criteria development for terminal ballistic simulation as well as to evaluate newly developed tungsten alloys.

Acknowledgments

The authors express their thanks to Mr. G. Nicolas (Cime Bocuze) for providing the Taylor tungsten alloy and to Mr. P. F. Louvigné (DGA/CREA) for providing compression properties of the Taylor tungsten alloy.

References

- [1] Magness L. S and Kapoor D., "Flow-softening tungsten composites for kinetic energy penetrator applications", Tungsten and Refractory Metals 1994 Cf., A. Bose and R. Dowding Eds., (1995) 11-20.
- [2] Weerasooriya T. and Magness L. S., "High rate testing of kinetic energy penetrator materials", Explomet 1995 Cf., L. E. Murr, K. P. Staudhammer and M. A. Meyers Eds., (1995) 893-899.
- [3] Couque H, Lankford, Jr. J and Bose A., "The role of swaging in the dynamic deformation and unstable shear in tungsten alloys", Tungsten & Tungsten Alloys 1992 Cf., A. Bose and R. Dowding Eds., (1993) 365-372.
- [4] Couque H, Manuscript in preparation.
- [5] Birnbaum N. K. and Cowler M. S., "Numerical simulation of impact phenomena in an interactive computing environment", IMPACT 1987 Cf., C. Chiem, H. Kunze and L. Meyer Eds, (1987) 881-888.
- [6] Erlich D. C., Shockey D. A. and Seaman L., "Symmetric rod impact technique for dynamic yield determination", Shock Waves in Condensed Matter 1981 Cf., Amer. Inst. of Phys. Eds., (1982) 402-406.
- [7] Bertholf L. D. and Karnes C. H., *J. Mech. Phys. Solids*, Vol. 23, (1975) 1-19.
- [8] Couque H, Lankford J. and Bose A., *J. Phys. III France* 2 (1992) 2225-2238.
- [9] Ramesh K. T., Yadav S., Davis J. A., "Shear localization in tungsten heavy alloys", Tungsten & Tungsten Alloys 1992 Conference, A. Bose and R. J. Dowding Eds., (1993) 299-306.