

Deformation and fracture behavior of Co-containing tungsten alloy

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Abstract

The influence of strain rate on the fracture behaviour of sintered Co-containing tungsten heavy alloy is examined using optical, scanning electron microscopy (SEM) and fine-probe energy dispersive spectroscopy (EDS) microanalysis techniques. The Co addition has improved the strength of tungsten alloy. However the mechanical properties of the alloy varied with the strain rate. It was revealed that the facetting of tungsten grains is attributed to the microsegregation and sintering process. Evidence of predominantly brittle fracture observed at different strain rate is presented and compared to elucidate the fracture behaviour of the alloy.

Riassunto

La microscopia ottica, la microscopia elettronica a scansione e la microanalisi per mezzo della spettroscopia a dispersione di energia con sonda sottile sono state adoperate in uno studio dell'influenza del gradiente delle deformazioni della velocità dell'applicazione del carico sul comportamento alla frattura di una lega pesante di tungsteno sinterizzato addizionato di Co. Si è visto che mentre l'aggiunta del Co ha migliorato la resistenza della lega, le proprietà meccaniche di quest'ultima variano in funzione del gradiente delle deformazioni. I risultati dello studio hanno dimostrato che la sfaccettatura dei grani di tungsteno è da attribuirsi al procedimento di microsegregazione e sinterizzazione. Le evidenze della frattura prevalentemente fragile raccolte a diversi gradienti delle deformazioni vengono presentate e confrontate allo scopo di illustrare il comportamento alla frattura della lega in parola.

INTRODUCTION

The unique combination of mechanical properties, machinability and corrosion resistance makes heavy tungsten alloys (WHA) suitable for a wide variety of applications such as radiation shields, vibration dampeners, heavy-duty electrical contacts and ordnance [1]. The structure is consolidated by the liquid phase sintering process in which the low melting matrix elements provide rapid transport of elements around the solid phase through a capillary force [2]. The solubility of solid in liquid matrix is also crucial in mass transport, grain shape and packing of the structure [1, 3]. The dependence of mechanical properties and embrittlement on the sintering parameters has been elaborated in previous work [4, 5]. The presence of impurity elements and formation of brittle intermetallic phase in tungsten alloys during processing can also cause deterioration in

the overall properties [5 – 7]. Nevertheless recent work [8] reported that significant strengthening could be achieved by hot-extrusion processing of tungsten alloy. Therefore it is important to understand and correlate the compositional and processing conditions with the mechanical behaviour of tungsten alloys. Previous work [4, 5] has reported structure and properties relationship in Cu-Ni-W and Fe-Ni-W alloys however the fracture behaviour has not been fully considered in Co-containing tungsten alloy. In this study, the effect of strain rate on the fracture behaviour of sintered tungsten alloy has been examined. The role of Co addition in the tungsten alloy is also considered. The grain boundary microsegregation observed at the W-W particles is also examined to assess deformation behaviour of the alloy.

EXPERIMENTAL

The tungsten alloy was prepared by liquid phase sintering process using high purity powdered elements. The green compacts were prepared by mechanical mixing of powders followed by isostatic pressing and sintering at 1500 °C in the reducing environment. The chemical composition of the alloy used in the work is presented in Table 1. The tensile tests of the specimens were carried out at strain rates of

10^{-4} and 10^{-3} , respectively. Metallographic and fractographic examination was performed on the tungsten specimens using an Olympus optical microscope and XL30 Philips scanning electron microscope (SEM) operated at 20-25 kV. Microanalysis and linescan concentration profiles were carried out by Link-ISIS energy dispersive spectroscopy (EDS).

TABLE 1 - Chemical composition of experimental alloys

Elements, nominal wt%			
Fe	Ni	Co	W
5.00	7.00	0.40	bal.

RESULTS AND DISCUSSION

a - Microstructure

Figure 1 shows an example of sintered tungsten alloy; the tungsten particles embedded in the Fe-Ni-Co matrix can be observed. The size of the tungsten particles varied between 5 and 50 μm . It is likely that Co addition may have resulted in precipitation of finer W- particles (arrow, Figure 1) in the matrix owing to reduced solubility of W in solution. Figure 2 shows EDS microanalysis of the matrix revealing the con-

centration of different elements which is consistent with the observations reported in previous work [7]. No evidence for the presence of the Fe, Ni and Co elements was found in the tungsten particles, which is in confirmation with the observations reported in previous work [4, 7]. It was also determined that the contiguity decreased with the grain size of tungsten in the alloy which is consistent with previous work [2, 7].

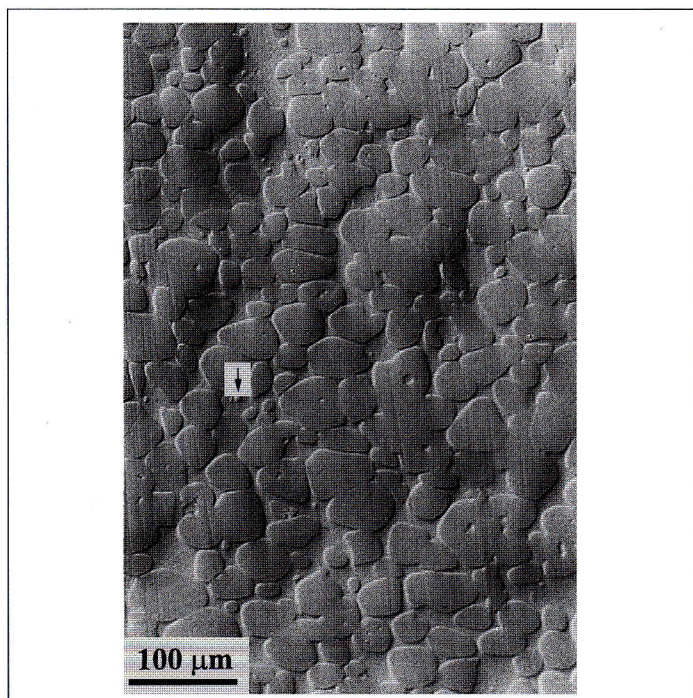


Fig. 1: Microstructure of Co-containing tungsten alloy

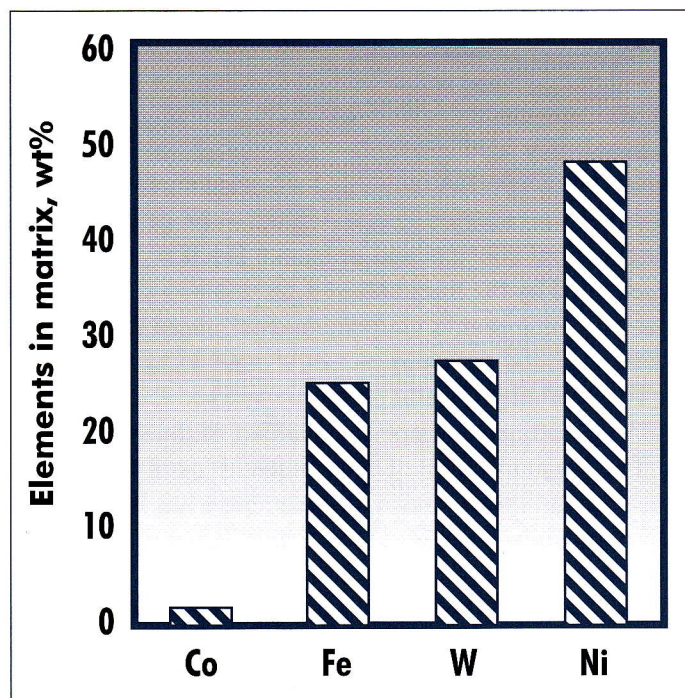


Fig. 2: Fine-probe EDS microanalysis from the matrix of the alloy

b – Mechanical Properties and Fracture behaviour

Figure 3 shows the tensile properties of tungsten alloy at different strain rates. It can be observed that the tensile strength increased with strain rate (Figure 3a) and consequently reduction in the tensile ductility was observed (Figure 3b). The change in the reduction in areas of the specimens observed is illustrated in Figure 4. The increased strength level observed in the alloy could be attributed to the finer tungsten grains that occurred as a result of Co addition in the alloy. Both the specimens exhibited intergranular

brittle fracture (Figure 5) and evidence of faceting and cleavage failure of W- particles was also observed (Figure 6). However the specimen tested at the slow strain rate revealed larger proportion of ductile fracture of the matrix as compared to the specimen tested at fast rate which is consistent with the tensile ductility. The microcracking along the W- particles in the fracture surface of the specimen tested at fast strain rate is also evident (arrow, Figure 6b) which could lead to decohesion of interfacial structure. The results of preferential cracking at the W-W particles and cleavage faceting are similar to the observations reported in previous work [9, 10].

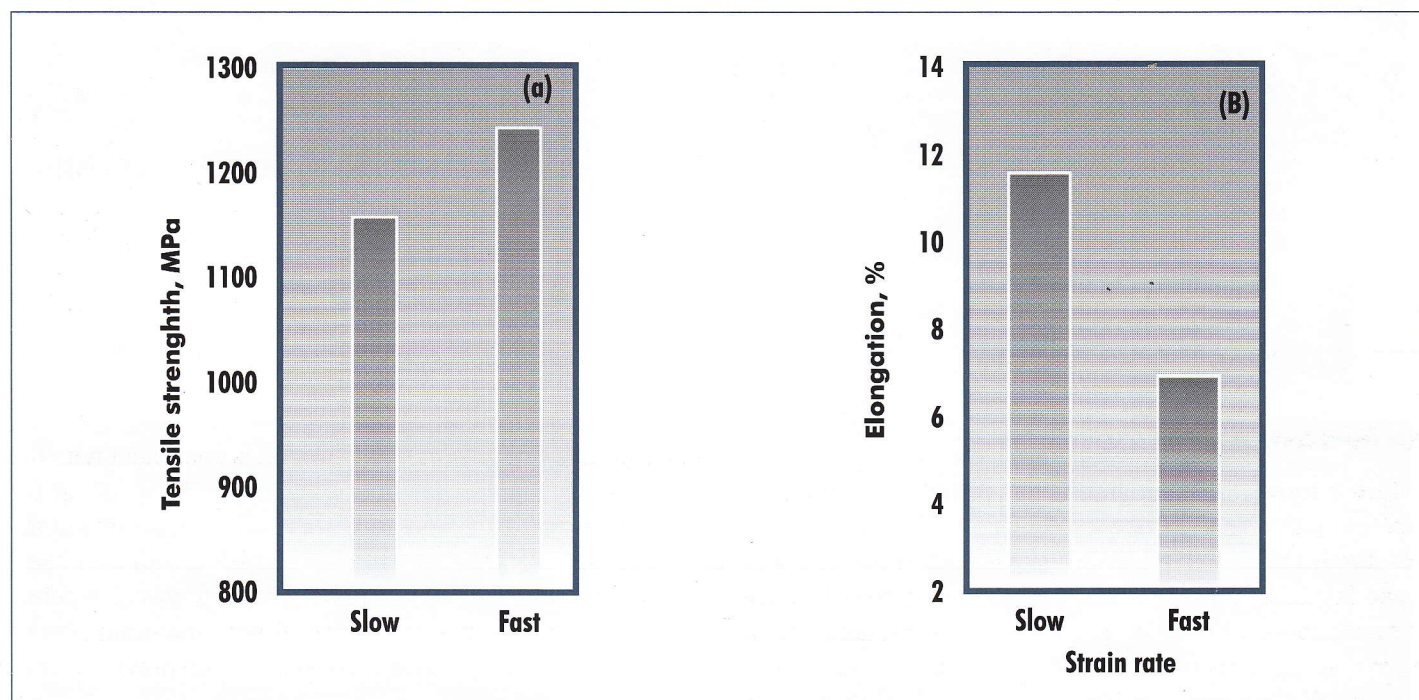


Fig. 3: Mechanical properties of alloy at slow and fast strain rates, (a) tensile strength and (b) elongation

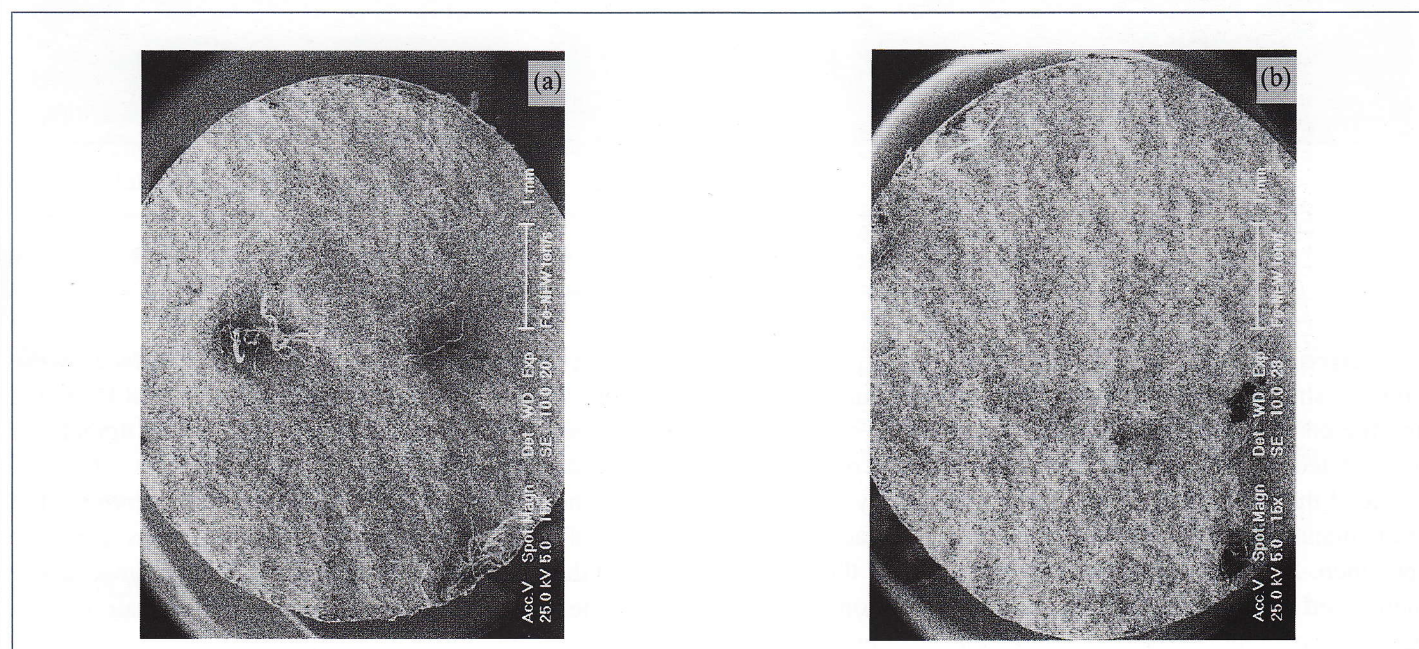


Fig. 4: Fracture surfaces of the specimens (a) slow strain rate and (b) fast strain rate

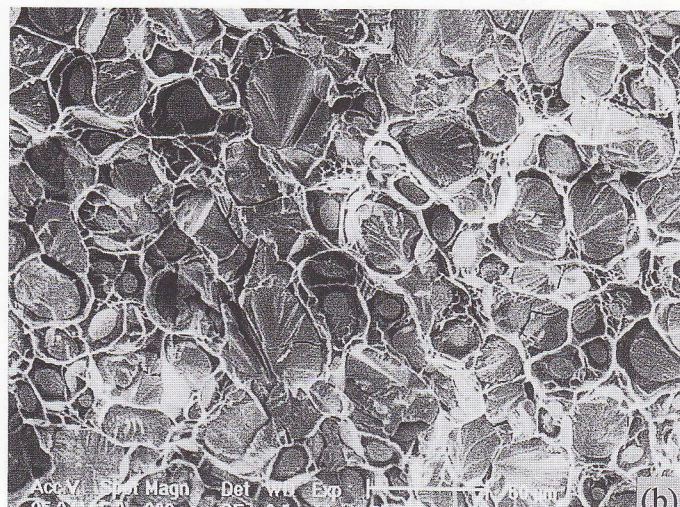
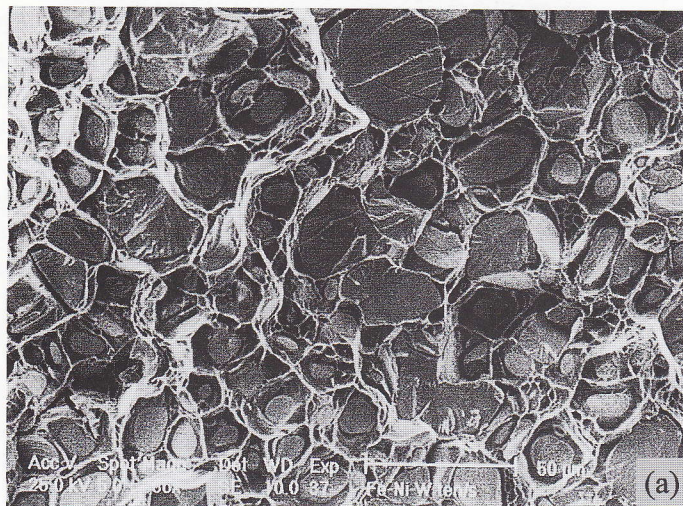


Fig. 5: Intergranular fracture of the specimens (a) slow strain rate and (b) fast strain rate

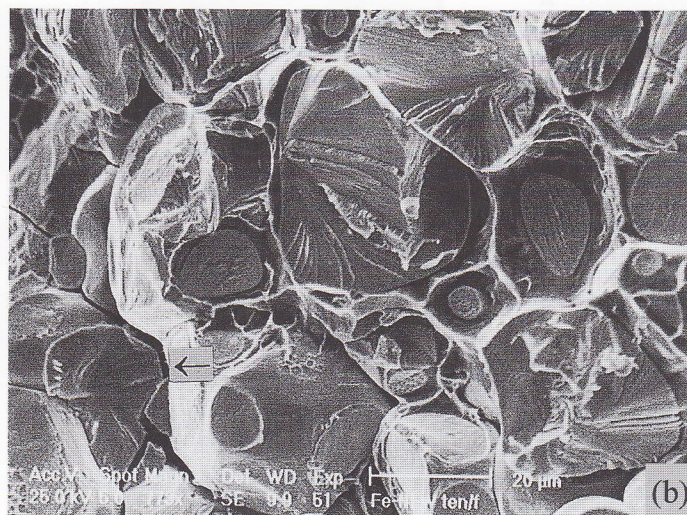
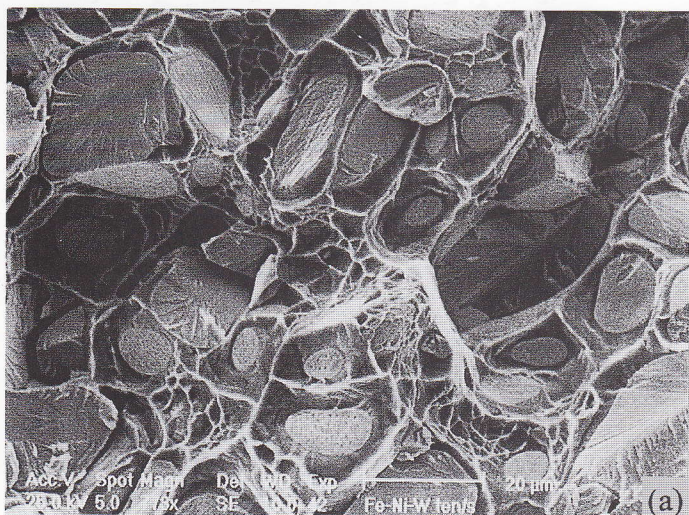


Fig. 6: Fracture surface revealing (a) faceting and ductile rupture at slow strain rate and (b) faceting and microcracking at fast strain rate

c - Segregation

Figure 7 shows SEM-linescan image of the fracture surface and the concentration profiles of elements from the specimens tested at fast strain rate. The fine-probe microanalysis revealed the presence of segregation of impurity elements at the planar W-W interfaces of the fracture surfaces of the specimen. Similar observations were found for the specimen tested at slow rate. The linescan concentration profiles have clearly demonstrated correspondence of impurity ele-

ments with the planar features of the fracture surfaces of the specimens. The microsegregation observed could affect the overall properties of tungsten alloy, which is in agreement with previous work [7].

Figure 8 shows planar filamentary features observed at the interface of W-W particles in both the specimens. It can be observed that these features are finer in the specimen tested at slow rate as compared to the fast rate. These features may have occurred as consequence of partial wetting during

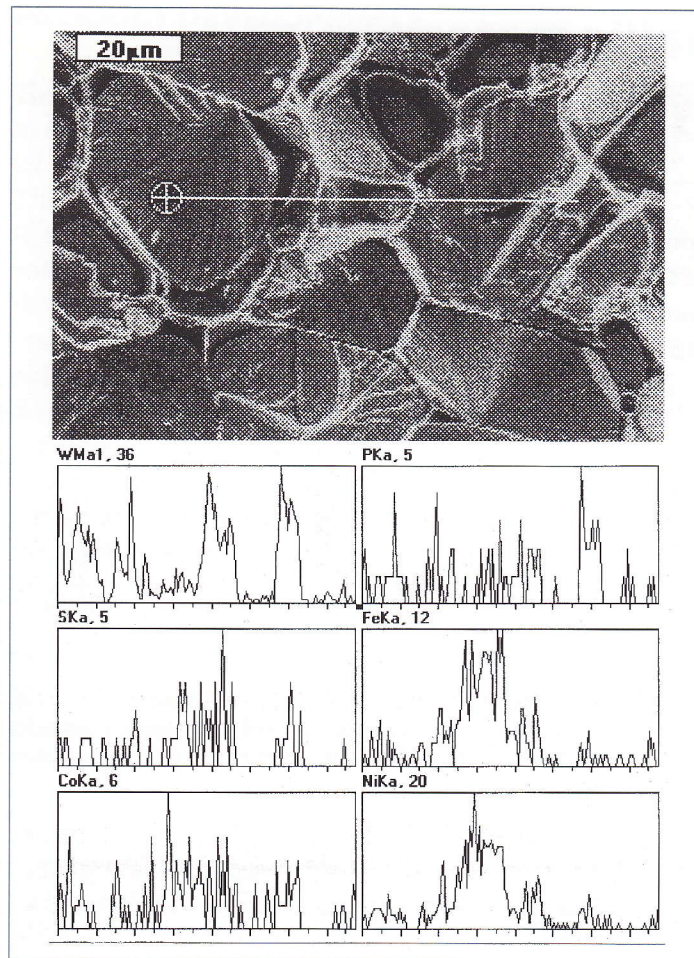


Fig. 7: SEM-linescan image and concentration profiles of elements from the fracture surface of tungsten alloy

sintering process that may have affected not only the tensile strength but also the tensile ductility of the alloy. Similar

CONCLUSIONS

The mechanical properties showed an increase in the tensile strength and decrease in the tensile ductility in the specimen tested at fast strain rate as compared to the slow strain rate. The fracture examination revealed predominantly intergranular brittle fracture in both the specimens however faceting and microcracking was evident in the specimen at fast strain rate.

The microsegregation of impurity elements was detected at the faceted regions of the fracture surface contributing towards brittle behavior of the alloy. The planar filamentary features observed in the specimens could be attributed to the partial wetting during sintering process.

ACKNOWLEDGEMENT

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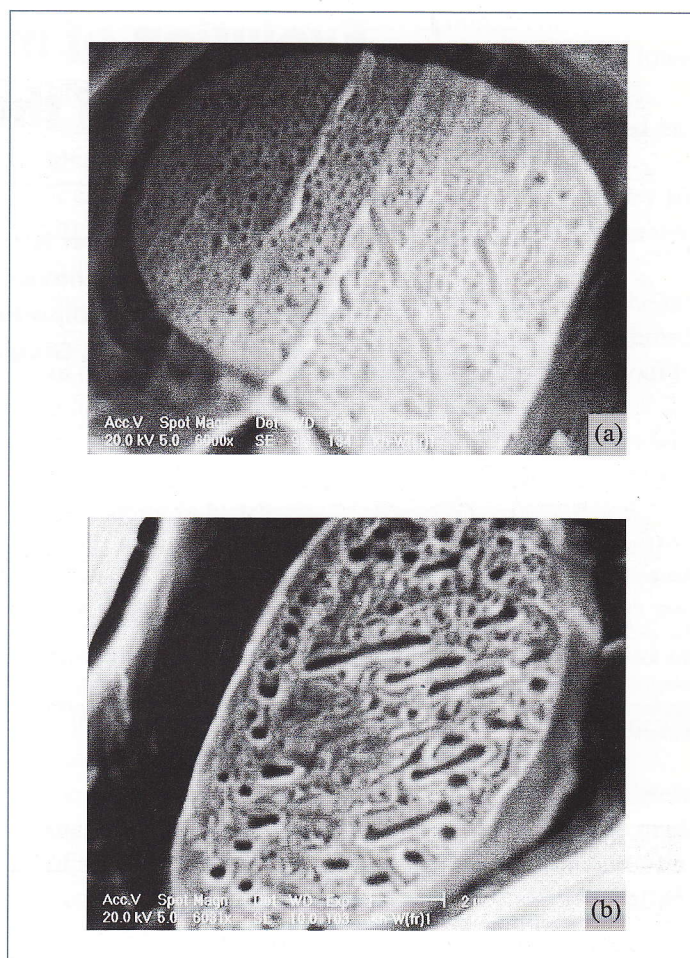


Fig. 8: SEM micrographs showing planar filamentary features in both the specimens, (a) slow strain rate and (b) fast strain rate

observations of planar filamentary features observed in tungsten alloys have been reported in previous work [11].

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