

SCALING EFFECTS ON THE DEFORMATION BEHAVIOUR OF W/Cu SINTERED COMPOSITE MATERIALS

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In order to investigate the scaling effects on the deformation behaviour of the metallic materials, sintered composites of tungsten/copper were selected. W/Cu-80/20 wt.% and W/Cu-75/25 wt.% were studied. Compression tests were carried out on different specimen's geometries under strain rates from 0.0001s^{-1} to 2000 s^{-1} at a temperature range from 20°C to 800°C . Shear tests were conducted on shear specimens as well and some tested specimens were metallographically investigated. The quasi-static flow curves were described with a material model. The mechanical behaviour of the sintered composite material W/Cu-80/20 was numerically calculated from the properties of its components W and Cu.

1 Introduction

The deformation behaviour of a metallic matrix reinforced by hard particles depends on the volume fraction, the size, the shape and the distribution of the reinforcements [1-3]. The tensile strength of the aluminium alloy 7075 reinforced with SiC particle was found [4] to increase when the particles size was $5\text{ }\mu\text{m}$ and $13\text{ }\mu\text{m}$ but with bigger particles ($60\text{ }\mu\text{m}$) the strength and the ductility was lower than the matrix alloy. Copper reinforced with 1 mm diameter tungsten wires was experimentally and theoretically investigated [4,5]. Although the behaviour of the fibre composites differ from the particles reinforced composites, it gives a light about the mutual reaction between the two phases (tungsten and copper) during the deformation process. It was found that [4,5] the arrangement and the volume fraction of the reinforcement have greatly affected the strain distribution and fracture mechanisms of the composite system. Cleveringa et al [1] have numerically investigated the effect of the particles morphology on the deformation behaviour of the particle reinforced composite materials. It was concluded that when the reinforcements block all matrix slip planes, the composite has a high strain hardening and there is a significant size effect. On the other hand, when veins of unreinforced matrix is present or clustering of the reinforcement [3], there is a yielding of the matrix followed by a decrease in the flow stress and there is no size effect.

A little work was carried out to investigate the effect of the relation between the size of the reinforcement and the size of the test specimen on the flow behaviour and fracture of the particle reinforced composites. In order to achieve that, metallic matrix (copper) reinforced with hard metallic particles (tungsten) will be tested. The volume fraction of the reinforcements and the specimens' geometry will be varied and investigated at different strain rate and temperature.

2 Test materials and experimental work

Tungsten/copper (W/Cu) sintered composite materials W/Cu-80/20 wt.% and W/Cu-75/25 wt.% with diameters of the tungsten particles of $D_p \sim 10 \mu\text{m}$ were used as testing materials. The microstructures of the studied materials are shown in Fig.1. The particles have mostly a spherical shape. Compression tests at a temperature range between room temperature and 800°C were carried out on W/Cu-80/20 and W/Cu-75/25 using specimens of a diameter $D_s/\text{height } H=1$ and different diameters of $D_s = 1, 2, 4, 6$ and 8 mm under a strain rate of 0.001 s^{-1} . Compression tests were also carried out at different strain rates of $10^{-4}, 10^{-2}, 10^0$ and $2 \times 10^3 \text{ s}^{-1}$ at room temperature. Shear tests were conducted on a cylindrical shear specimens [6] (Fig.2) at $20^\circ\text{C}, 400^\circ\text{C}$ and 800°C under strain rates of $0.01 \text{ s}^{-1}, 1.0 \text{ s}^{-1}, 100 \text{ s}^{-1}$. The tested specimens were metallographically investigated to show the fracture behaviour of the studied materials.

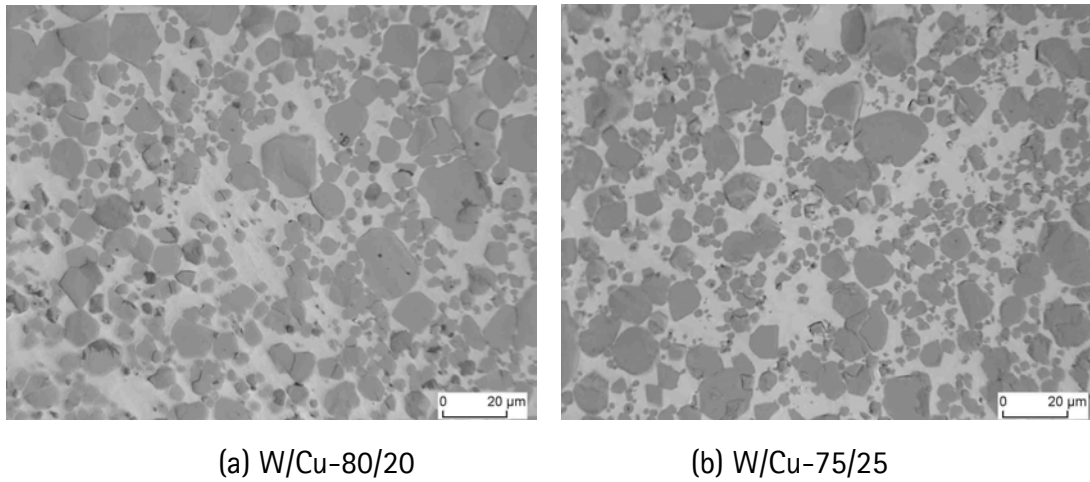


Fig.1: Microstructure of the investigated W/Cu sintered composite materials ($D_p \sim 10 \mu\text{m}$).

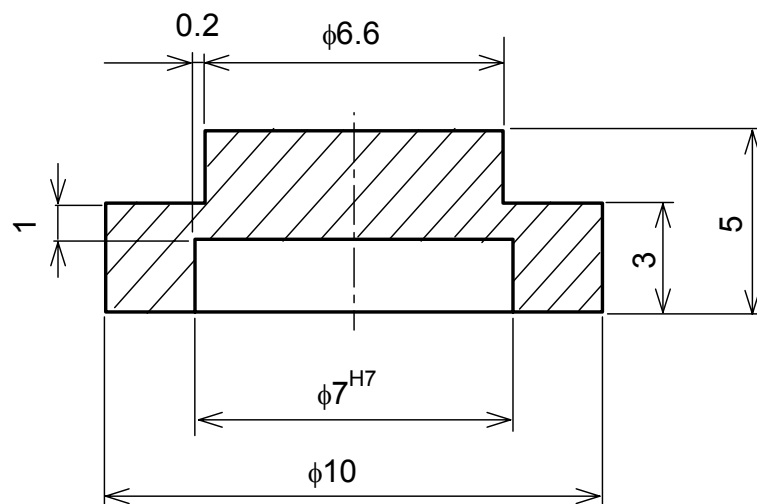


Fig.2: Cylindrical shear specimen [6].

3 Results and discussion

3.1 Scaling effects at different temperatures

A clear size effect on the flow curves was shown on testing of the sintered material W/Cu-80/20 in compression at the temperatures range from the room temperature to 800°C (Fig.3.a). A gradual increase of the flow stress was noticed with decreasing the size of the specimens of W/Cu-80/20. A slight scaling dependence of the flow curves was noticed on quasi-static compression testing of W/Cu-75/25 (Fig.3.b), particularly at temperatures higher than 200°C. The flow stress lowers with increasing the temperature.

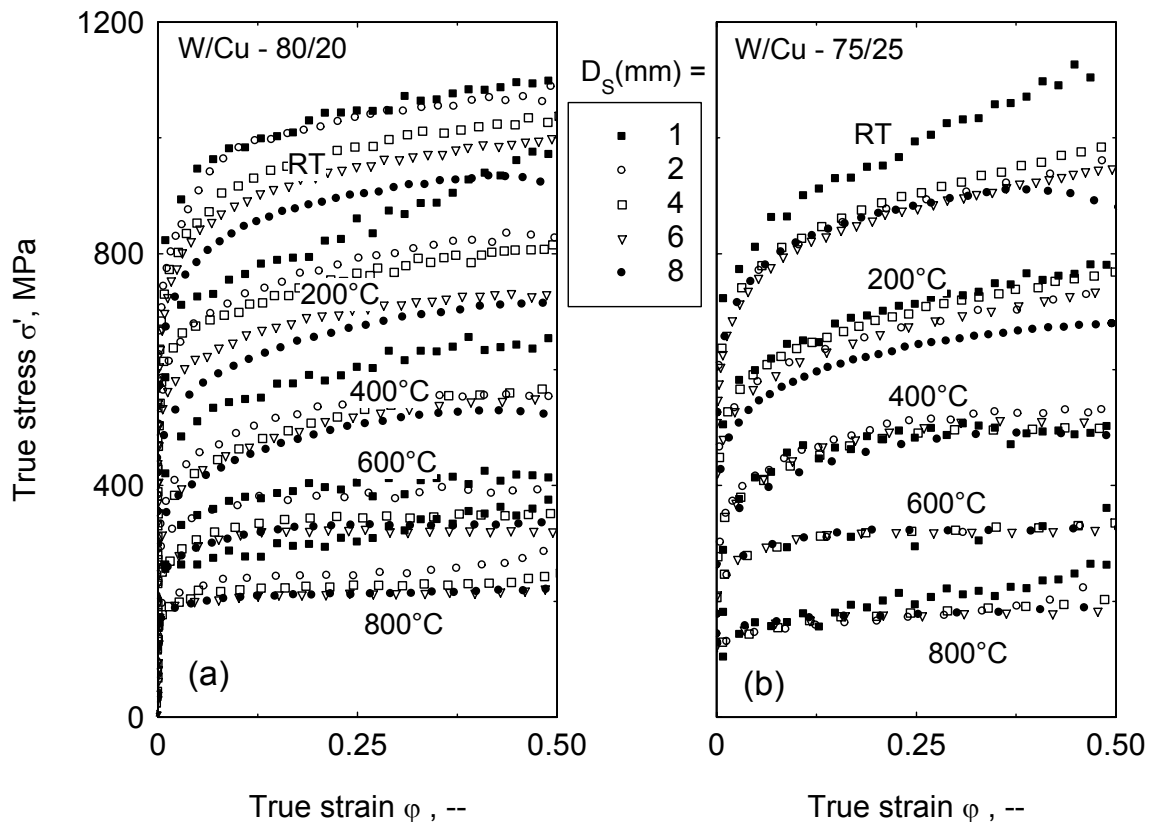


Fig.3: Flow curves of (a) W/Cu-80/20 and (b) W/Cu-75/25 under strain rate of $0.001s^{-1}$ at different temperatures.

The flow stress at different compression degrees and different temperatures is represented as a function of the ration of the specimen diameter (D_S) to the particle diameter (D_P) (Fig.4.). A clear scaling dependence can be shown in W/Cu-80/20 (Fig.3.a and Fig.4.a). This effect decreases to some degree at higher temperatures due the enhancement of the recrystallization process of the matrix at higher temperatures and strains [4]. The lower stress level in the bigger specimens of W/Cu-80/20, especially at higher temperatures, could be related to the higher probability of occurring veins or zones poor of the reinforcement. Theses zones develop an easier yielding in the matrix and non-homogeneous deformation which decreases the overall strain hardening [1]. This can interpret the insignificant scaling dependence of the composite material W/Cu-75/25 that has a less volume fraction of the reinforcement (0.58 W) than W/Cu-80/20 (0.65 W).

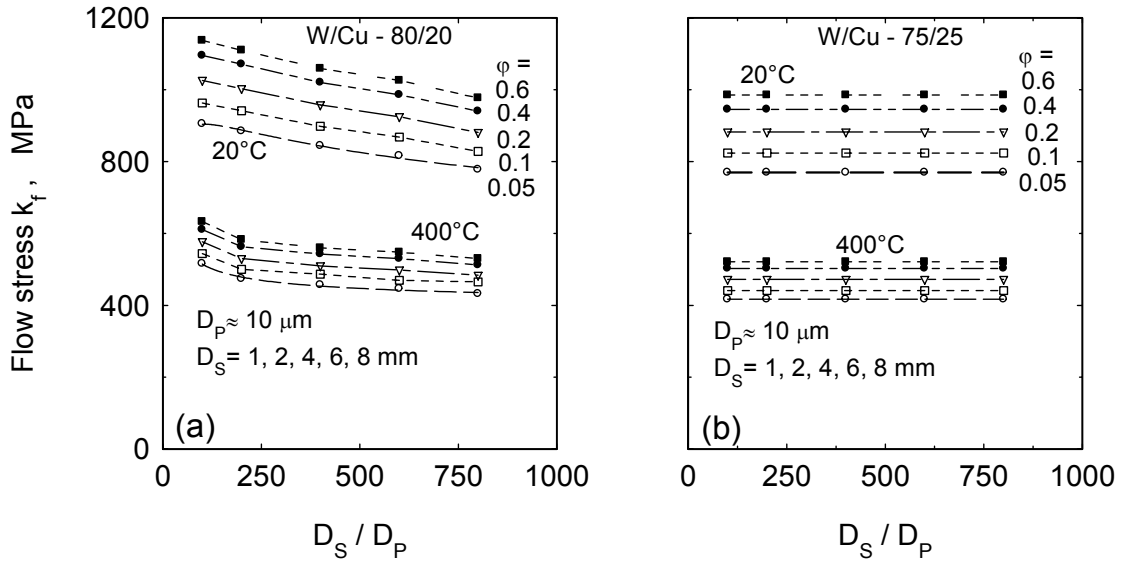


Fig.4: Flow stress as a function of the ratio of the specimens diameter (D_S) to the tungsten particle diameter (D_P) of (a) W/Cu-80/20 and (b) W/Cu-75/25 at different compression degrees and temperatures.

3.2 Scaling effects at different strain rates

On deformation of metallic materials at high strain rates the flow stress increases obviously [7-8]. The specimen's size effect on the flow stress at higher strain rates was noticeable, especially for W/Cu-75/25 (Fig. 5.c,d). It could be related to the hardening effect of the matrix at higher strain rates deformation (2000 s^{-1}), particularly at lower degrees of deformation (up to $\phi \sim 0.15$).

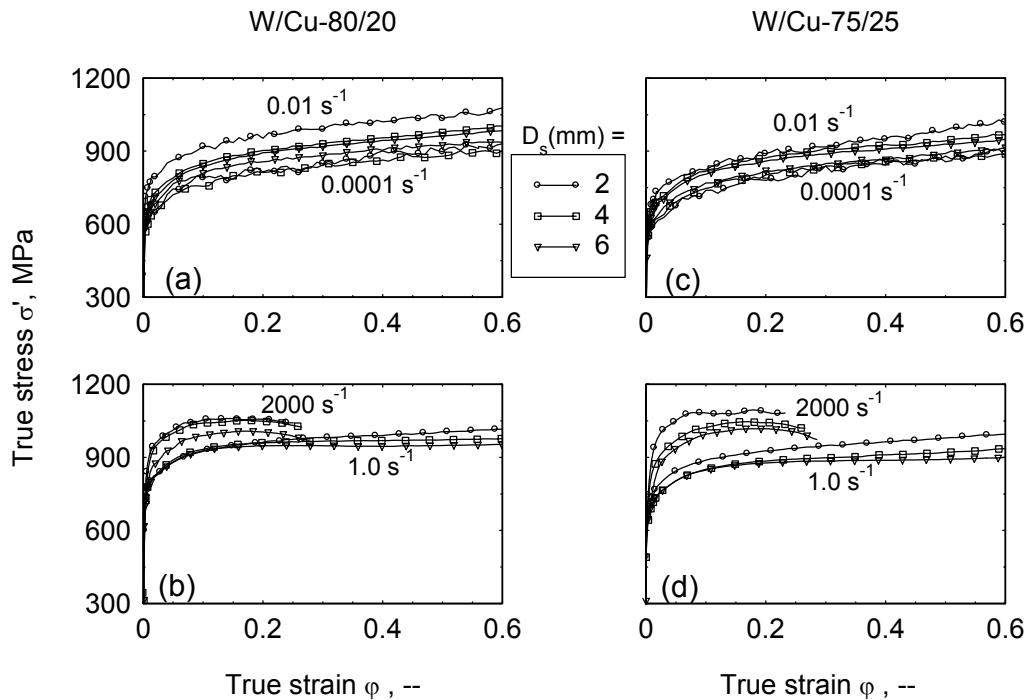


Fig. 5: Specimens' size effect on the flow curves of W/Cu-80/20 and W/Cu-75/25 on compression under strain rates of 0.0001, 0.01, 1.0 and 2000 s^{-1} at room temperature.

3.3 Results of the shear tests

The deformation localization in the shear zone has also appeared the strain rate sensitivity of the sintered W/Cu materials (Fig. 6.a, b). The shear strain at fracture increases with the temperature.

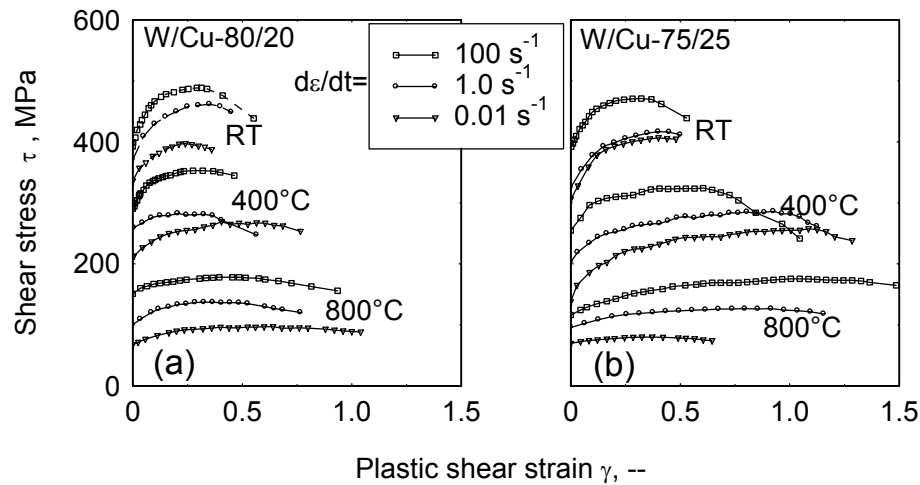


Fig. 6: Shear stress - plastic shear strain curves of (a) W/Cu-80/20 and (b) W/Cu-75/25 under strain rates of 0.01 s^{-1} , 1.0 s^{-1} , 100 s^{-1} at temperatures of 20°C , 400°C and 800°C .

Analyzing the fracture of the shear specimens led to the conclusion that under most testing conditions the cracks initiate by interfacial debonding and grow through the copper matrix especially at high temperatures (Fig. 7.b). At room temperature a mixed mode between particle fracture and interfacial decohesion was observed (Fig. 7.a). The competition between two damage mechanisms is controlled by which critical stress (i.e. interfacial debonding stress or particle fracture stress) is first obtained [4].

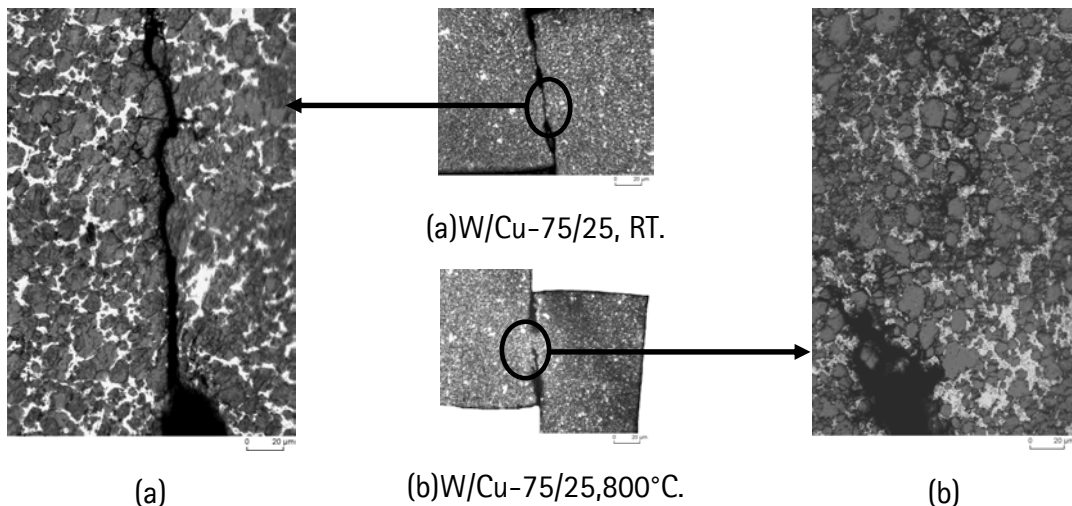


Fig. 7: Fracture of the shear specimens at 20°C and 800°C under strain rate of 0.01 s^{-1} .

4 Modelling of the materials behaviour

The flow curves of the composite materials W/Cu-80/20 and W/Cu-75/25 under quasi-static (0.001 s^{-1}) compression loading were described with the material law from Swift [9]:

$$\sigma_f = k(B + \varepsilon)^n \quad (\text{Eq. 1})$$

where: B is a constant, K and n are temperature dependant material parameters. A value of $B = 0.001$ was found to be suitable for the tested materials at the whole test temperatures. The flow curves of the material W/Cu-80/20 were described for every specimen size Fig. 8.a. But due to the nearly similar behaviour of the different sizes of the specimens of W/Cu-75/25 at the same temperature (Fig. 8.b), the flow curves were described by only one curve for all the specimen sizes.

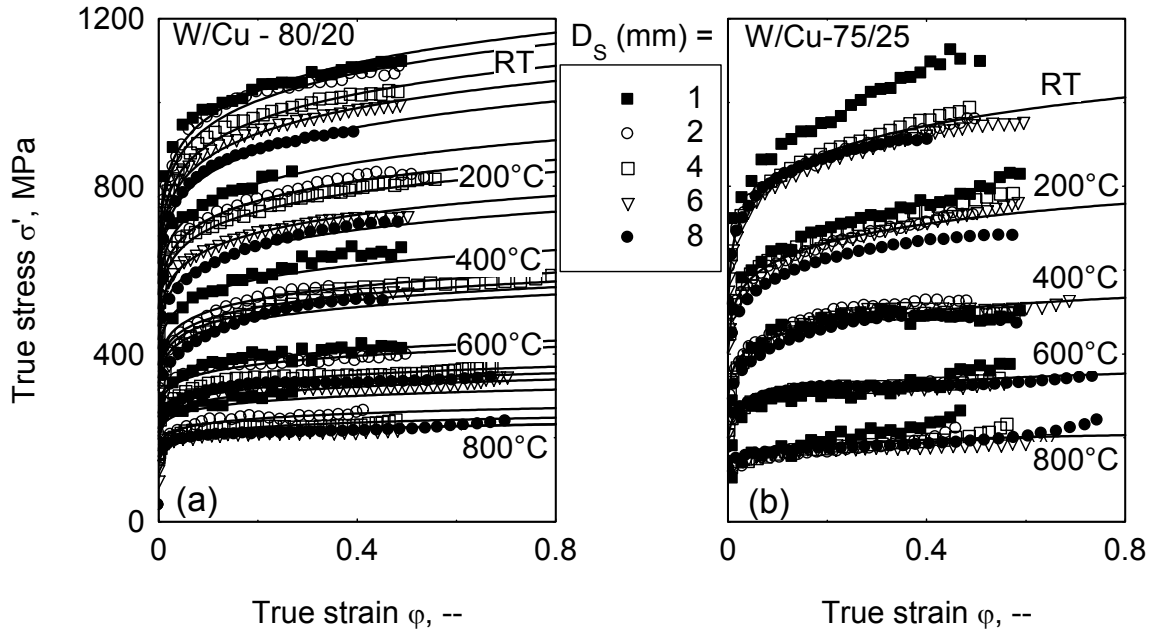


Fig. 8: Description of the quasi-static flow curves of the composite materials (a) W/Cu-80/20 and (b) W/Cu-75/25.

The temperature dependence of the parameter k can be described by a second degree polynomial (Fig. 9.a, b), while the parameter n shows linear temperature dependence (Fig. 9.c).

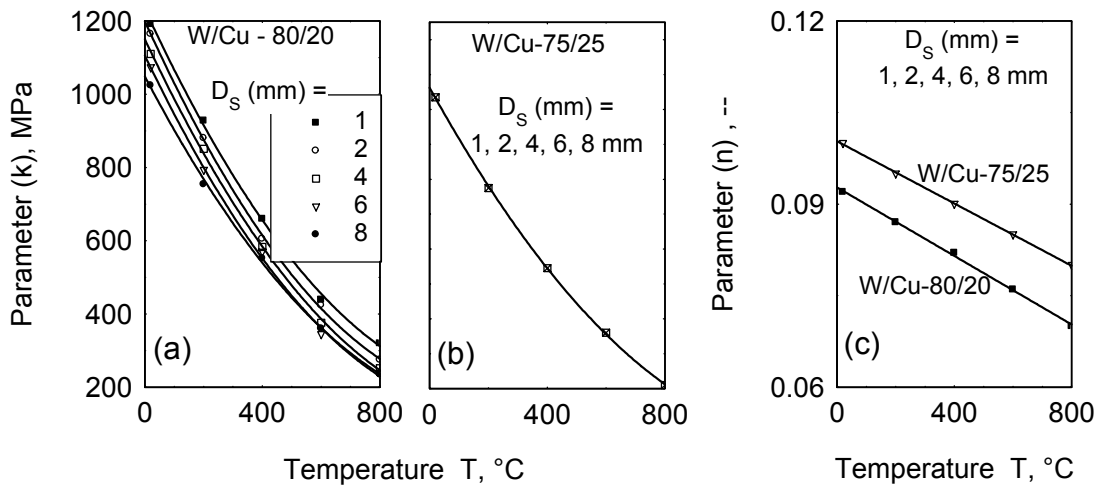


Fig. 9: Material parameters k (a,b) and n (c) as a function of the temperature of the composite materials W/Cu-80/20 and W/Cu-75/25.

Finite element computation

The nominal stress-strain curve at room temperature of the sintered composite W/Cu-80/20 was computed using the properties of the composite components with the commercial Finite Element program (ABAQUS-Standard). The material parameters (Eq.1) were determined from the flow curves of pure tungsten and oxygen-free copper for electronic purposes (SE-Cu) under quasi-static compression tests at room temperature and the elastic properties from [10]. They are for SE-copper: $k = 492\text{MPa}$, $B = 0.001$, $n = 0.415$, $E = 110\text{GPa}$, $\nu = 0.35$ and for tungsten: $k = 1398\text{MPa}$, $B = 0.01$, $n = 0.0414$, $E = 400\text{GPa}$, $\nu = 0.28$. A simple 3D-model like the BCC unit cell was suggested with the volume fraction W/Cu (0.65/0.35) corresponding to the composite W/Cu-80/20 wt.% with tungsten particle diameter of $10\mu\text{m}$. This unit cell 3-D model was found through many trials with 2D-models and from the other works [11] to deliver a more consistent results with the experimental one. Fig. 10.a shows that the finite element result is comparable with the experimental compression stress-strain curve of the composites W/Cu-80/20 ($D_s=1\text{ mm}$). The equivalent stress distribution (Fig. 10.b) shows that the tungsten particles are carrying the main part of the stresses. It is shown also that the matrix is highly stressed at narrow regions between the adjacent tungsten particles. These regions are subjected to the highest strain (Fig. 10.c).

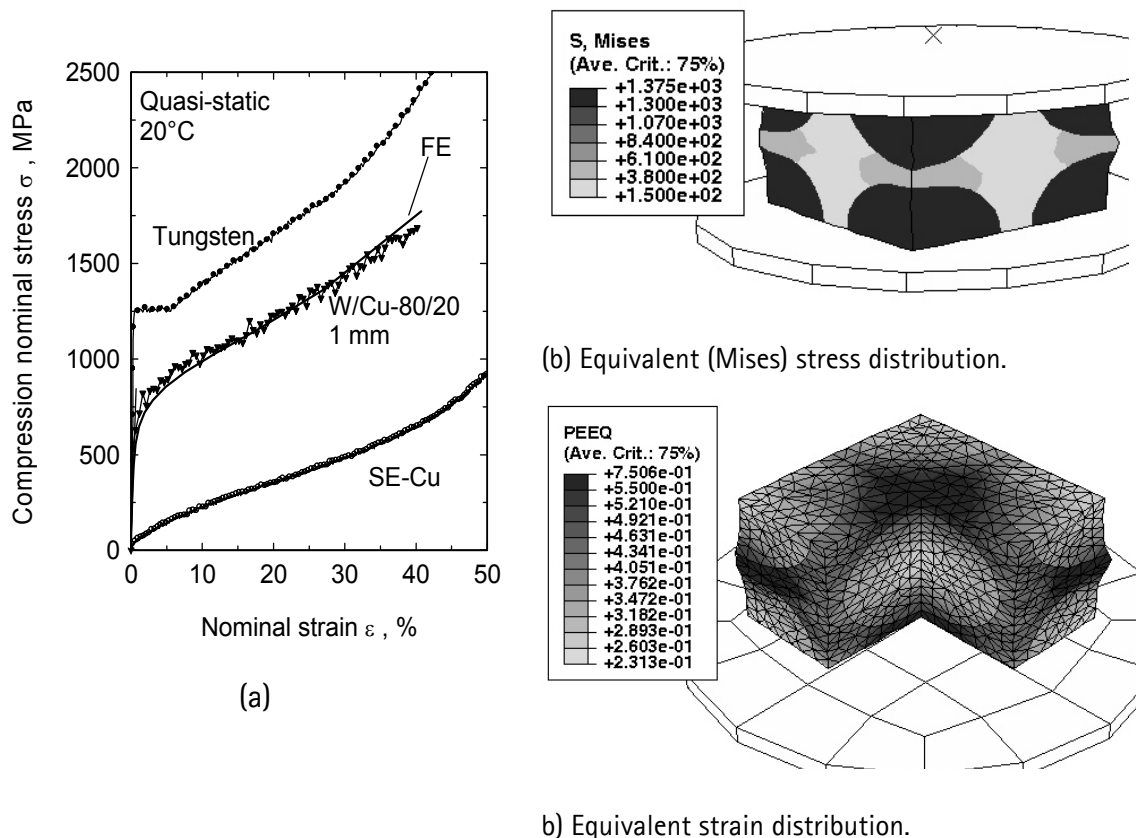


Fig. 10: Results of the finite element calculation of the composite model of W/Cu-80/20 compared with the experimental compression stress-strain curves of the specimen of 1mm diameter and the composite components (W) and (Cu) at 20°C.

5 Conclusion

The sintered composite material W/Cu-80/20 has an obvious scaling effect on the flow behaviour, while W/Cu-75/25 does not show a clear scaling effect, particularly at low strain rates. The specimens' size effect of the tested materials becomes higher by deformation under higher strain rates. A mixed mode of fracture from interfacial decohesion and particle fracture was observed at room temperature under localised deformation. The flow behaviour under quasi-static compression was good described by the material law from Swift. The nominal stress-strain curve of the sintered composite materials has numerically determined from the properties of the composite components. The computational result was in consistence with the experimental one.

6 References

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