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Impact Bending Tests on Selected Tungsten Materials

Different tungsten rod and plate materials (W, 2 grades of WL10, WVM, WL10 with 1% Re) as well as TZM from Plansee were used for Charpy tests with standard specimens of KLST type. The according microstructures are compiled in Fig. 1. The test results of the rod materials are shown in Fig. 2. It can be clearly seen that only TZM shows the classical embrittlement behaviour which is typical for most body-centred cubic structured metals: (1) there is a clear transition from brittle (at lower temperatures) to ductile (at higher temperatures) fracture (→ DBTT), and (2) there is an extended regime of ductile fracture (area of almost constant energy → upper shelf). Compared to TZM, the results of the tungsten materials look quite different. Only specimens of pure tungsten show an upper shelf starting at 900 °C. Potassium doped tungsten seems just to reach the upper shelf at 900 °C. But all other rod materials don't show ductile fracture within the whole test temperature range. However, all tested materials tend to brittle fracture at temperatures below 500 °C. But above that temperature, the specimens show cleavage fractures which propagate along the former rod axis, that is, parallel to the specimen's long side and perpendicular to the notch (see Fig. 3). In summary, there are three types of fractures (brittle, cleavage, ductile) which are linked by a brittle-to-cleavage transition and a cleavage-to-ductile transition. The brittle-to-cleavage transition temperature (defined in analogy to the DBTT) varies around 500 °C for all tungsten materials while the cleavage-to-ductile transition temperature is about 900 °C for tungsten and about 1000 °C for the potassium doped tungsten (see Fig. 2).

Compared to the rod materials the Charpy tests with the specimens of the plates reveal two trends (see Fig. 4): (1) the energies are lower by more than 50 %, and (2) there is a smaller but still significant difference in the specimen's orientation (parallel or perpendicular to rolling direction). However, the later result is not surprising since the plates were not cross rolled, i.e. direction was not changed frequently during production. Therefore, a distinct anisotropy of the microstructure can be expected. A reasonable explanation for the severe reduction of charpy energy might also be found in the plate microstructure (Fig. 5) and, as a result, a specific fracture type which is called delamination (Fig. 6).

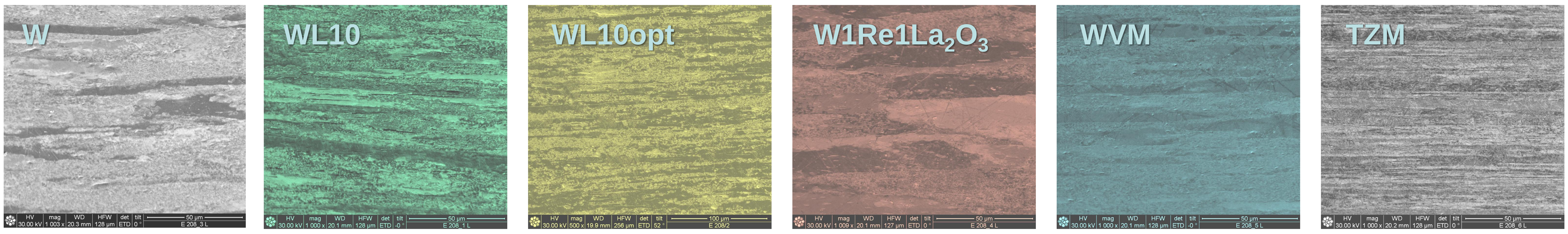

Fig. 1: Microstructure of the different rod materials (longitudinal cross-sections).

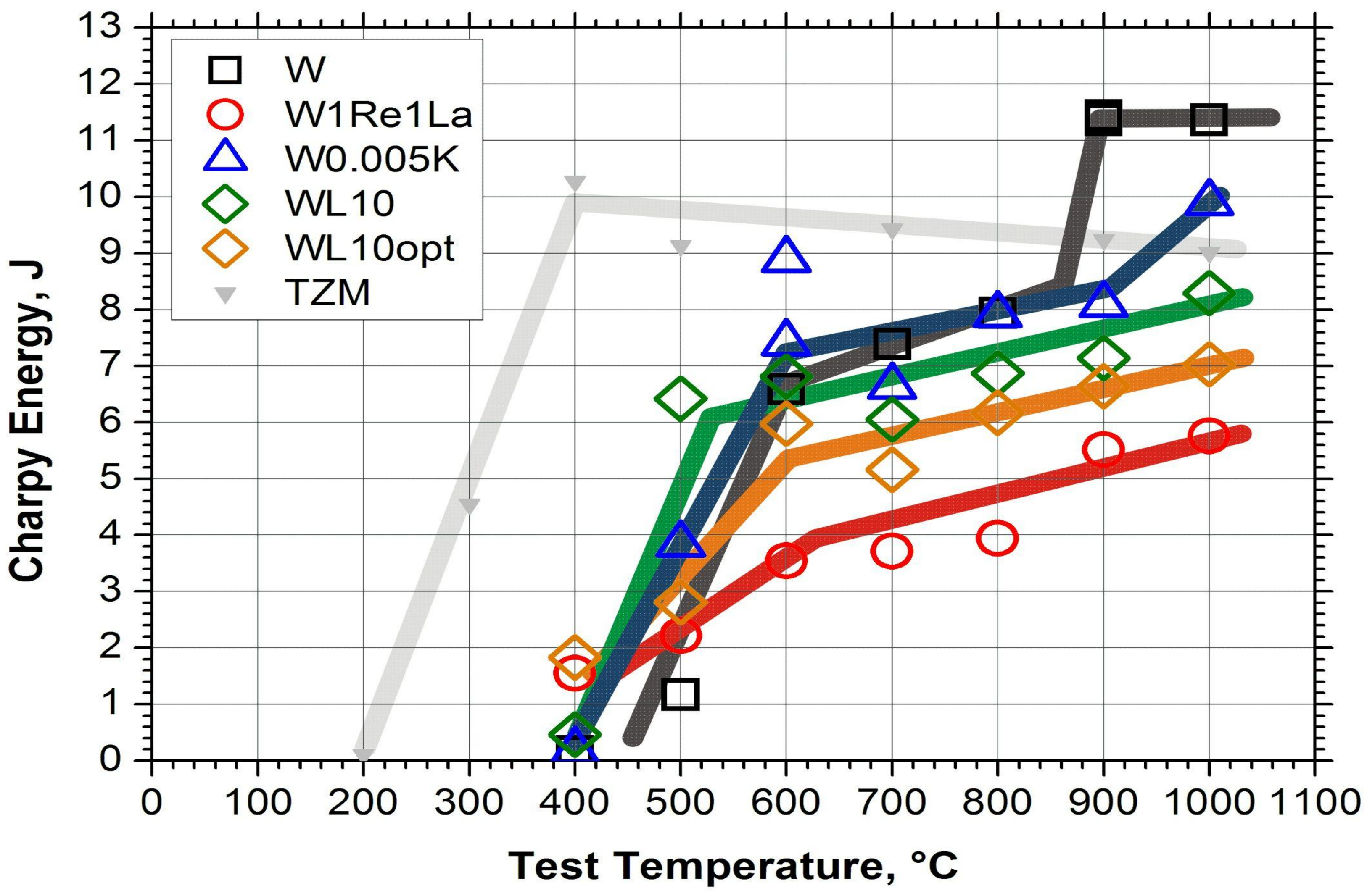

Fig. 2: Charpy test results of the rod materials. Between 400 °C and 600 °C there is a transition from brittle to cleavage fracture. Only pure tungsten and WVM shows a second transition at about 900 °C to ductile fracture.

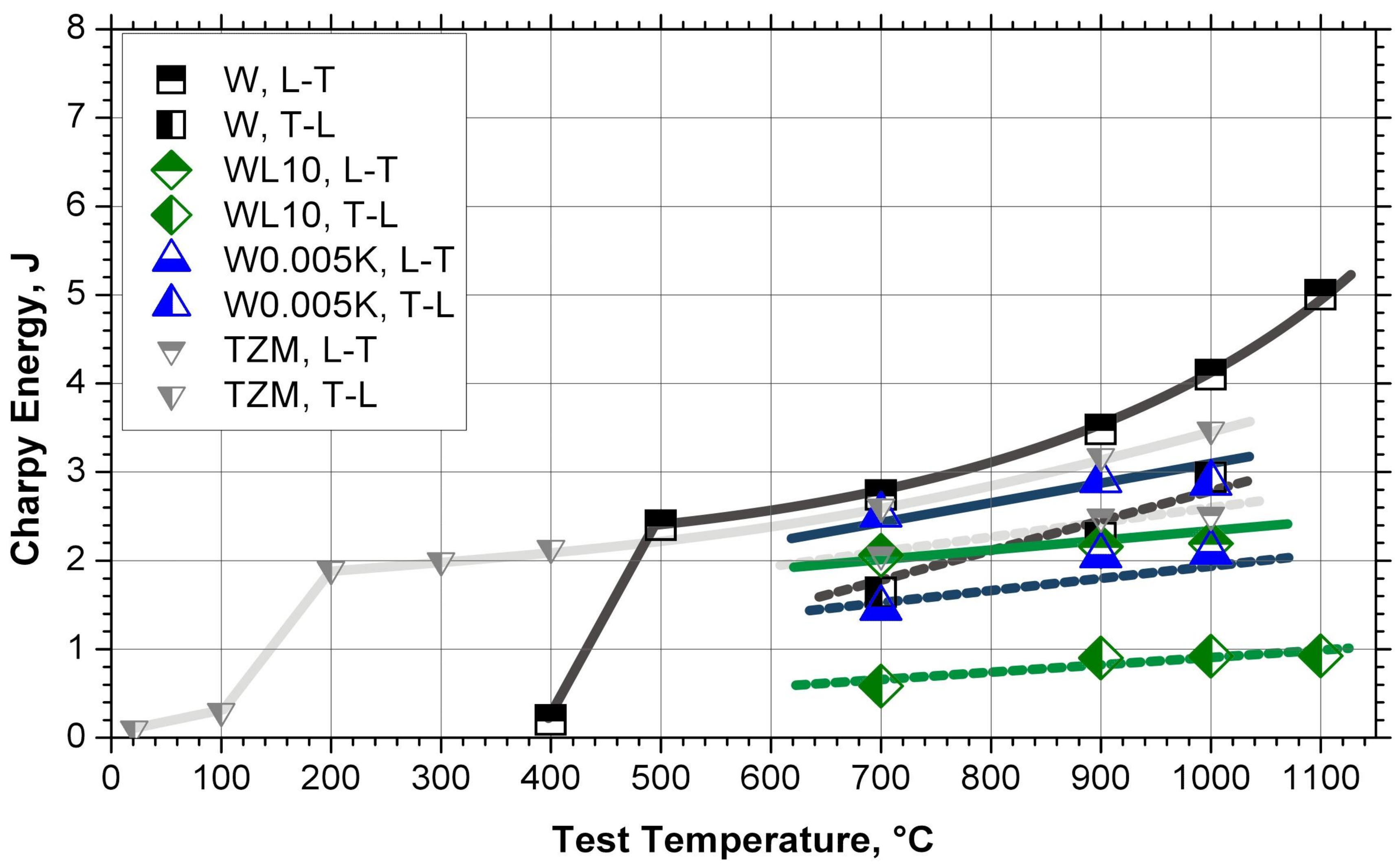

Fig. 4: Charpy test results of the plate materials (L-T: longitudinal, T-L: transverse to rolling direction).

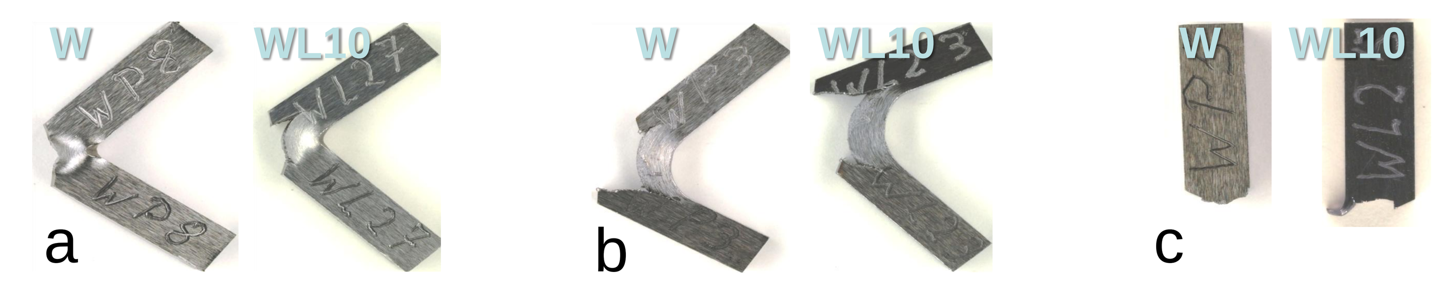

Fig. 3: Fractured specimens of pure tungsten and WL10 at:
(a) 900 °C, (b) 600 °C, and (c) 400 °C.

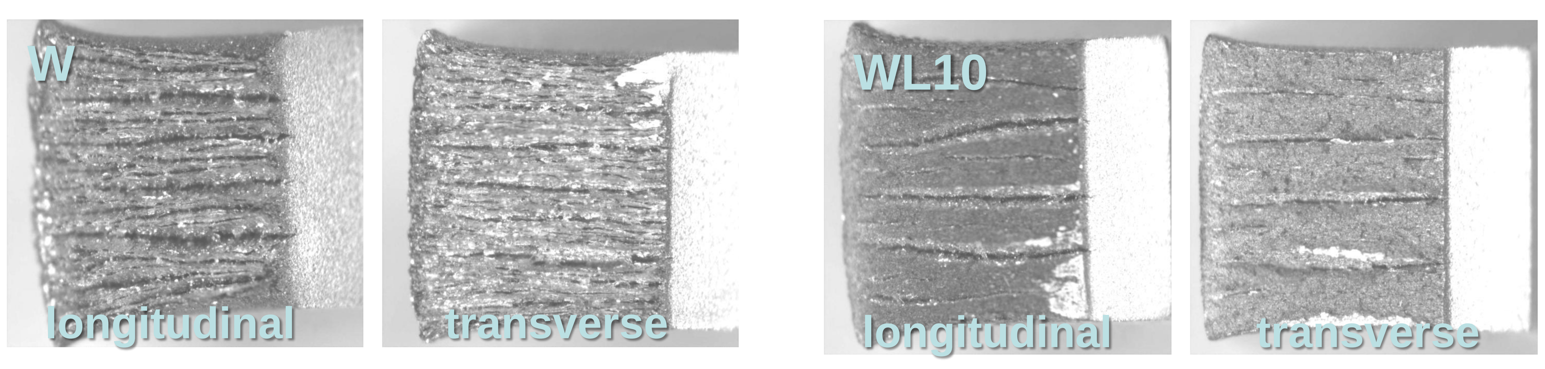

Fig. 6: At 900 °C delaminated fracture surfaces of typical plate specimens.

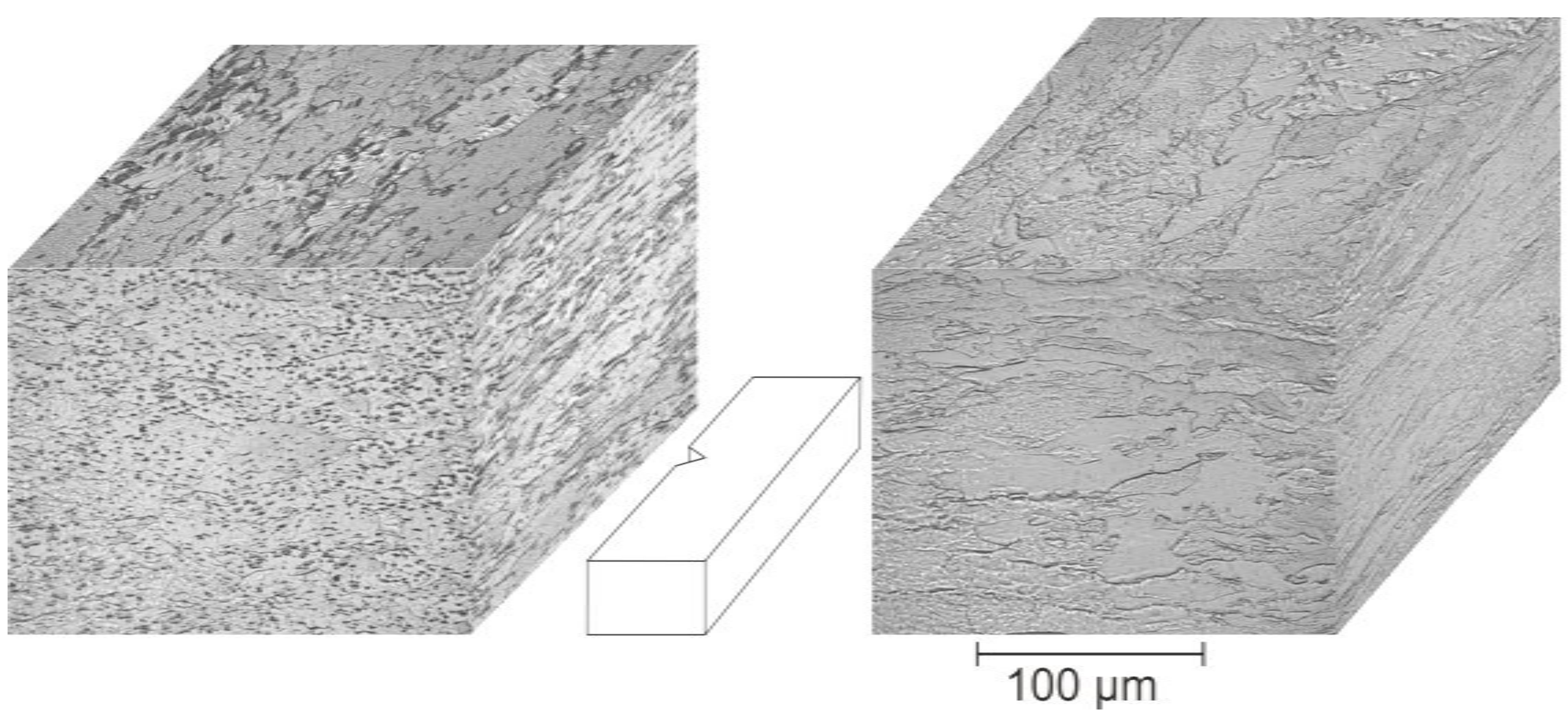

Fig. 5: Microstructure of tungsten and WL10 plates. The L-T specimen orientation is also illustrated.