FRACTOGRAPHICAL INVESTIGATION OF FRACTURE MECHANISMS OF NaCl SINGLE CRYSTALS UNDERGOING A BRITTLE-DUCTILE TRANSITION

V.I.Betekhtin, A.N.Bakhtibaev, A.D.Vasilev, *
D.A.Imanbekov, V.V.Kovylyaev, S.A.Firstov

Tensile strength,plasticity and fracture mechanisms of Nacl single crystals were investigaded at transition from brittle state into ductile one. It was found that cleavage as the mechanisms of fracture is valid at temperatures up to 0,85 T_{melt} . At temperatures above 0,4 T_{melt} the cleavage is proceded by the dimple-like ductile fracture that is formed due to the intercellular nucleation of pores, their growth and coalescence, as well as intercellular delaminations and slidings. At temperatures above 0,8 T_{melt} NaCl goes into the superplastic state fracturing by the intergranular sliding.

INTRODUCTION

Investigation of mechanical properties and fracture mechanisms of ceramic materials over the wide temperature range of the brittle-ductile transition is an important problem both from theoretical and practical points of view.

Due to some difficulties in preparation of sample for mechanical tests from ceramic materials, most researchers use only three and four-points bending tests (TPB and FPB tests).These methods give sufficient results only at the relatively low test temperatures, but do not allow to investigate mechanical properties and fracture mechanisms in the temperature range where a considerable plastic deformation preceding fracture takes place due to brittle-ductile transition. A great number of ceramic materials has rather high melting temperatures, T_{melt} .For this reason studies of fracture mechanisms are complicated,since both special high-temperature furnaces and special equipment for mechanical tests are needed.

* Frantsevich Institute for Problems of Material Science, Krjijanovskogo str., 3, Kiev 252680, U.S.S.R.

The main purpose of the work done was to study fracture mechanisms of NaCl chosen as to model a low-melting ceramic material under uniaxial tension.

MATERIALS AND METHODS

In the present investigation NaCl single crystals have been chosen as a model material. Uniaxial tensile tests were carried out in vacuum chamber (pressure 100 Pa)in the temperature range from 77K (0.1 T_{melt}) to 953K (0.9 T_{melt}). This temperature interval covers brittle,combined brittle-ductile and ductile types of fracture.

Sample 3x5x50 mm were cleaved from large NaCl single crystals along [100] crystallographic planes.They were not subjected to any additional treatment before mechanical tests.

Fracture mechanisms were studied with the scannig electron microscope "Superprobe - 733" (JEOL).

RESULTS AND THEIR DISCUSSION

As may be seen from Fig.1 (curve 2), fracture stress is practically constant in the temperature range 0.1 - 0.3 T_{melt} ,that increases between 0.3-0.5 T_{melt} showing an rather abrupt maximum, and gradually decreases under the further temperature increase. Tensile elongation increases noticeably at temperature more than 0.4 T_{melt} and reaches 130%. This value of deformation is kept practically constant up to 0.85 T_{melt} and then rock salt exhibits superplastic behaviour when elongation before fracture has exceeded 200%.

SEM fractographs of samples fractured at different temperatures has clarified the reasons for fracture and showed the mechanisms of it in temperature ranges of brittle, ductile and combined modes of fracture.

When temperature of loading is less 0.4 T_{melt} (430K),fracture is not preceded with noticeable plastic deformation.Fracture mode is cleavage, sources of fracture are surface defects, mainly located on its edges. This temperature range may be defined as the region of brittle fracture.

At temperature above 0,4T_{melt} fracture is preceded with substantial plastic deformation, as can be seen from Fig. 1 (curve 2). Samples are narrowed "as knife" but cleave as in case of brittle fracture (Fig.2).

When temperature is risen above 0.8 T_{melt} (873K)rock salt becomes superplastic under the given loading rate. Misoriented cellular structure is formed in the neck of the sample transforming singe crystal into polycrystalline material with grain size of 2 - 5 μm. Fracture by cleavage in this temperature interval is preceded with the fracture along the boundaries of the above described new structural elements, that as a matter of fact is the intergranular fracture (Fig.3).Relative part of this type of fracture increases gradually displacing the cleavage with the temperature rise. Nevertheless the cleavage was observed even under the highest test temperature 923K (0.85 T_{melt}).

Stereoscopic observation of part of intergranular fracture (Fig.3) shows that pores are contained in it, being elongated along the grain boundaries. These pores are not equal-sized across the transverse section. The size of pores decreases as moving away from the center of sample.

In fact,according to all morphological features the concerned intergranular fracture is a dimpled one, being the result of nucleation of pores and their subsequent growth and coalescence. These pores are nucleated at the grain boundaries as were shown by Vasilev at al (1) and Wilsdorf (2), appropriate grains being the result of trasformation of dislocation cells due to high temperature more then 0.8 T_{melt} and large deformation more then 100% . Pores result from formation of both misfit steps onto the boundaries when slip passes from one cell to another as Ribin et al have shown (3), and also of wedge-like craks of intergranular sliding, favored by intergranular diffusion.

Thus, the transition of rock salt single crystals from brittle state into ductile one occurs over the wide temperature range. The lower limit of the brittle-ductile transition named T^{L}_{bd} lies near 0.4 T_{melt} at given loading rate. The mechanism of ductile fracture is the intergranular (intercellular) sliding. Under uniaxial tension the latter together with tri-axial stressed state in the sample neck produces the specific dimple fracture surface looking like that in metals. Moreover, pores, the growth and coalescence of which result in formation of ductile fracture surface, have nucleated as in metals along boundaries of cells and grains. This process is complicated by diffusion.

When temperature exceeds 0.8 T_{melt} the superplasticity takes place in the rock salt.

REFERENCES

(1) Vasilev, A.D., Malashenko, J.S., Trefilov, V.I. et al. Phys. met. and Met. Sci., 1977, Vol.43, No3, pp.640-664, in Russian.

(2) Wilsdorf, H.C.F., Krist.und Techn., 1979, Vol.14, No 12, pp. 1265-1274.

(3) Ribin, V.V.,Polyectov, Yu,N., Likhachov, V.A. et al, Phys. Met. and Met.Sci., 1973, Vol.35,No.4, pp. 993-998, in Russian.

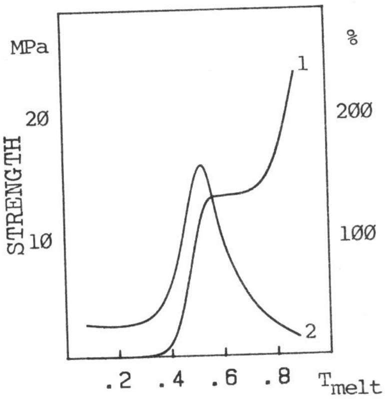

Figure 1. Elongation (1) and strength (2) vs temperature

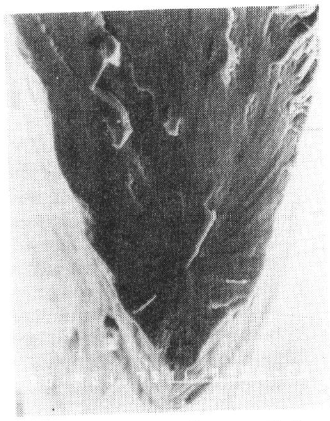

Figure 2. SEM view of fracture by cleavage of NaCl at 0.4 T_{melt}

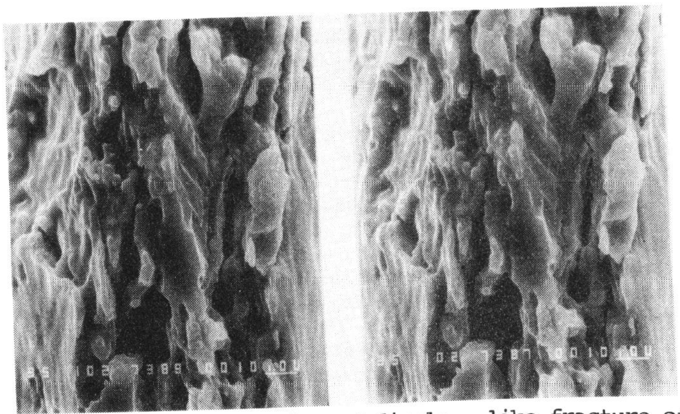

Figure 3. SEM stereoscopic view of dimple - like fracture of [100] NaCl single crystal at 0.85 T_{melt}