A THERMOMECHANICAL ASPECT OF THE CERAMIC-CAPPED PISTON OF HYPOTHETICAL ADIABATIC DIESEL ENGINE

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Abstract

The paper concerns a hypothetical Al.-alloy piston coated (capped) first by labradore and then capped by YSZ. The labradore, a member of the feldspar group is deemed thermal-shock resistant, the YSZ(PSZ) can be shock-resistant, but the outcome of the two with the Al.-alloy is not known. The analysis were made in two ways by ANSYS 10.0, as wholly isotropic materials and (second) labradore treated as wholly orthotropic one as basing on a designed texture. The above programme was fed up by the FORTRAN95-outcome of temperatures and the other B.C.'s.The temperatures between the ceramics and the alloy (except one node!!, the FORTRAN) are (from the above two procedures), 222.63 to 270-300°C, at the first groove are about 290°C, and, surely lower (orthotropic). The relatively low (to ceramic) inner tensile stresses are embraced by the compressive ones from all the sides. The only problem is the-alloy bearing capacity at some sections at the ceramic boundary (and only there). But, it was the aim of the work to stick ceramics there.The dangerous stresses can occur at the pin .The 'orthotropic ' results are better than the 'iso'-ones and more true.. Taking into account that the real loading will be lower (porosity of the ceramics, the mass and the possible subtraction of stresses ,i.e. those ceramic-production-confined ones) , the laboratory production of the piston appears worth.

Keywords: *piston cap, adiabatic engine, radiative transfer, YSZ, thermal conductivity, absorption coefficients, joining of materials*

1. Introduction

The input temperatures and the other B.C.'s and measures were taken from [2,3] and the literature therein, but see below. The temperatures between the ceramics and at the alloy/ceramic boundary were computed using a FortranPlus simplified integral equation of one of the authors. Where the temperature drops were too high, ANSYS was allowed to depict it. The piston was regarded as follows:a). 6YSZ(tetragonal, 6mm)\labradorite(1mm)\the piston Al.-Si alloy – all that as isotropic, and, b). as above, but the labradorite layer – orthotropic. The YSZ is of good quality of [1]. Labradorite is an aggregate of labradore; labradore being a triclinic Ca-rich member of the feldspar group of minerals of the series, $NaAlSi_3O_8$-$CaAl_2Si_2O_8$. Though we are operating on aggregates, the ,e.g. <110>/(001) of labradore will match <110>/(111) of Al. There is no such 'traditional' epitaxy relation to YSZ, except some similarity of the polyhedra, but epitaxy of the YSZ-akin compouns on feldspars is known. As far as possible ,the temperature dependence of all the input data were used. Labradorite is of about 2.0-1.6 W/mK thermal conductivity and of varying and travelling coeff. of thermal expansion, CTE, $16*10^{-6}$ was adopted for the 'isotropic' case, i.e. in between those of the piston alloy, $20.5*10^{-6}$, and YSZ, $7.7\text{-}11*10^{-6}K^{-1}$. According to the Junior author's opinion feldspars project far below the graph of [7] regarding (thermal-shock)-deformational answer of the material as a function of temperature vs. atomic mass.Thence, also from this point they should be insensitive to thermal shock. YSZ is semitransparent (especially as a coating, and /or at high temperature).To stop the IR radiation in part from the YSZ , one can use labradore with its high crystallisation force, cf. also [3,5]. Labradore (labradorite!) is deemed withstand the engine millieu (water,etc) in high grade. Further, using a material with rel. high compressivity (large unit cell) like feldspar, one theoretically make the joining to metal easier; also using a complicated scheme of CTE of the feldspar and the CTE hystetresis of the alloy the feldspar grains can be arrested within the alloy, surely under compressive stress. The other grains, in turn, can be embraced by PSZ. There, in rocks, a YSZ-like material, e.g. UO_2 contacts feldspar via a K-feldspar film. It can be interpreted as an intermediate zone with moderate E modulus and thermal conductivity – thus, alleviating the input of 'hot and stiff' phase (UO_2) into feldspar. Moreover due to 'more diverse' electronegativity between U and K than between U and Ca, a film of uranates might come into being. A similar 'alleviating' zone can be introduced into structure under consideration, but let us try without. For comparison to the 'isotropic' computation, a computation with the wholly orthotropic labradorite layer was used. Why orthotropic to the aggregate of these triclinic crystals? It was namely possible to approximate that by monoclinic and then, by unique orthohexagonal transformation design a subunit with <130> parallel to <010>.Then, using or not an 'intergranullar' twinning on (021) diverse microstructures (Textur(a) –Germ., Russ;texture henceforth) of 2mmT symmetry from 2mm and 4mm were designed [4]. From thence a computation of diverse 3 E moduli, and, thereafter, Kirhoff's, G and Poisson, ν were possible. The texture bears similarity to some natural and surely artifical ones. The CTE of labradorite was recasted from data of [6] and treated as if all the axes were in rectangular system; Z* of texture and Z of CTE of labradore(ite) was taken for Y by ANSYS. The piston of 4CT107 Diesel engine was used as a template to our considerations,but with highly unconvenient and harsh conditions, 2500 RPM, 1200°C of the working medium (1473.15K), 13 MPa to-stress pressure, 20.342 kN side (transverse) force, very high flux, and treated as axisymmetric (which is not). Film coefficient computations were performed in a common way to become fluxes for the Fortran95 temperature computation. The only 'cooling' was an oil spray from the crankcase side with 75 W/m^2K and 75°C (348.15K).The input temperatures fom the centre of the bowl to the rand via the crown at diverse boundaries are shown in the Tab.1.

Table.1.The input temperatures on the boundaries, °C

YSZ/gas	716	750	800	925	1000	900
YSZ/labrador.	Ad	Ad	Ad	SAd, 403.26*	594.09	343.55
Labradore/piston alloy	Ad	Ad	Ad	SAd, 290.06*	510.38	222.63

Ad – ANSYS-defined due to too high drop of temperature; SAd – ANSYS-defined; * - if it were iput, the ANSYS temperatures are about 50°C higher.

The temperatures on the skirt (deemed too high!!!), 332, 282, 216, 192 and 180°C were taken from [8] (templugs). Then temperatures were interpolated. The ANSYS 10.0 programme was fed up with the FORTRAN95 output data, respective B.C. and material constants. As a result , the temperature field, principal stresses, shears maps were obtained as well as the same variables on the boundaries + stress intensity. Owing to the editorial all the pictures cannot be published here (about 40). To support the structure in ANSYS a fictive pin of cast iron was used while observing the mass, and the respective nodes were merged. The same cast iron, close to Niresist is a part of the first groove; the Al.-Si alloy (AK12) can be realated to quench-aged Mahle124. The absorption curve for YSZ was computed for refraction coeff., n =2.17, and, the alloy emissivity was taken constant, 0.186.

2. Results

Owing to the shortage of place only some Figures for 'orthotropic one' + one of 'isotropic' [,i.e. 'ortho' and 'iso']can be presented. The other ones upon request. The outcome temperature field is similar in both cases (Fig. 1.). The temperature at the boundary to labradorite is 222.63 to 270-308.95 but with a single node of 510.38^{o}C. In the deepest inner of the first groove, there is 296.47 to 307.35^{o}C, but otherwise from 289 to 318 (iso).; the 'ortho'-ones appears lower. The max. deformation is common about $0.5*10^{-3}$ m. The general picture is that a more or less expanded core of all the ceramics is surrounded by a thick compressive shell of YSZ or of the alloy.However, on the crone, there is one sharp tip and one rapid crooking, both of those being a source of high tension, partly fictive. They will be regarded in conclusion. The surface beneath ceramics could be made more smooth and flat and, thence, deleting the tension sources.As regards first principal stress the alloy displays mainly : -8.12 to +117 MPa, but also to –133 MPa (ortho) and even to +313 and +525 at the boundary to labradorite(iso). The most dangerous place for the alloy is at the pin – a patch above +618 MPa not seen by 'iso'.YSZ display the same or a bit more compressive stress as the alloy except one point at the boundary to labradorite, +493Mpa (ortho) and they are –324 to +313 (iso). In the labradorite layer, +368 to +493, but also –8.12 MPa. In the 'iso' case , there can be patches above 525 MPa. The picture of the 'iso' case is more homogeneous in colour (-112 to +101) in the alloy. Likewise , homogeneous are the other 'iso' ones. The second principal is of patchy distribution in the alloy (ortho), being from -171 to +142 MPa. Labradorite mainly displays +142 to +299, but YSZ at the boundary to labradore can be a bit above +456 MPa. At the pin, there is about +142. The same 'seen' by the 'iso ' case displays low stress; the alloy from -78.8 to +94.5 MPa; YSZ at labradorite something above +441. We still (!!!) do not regard the-above crooks and tips of the crone!. The third principal is wholly negative (ortho) except a few patches from YSZ side at feldspar of + 1.1 MPa. At the two-above points on the crone and at the pin ,there are points a bit above +124 or +110 to +124.. In the 'iso' method , the same area was almost wholly 'covered' by –85.4 to +84.2 MPa. More compressive it is only in YSZ. The shearings pictures are similar , compressive in the bowl and tension just below the crone,generally low, but about +28.8 to +89.5 in YSZ(iso) vs. above +200 MPa (ortho, a patch). As regards the principal forces the and shares at the alloy / labradorite boundary, one can see that the values are one half or one order lower for the 'ortho' case. For example, first principal in 'ortho' is of +440 and +613 (crook) whereas the same in 'iso' being close to+ 700 and +1586 MPa (crook). Likewise, the shear, from –154 to + 159 (ortho) whereas in 'iso' from –274 to +260.9. At the second boundary at YSZ the first principal is +235 (ortho) and +438 (ortho, crook), but at the 'iso' case it becomes +303 and +1149 MPa, respectively! Finally, shearing there is –67.4 to +118.7 (ortho) and -221 to +337 (iso)! This text is accompanied by the Figures 2-10.

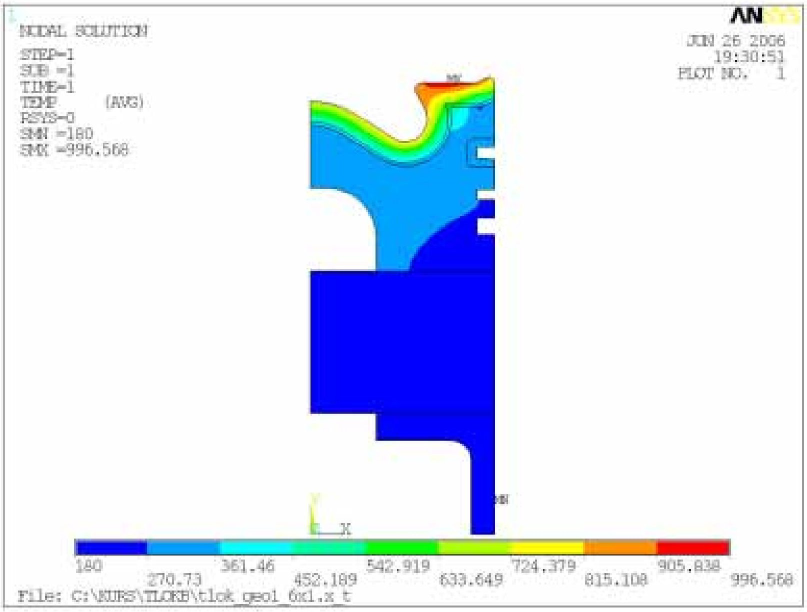

Fig.1. The temperature field of the piston with the orthotropic layer (=orto).

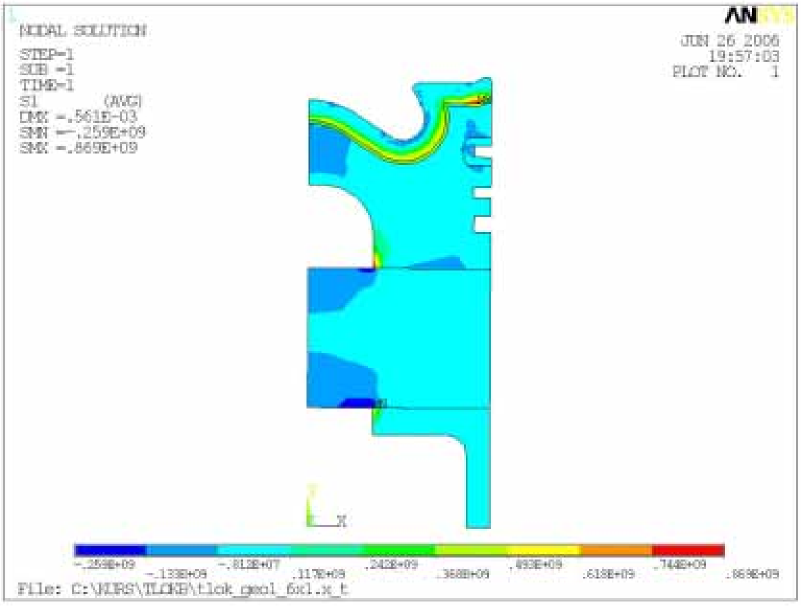

Fig.2.First principal stress (ortho)

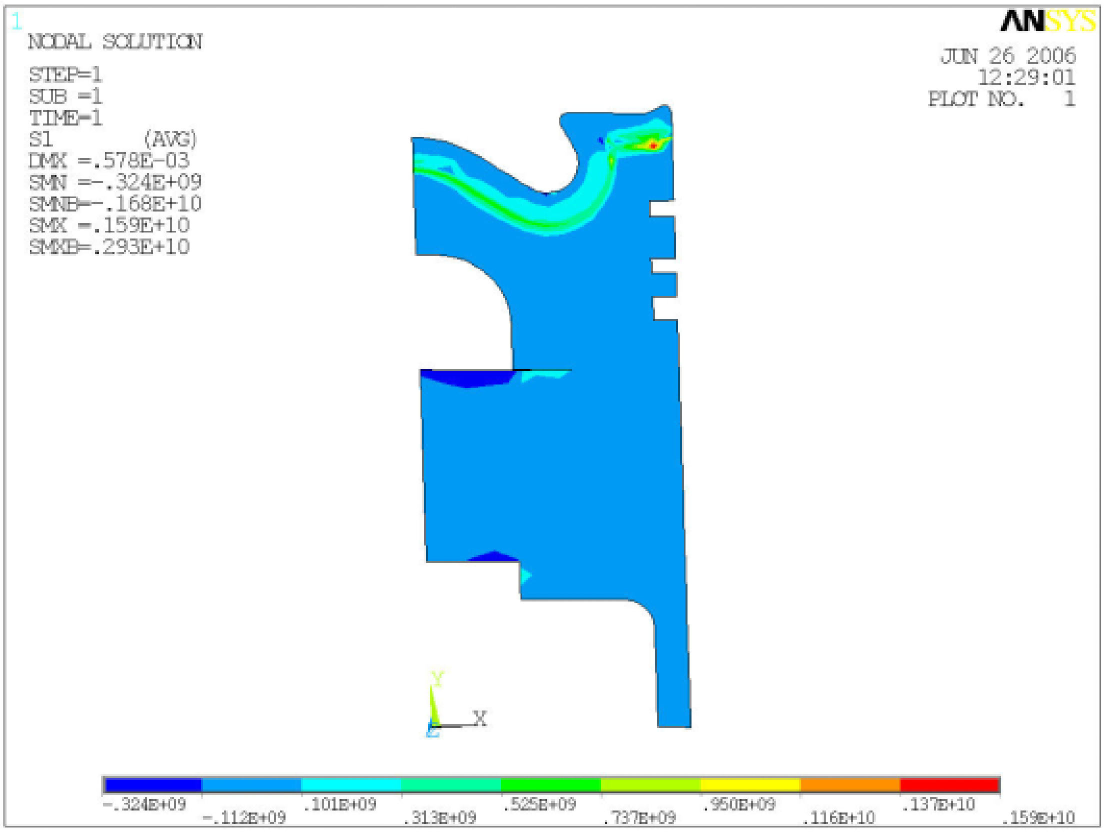

Fig.3First principal stress (iso)

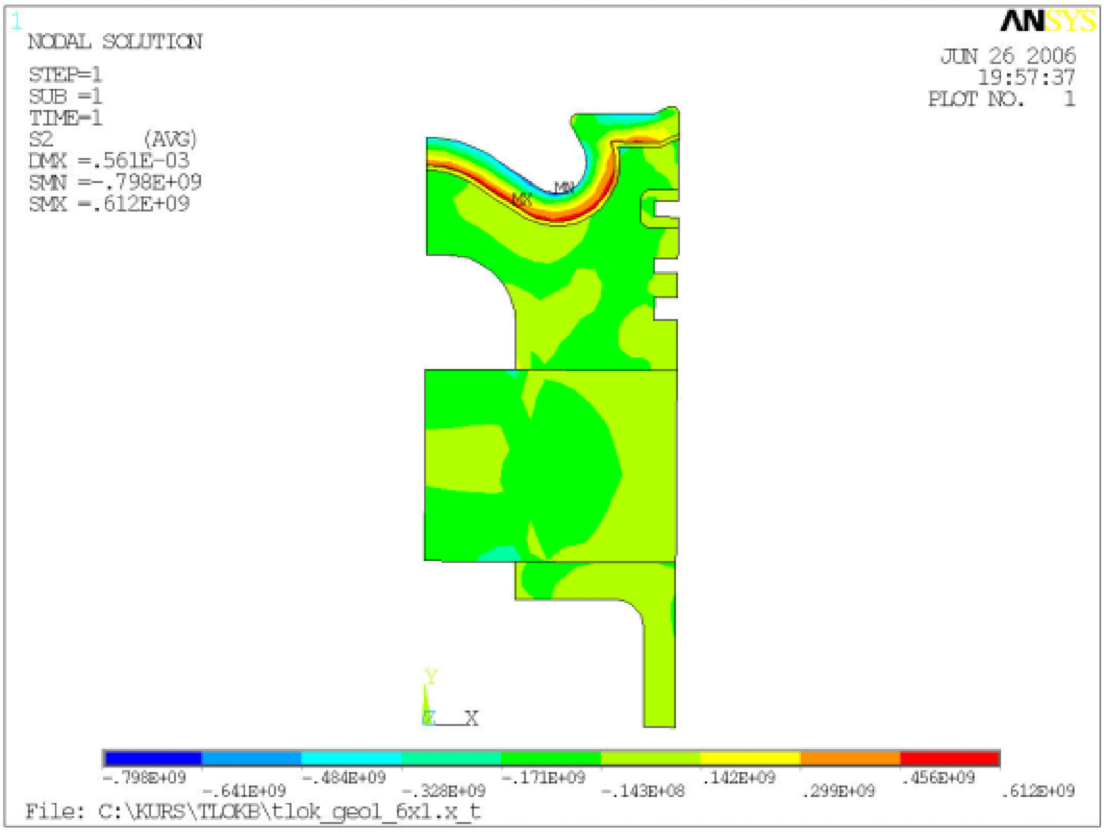

Fig.4.Second principal stress(ortho)

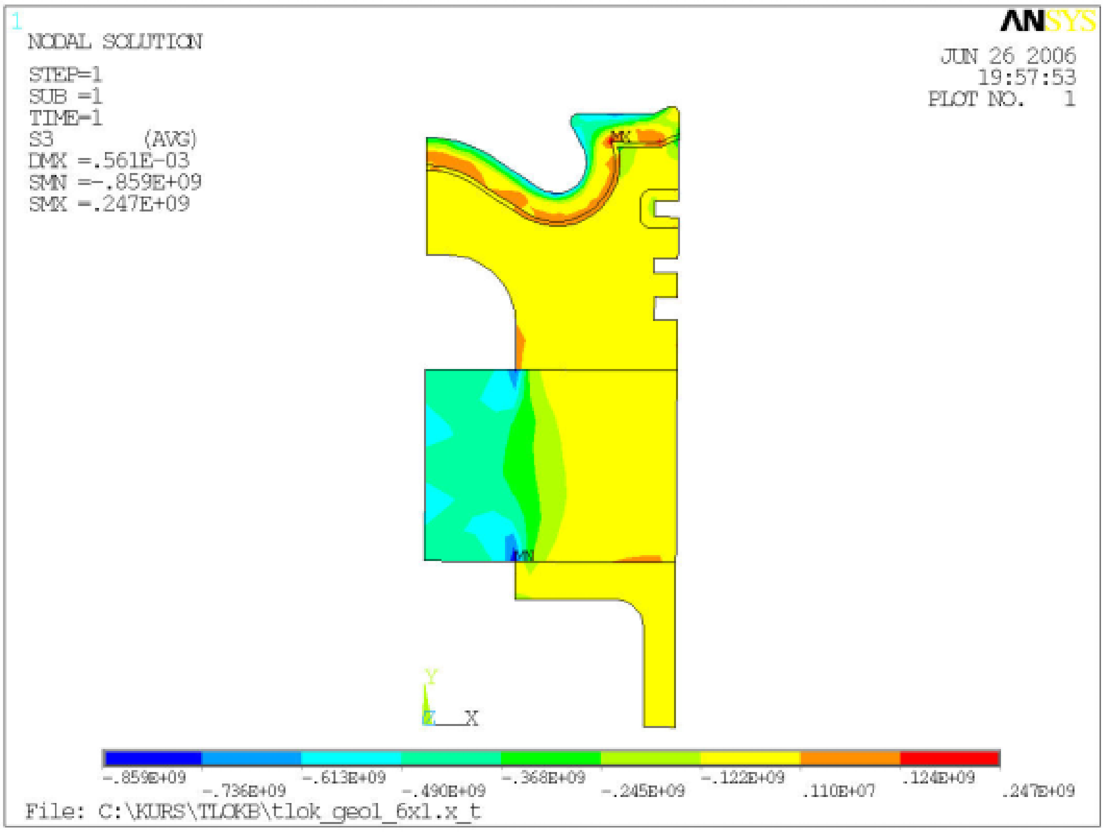

Fig.5.Third. principal stress (ortho).

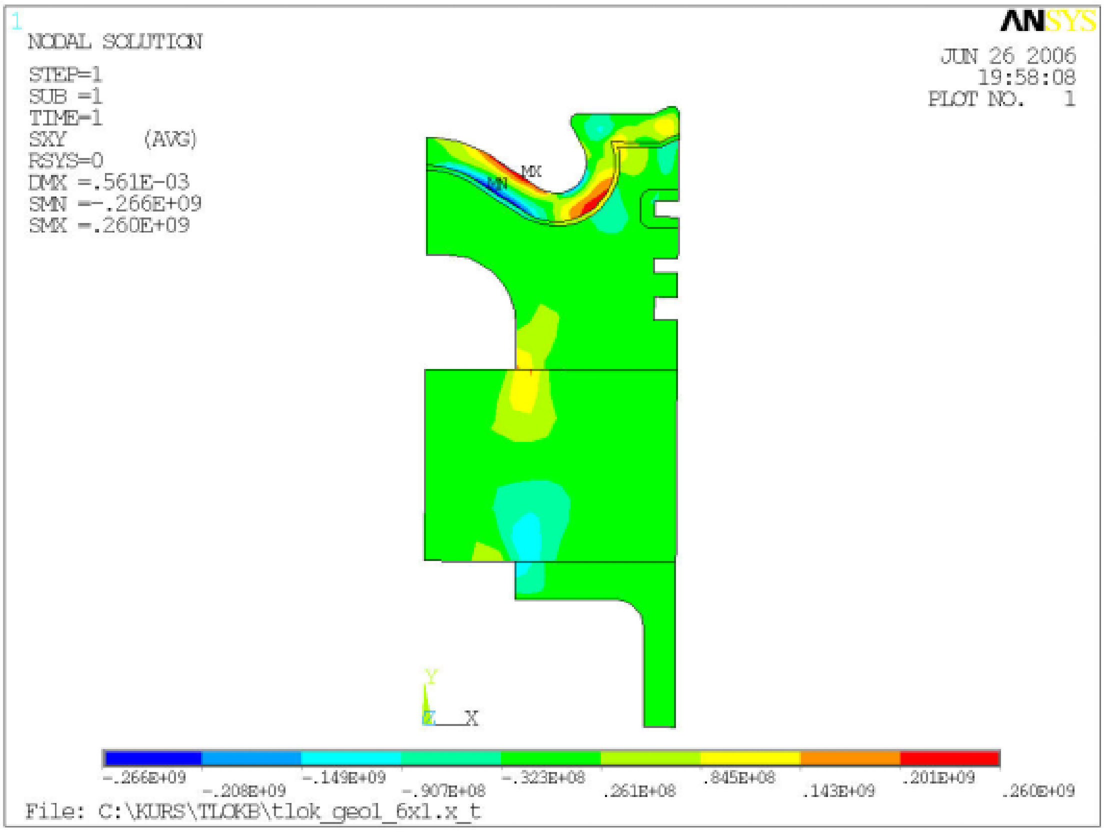

Fig.6. Shear (ortho)

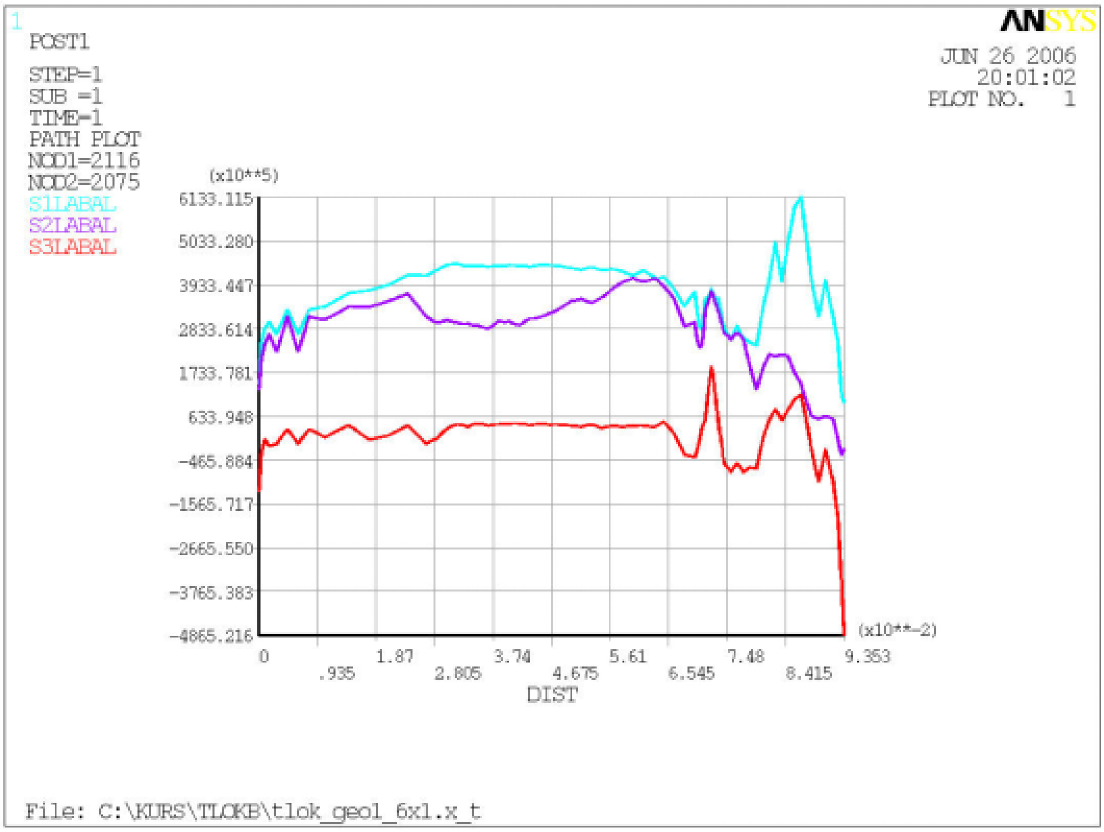

Fig.7.Principal stresses at the boundary the alloy/labradorite (ortho).

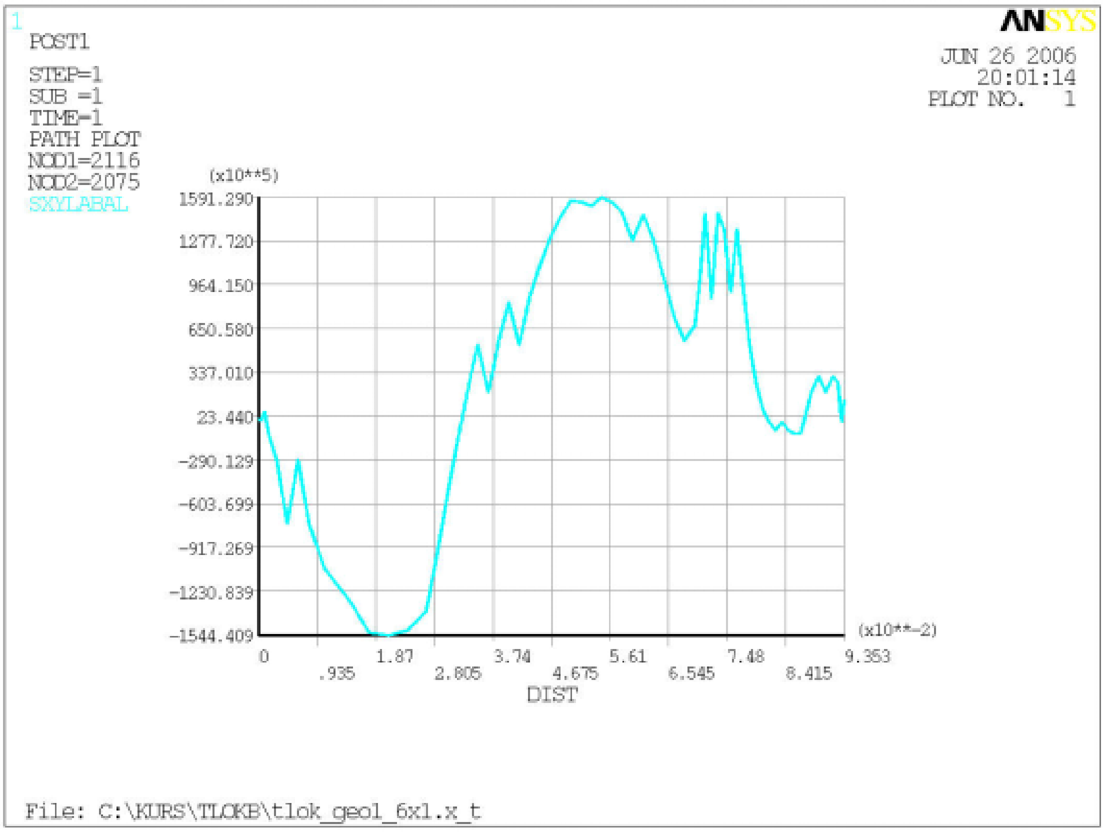

Fig.8. Shear at the boundary the alloy/labradorite (ortho)

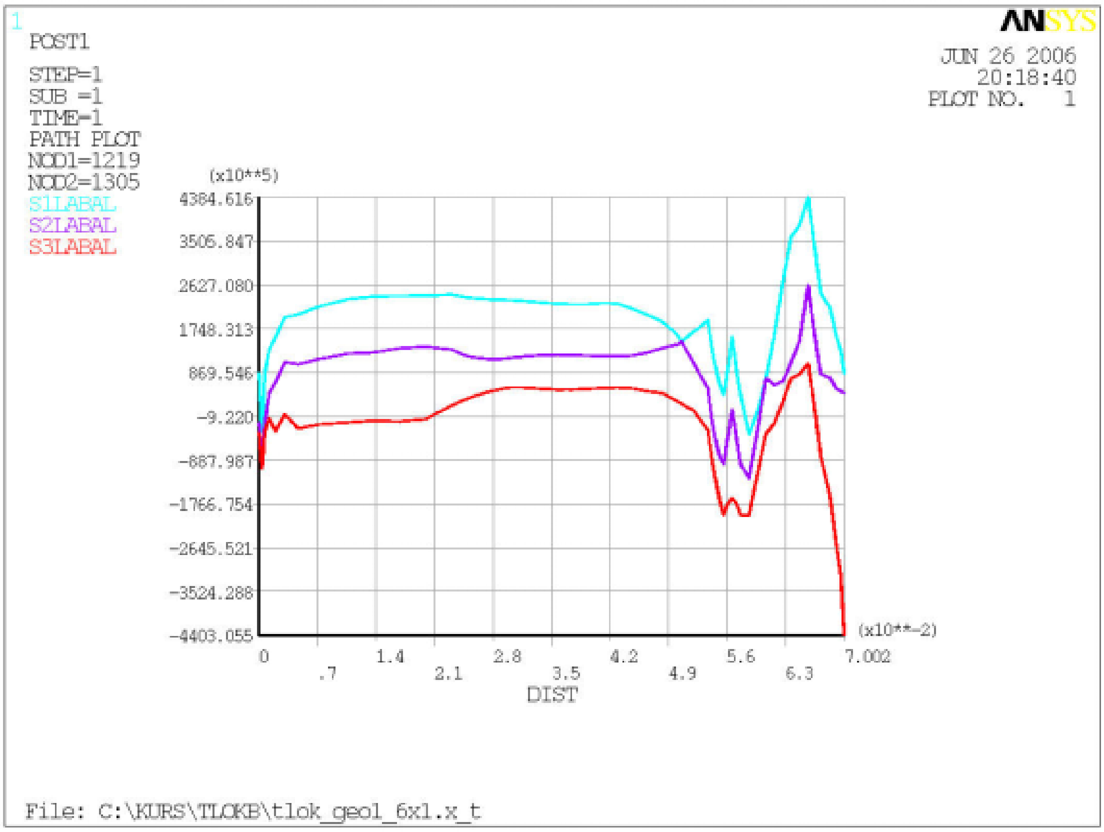

Fig.9.Principal stresses at the boundary labradorite/YSZ (ortho).

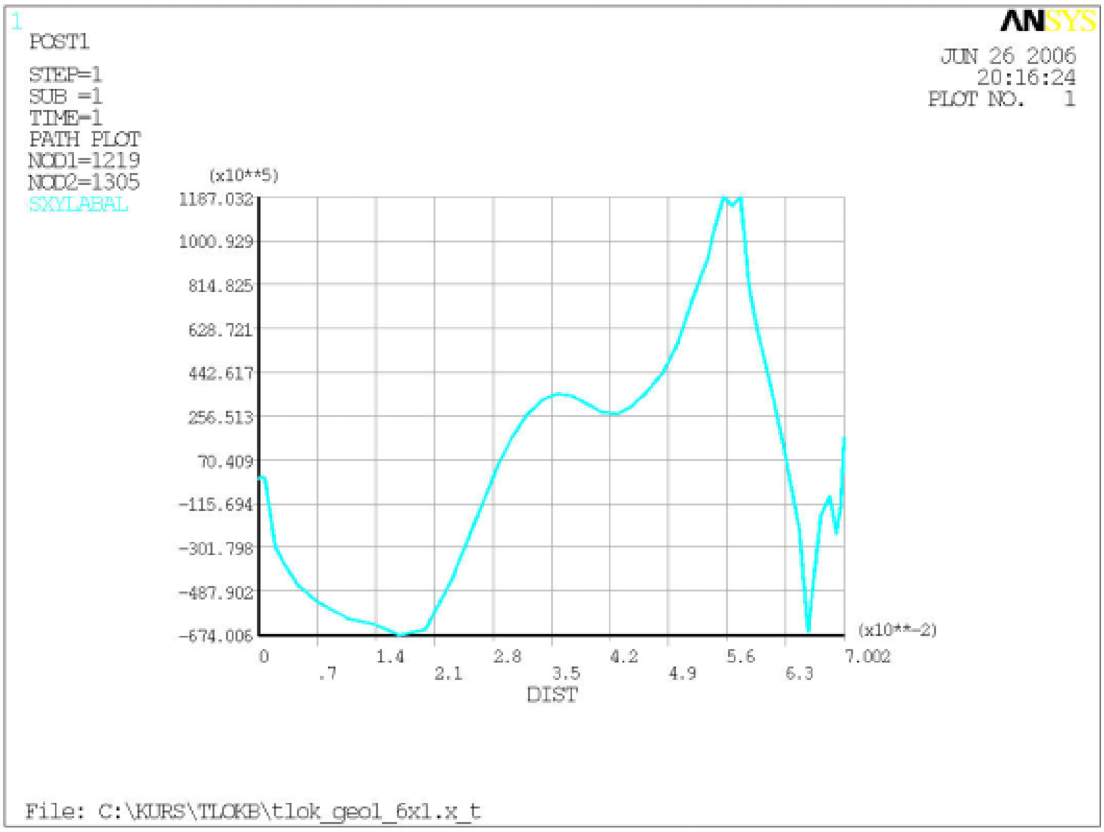

Fig.10. Shear at the boundary labradorite/YSZ (ortho).

3.Conclusion

The sharp tip and the crook on the crown should be deleted, at any rate beneath ceramics. The stresses there might (or are!) not be dangerous for labradorite, but can become for YSZ. The fact of encapsulation of the core of ceramics by a zone of compressive stresses is encouraging and diverse stresses are not huge.Taking into account that YSZ will withstand 391-546 at 322^{o}C and 278-333 MPa at 900^{o}C and more (bending) and labradore above 1600 (fracture),above 500-600 (bending), 800 (shear) and 390 MPa (shear at 1000^{o}C) [in fact it is count in GPa and only flaws can make it much lower, upon request] there would be no problem even when the isotropic model came true. We suppose that the orthotropic one is more real, i.e. refraining from discussion on better results on it. There are, however, two apparent(?) problems, anyhow! Firstly, the bearing capacity of the alloy at the boundary to ceramics (and only there!) in a part of section is above the plasticity of the alloy (the odd points on the crone are with), i.e. making a rough estimation in the bowl of the Treska-Coulomb hypothese one can compute 383 MPa which is above plasticity at room temperature of the alloy, and it ‘works’ about 223 to 300^{o}C , on average. It happens surely only on that boundary, and it was the aim of this work to theoretically stick labradore(-ite) to the alloy. That loss of the capacity can be counteracted. An exact consideration of safety coefficients for ceramics is not possible now due to the lack of data. However, labradorite should act on ‘its’ temperatures as a accomodating (alleviating) medium for stresses (ferroplasticity, a second order domain-transition). At the pin, there can be stress of above +618 MPa to which the isotropic model is insensitive. The problem is known for heavy-loaded Diesel engines.Several items should be stressed: we have operated on rather totally dense ceramics – thus, in reality, the temperatures would be lower, and, secondly, the model does not take into account stresses from the production of ceramics which, in general case, may subtract from the presented ones. It should be added that the mesh refining at the all odd places were performed. The 3D model will be made.Thence, a laboratory production of such a piston is worth doing.

References

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