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LOW-CYCLE FATIGUE & MECHANICAL CONTACT

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This article shows some studies of a low-cycle material fatigue caused by cyclical contact between two spheres with the same diameters. The spheres are made from modified 15219 steel. The problem was solved by FEM (SW MSC.MARC/Mentat). The numerical model is axi-symmetric. The material is considered to be isotropic with a von Mises surface of plasticity and it follows the kinematic hardening rule. The results show hysteresis loops from which the number of cycles until fracture can be determined.

Klíčová slova: FEM, Mechanical Contact, Low-cycle Fatigue.

INTRODUCTION

For material failures that are caused by the low-cycle fatigue (LCF), it is necessary to describe material behaviour using a closed hysteresis loop (an area of cyclical plasticity). To determine the lifetime of machine parts it is important to find the total number of cycles which cause the initialisation of first fatigue cracks. This paper describes some case of LCF study for the mechanical cyclical contact between two spheres with the same diameters. Friction influence has been neglected. For all presented solutions the FEM (MSC.MARC/MSC.Mentat software) has been used. Both spheres are made up from the same modified steel material 15219 (0.06%C, 1.72%Mn, 0.26%Si, 0.009%P, 0.0105%S, 0.32%Mo, 0.063%Nb, 0.027%Al). Material behaviours were acquired from experiment [1], [7] and [8].

THE NUMERICAL MODEL

The basic boundary conditions are the axi-symmetric condition (around the X-axis) and the planar symmetry (YZ-plane). During the pulse pressing of two identical spheres (with diameter $\phi 210\ mm$), the contact area must be a circle plane. Therefore it is advantageous and necessary to solve only one sphere, which is in mechanical contact with the absolutely rigid plane. For more details see fig.1.

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A time-dependent periodical force F=F(t) (which contains four cycles with maximum value Fmax = 200000 *N* and minimum value Fmin = 0 *N*) acted in the centre of the sphere, see fig.1. The time solution (8 *s*) was divided into 628 steps with various sizes, see fig.1.

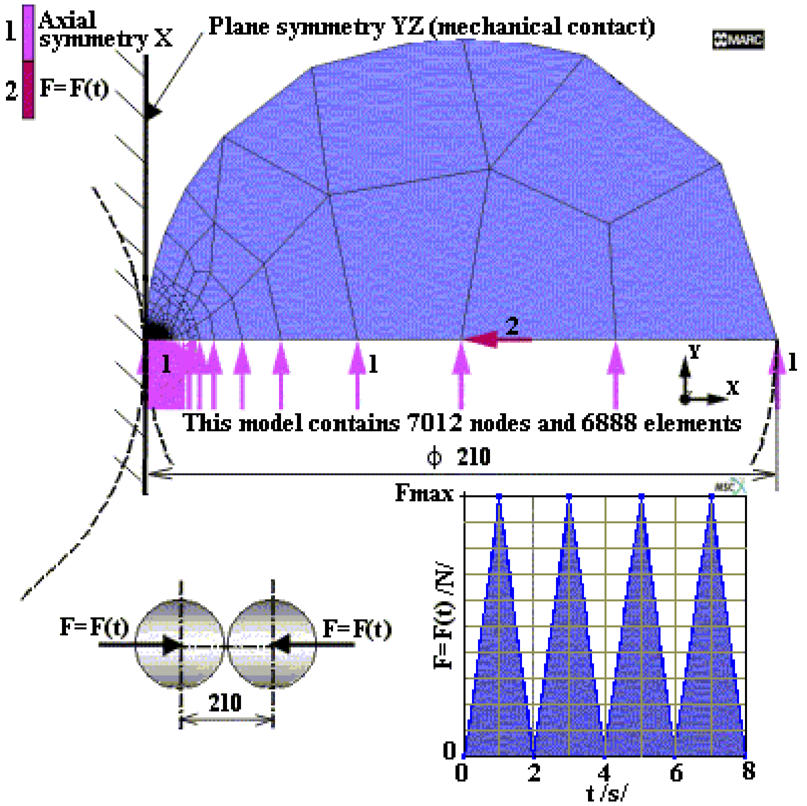

Fig.1. FEM model with loads, symmetry conditions and boundary conditions.

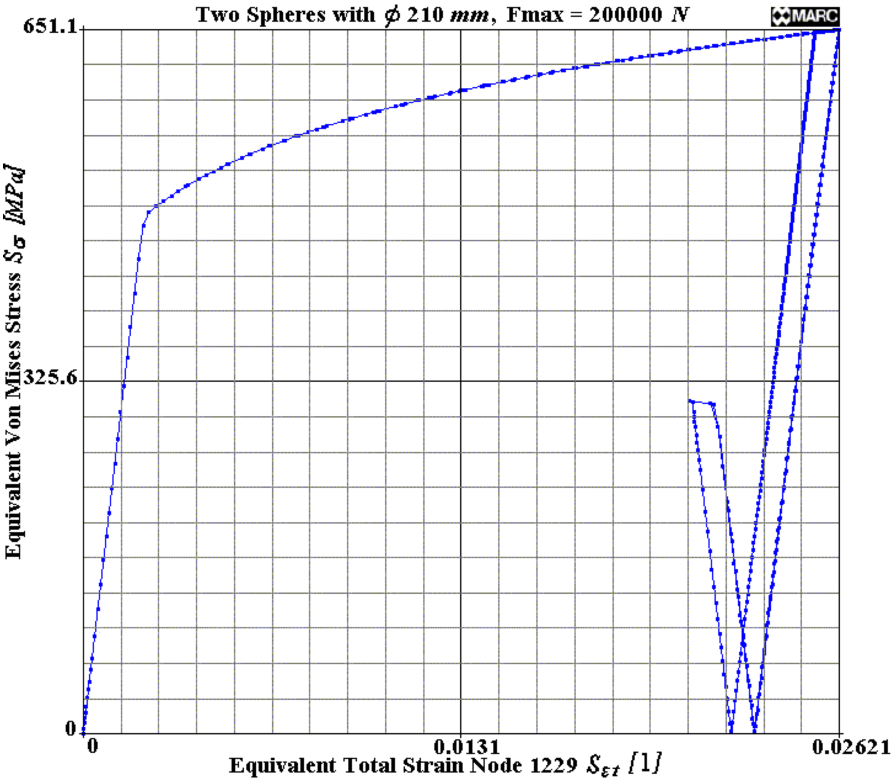

Fig.2 The $S_{\varepsilon t}$ - S_{σ} dependence during the solution.

Mechanical contact has been simulated by putting the fixed rigid plane in contact with the edges of quadrilateral (four node) elements. Mesh density has been increased in the area of mechanical contact. The contact element edges were approximated analytically using a spline function (giving a more realistic solution), see [3] and [4]. The Finite element mesh contains 7012 nodes and 6888 elements.

Both spheres are made from modified 15219 steel (yield stress R_e = 477.9 *MPa,* tensile strength R_m = 690 *MPa*), see [1] and [2] or [7] and [8]. The material is considered to be isotropic and elasto-plastic with kinematic hardening rule, which is sometimes advisable for the LCF phenomenon.

THE RESULTS FOR CYCLICAL CONTACT BETWEEN TWO SPHERES

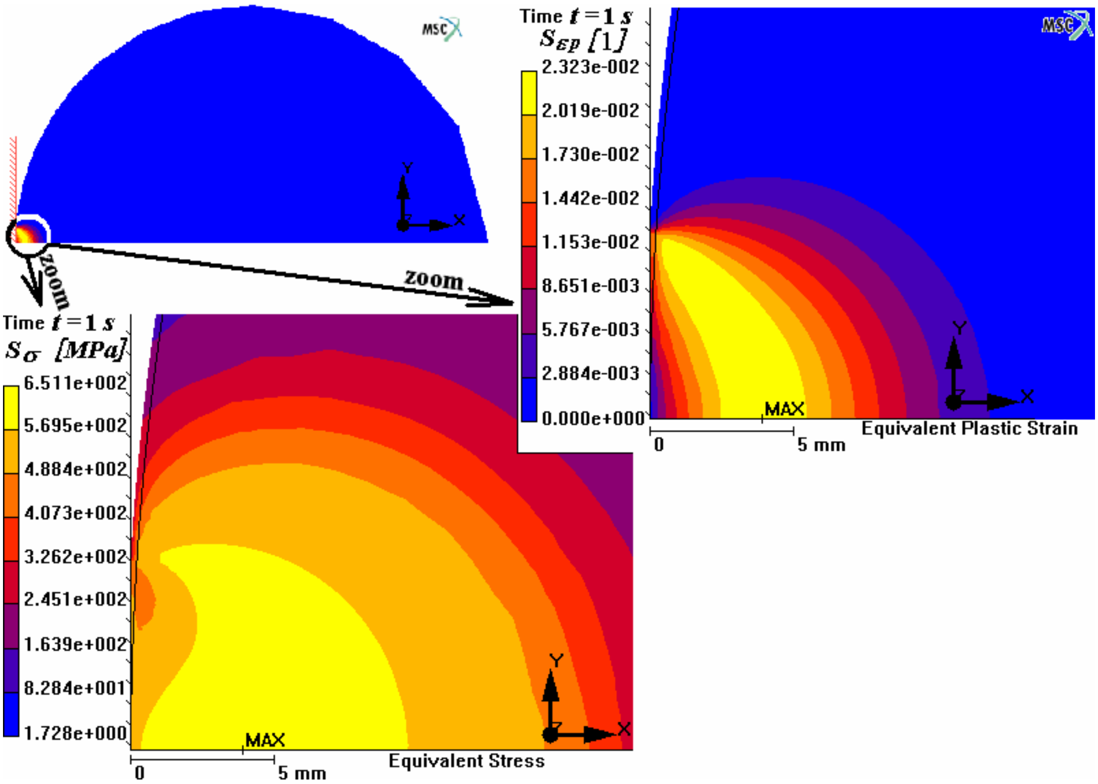

Fig.3 The values of equivalent plastic strain $S_{\varepsilon p}$ and equivalent von Mises stress S_σ.

In this case, the hysteresis loop (equivalent total strain $S_{\varepsilon t}$ *[1]* - equivalent von Mises stress S_σ *[MPa]* dependence) for the critical point of the material was calculated from FE solution as depicted in fig.2. The cyclical changing of equivalent plastic strains $S_{\varepsilon p}$ *[1]*, equivalent elastic strains $S_{\varepsilon e}$ *[1]*, equivalent total strains $S_{\varepsilon t}$ *[1]* and mean normal stresses $\sigma_m = (\sigma_1 + \sigma_2 + \sigma_3)/3$ *[MPa]* are shown (cyclical plasticity), see fig.2, 3 and 4.

At this point it is possible to calculate the number of cycles N_f *[*cycle*]* needed for initiation of fatigue cracks. For some methods and examples of how to calculate N_f see [1], [6], [7], [8], [10] and [11].

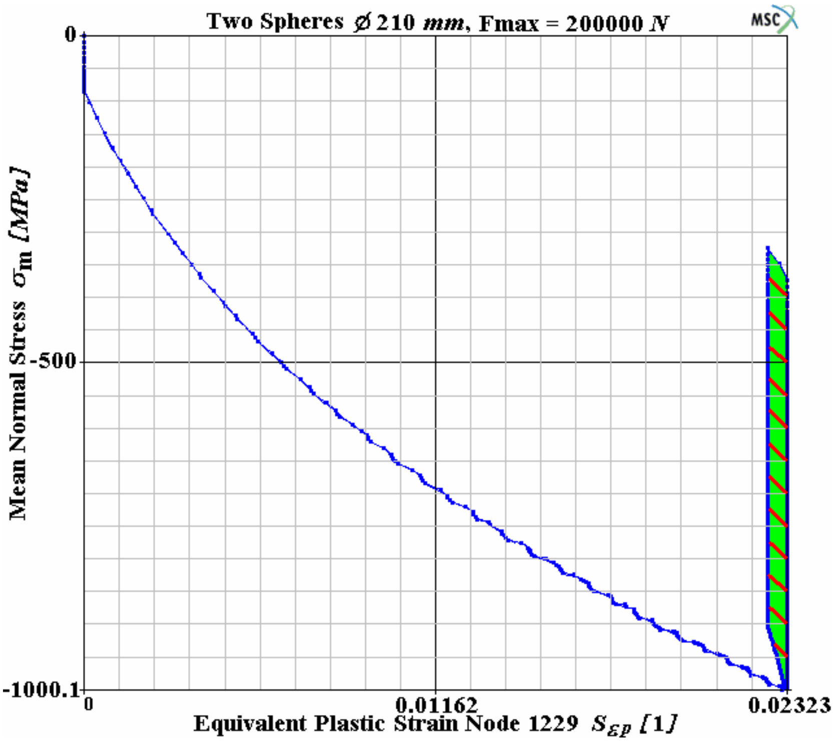

Fig.4 First proposal model of fictive hysteresis loop ($S_{\varepsilon p}$ - σ_m dependence).

FIRST PROPOSAL MODEL OF HYSTERESIS LOOP

Hence Fig.4 shows first proposal model of hysteresis loop based on $S_{\varepsilon p}$ - σ_m dependence. This fictive hysteresis loop (shaded area in fig.4) should be important in calculating the number of cycles N_f necessary for fatigue crack initiation, see also [1], [7], [8] and [11].

SECOND PROPOSAL MODEL OF FICTIVE HYSTERESIS LOOP

Figure 5 shows second proposal model of fictive hysteresis loop ($S_{\varepsilon t}$ - $S_{\sigma\,fict}$ dependence) based on the fig.2. ($S_{\varepsilon t}$ - S_σ dependence), where $S_{\sigma\,fict}$ is a fictive equivalent stress measured in *[MPa]*. This fictive hysteresis loop (shaded area in fig.5) probably should be important in calculating the number of cycles N_f necessary for fatigue crack initiation. The fictive loop was created by reflecting of some parts $S_{\varepsilon t}$ - S_σ dependence about the axis of symmetry. This axis of symmetry is defined via values where S_σ = 0 *MPa*.

The number of cycles N_f with consideration of mean and amplitude stresses can be calculated using the following equation.

$$N_f = \frac{1}{2}\left(\frac{S_{\sigma\,fict_a}}{\sigma'_f}\right)^{\frac{1}{b}}\left(1-\frac{S_{\sigma\,fict_m}}{\sigma'_f}\right)^{\frac{-1}{b}}, \qquad (1)$$

where σ'_f *[MPa]* and *b [1]* are material parameters of 15219 steel.

For more details and derivation of equation (1) see [8] or [1] and [7] or [11].

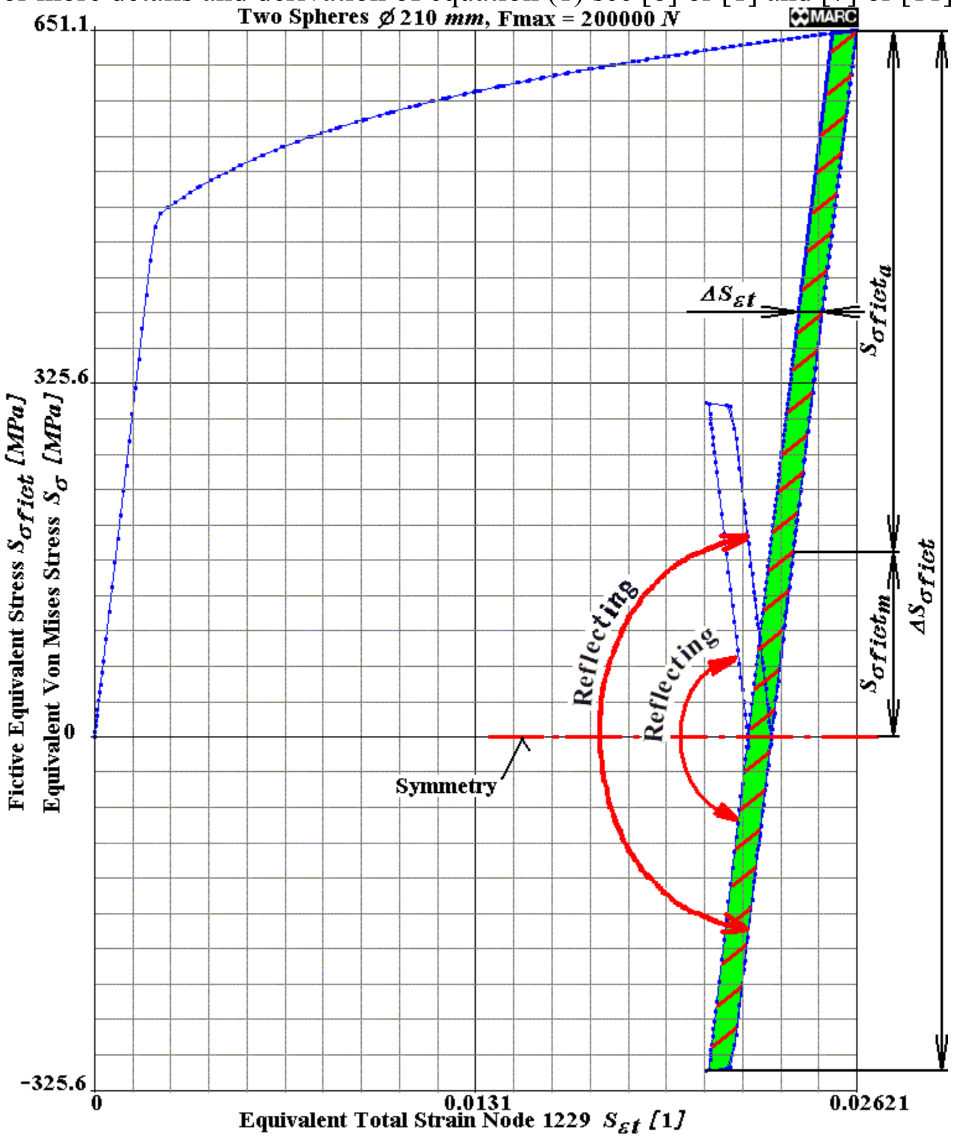

Fig.5 Second proposal model of fictive hysteresis loop. The $S_{\varepsilon t}$ - S_σ and $S_{\varepsilon t}$ - $S_{\sigma\, fict}$ dependencies during the solution.

For similar problems of contact fatigue see also [9] (SW ANSYS) and [10] (SW ABAQUS).

CONCLUSIONS

By FE simulations of twin spheres with the same diameters, which follow the kinematic hardening rule, it is possible to solve LCF problems. Figure 2, 4 and 5 show the hysteresis loop and fictive hysteresis loop, which are important for calculation of the number of cycles necessary for fatigue crack initiation. Equation (1) describes one possible way of calculating the number of cycles N_f.

This numerical study is good base for future experimental measurements in our department.

Taken together, this paper, and the given references [1], [2], [9], [10] and [12] show that the FE model can be used to simulate plastic shakedown and ratchetting material responses but experiments are necessary.

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