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EXPERIMENTAL AND NUMERICAL SOLUTIONS OF CONTACT FATIGUE

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Summary: *This article shows:*
1. Some studies of a low-cycle material fatigue caused by cyclical contact between two spheres with the same diameters. The spheres are made up from modified 15219 steel. The problem was solved by FEM (SW MSC.MARC/Mentat. The results show hysteresis loops from which the number of cycles until fracture can be determined.
2. The realisation of test device for the research of contact fatigue as complement of the loading test machine INOVA, which is directed to look for quantitative coherence between number of cycles to the origin of fatigue cracks in the area of mechanical contact.

1. 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. Material behaviours were acquired from experiments. The test machine for the research of contact fatigue as a complement of the servo-hydraulic machine INOVA 200kN is shown in fig.4. This machine was proposed and realised in the department of mechanics of Materials at VŠB – TECHNICAL University of Ostrava.

2. The Numerical Solution

The basic boundary conditions are the axi-symmetric condition (around the X-axis) and the planar symmetry (YZ-plane).

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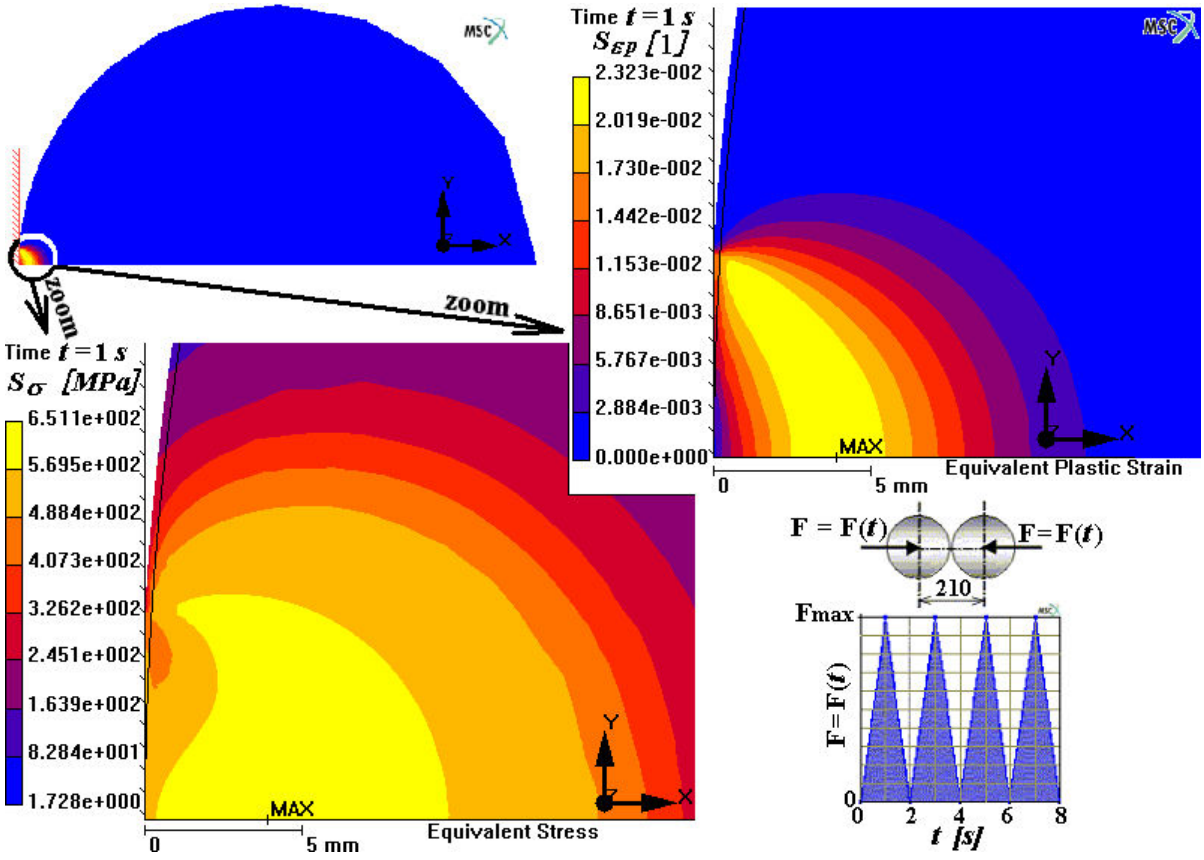

Fig.1 The values of equivalent plastic strain $S_{\varepsilon p}$ and equivalent von Mises stress S_{σ}.

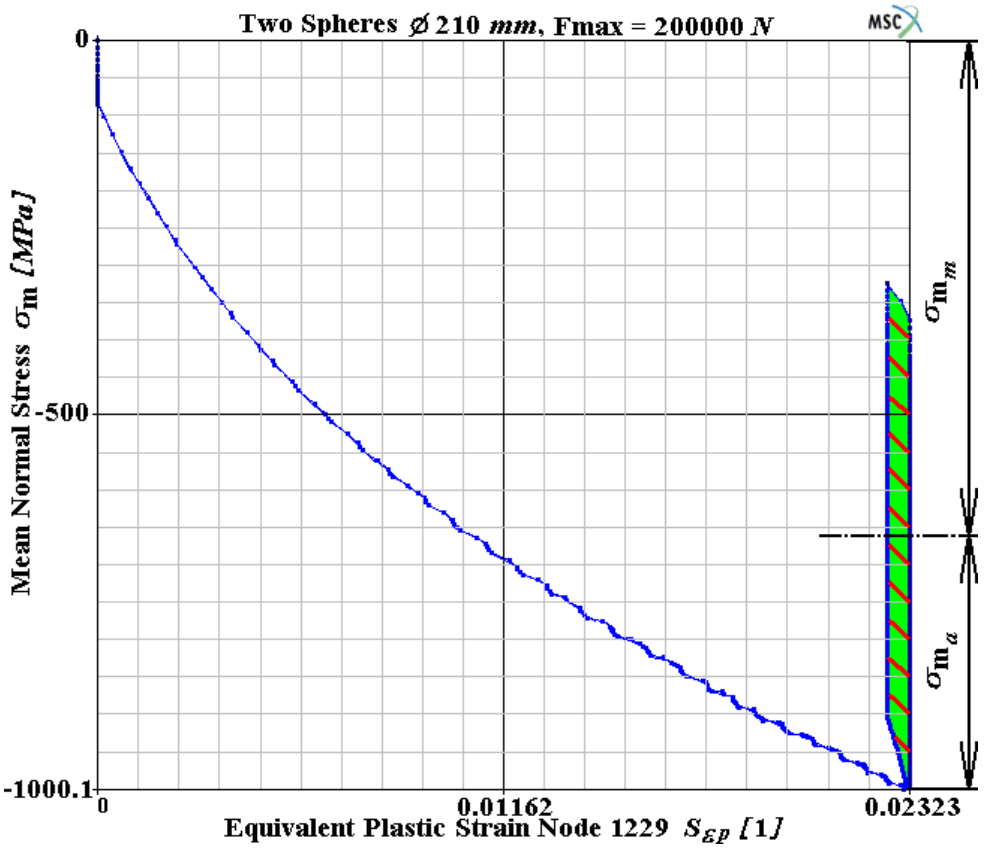

Fig.2 First proposal model of fictive hysteresis loop ($S_{\varepsilon p}$-σ_m dependence).

During the pulse pressing of two identical spheres (with diameter ϕ 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.

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 material is considered to be isotropic and elasto-plastic with kinematic hardening rule, which is sometimes advisable for the LCF phenomenon.

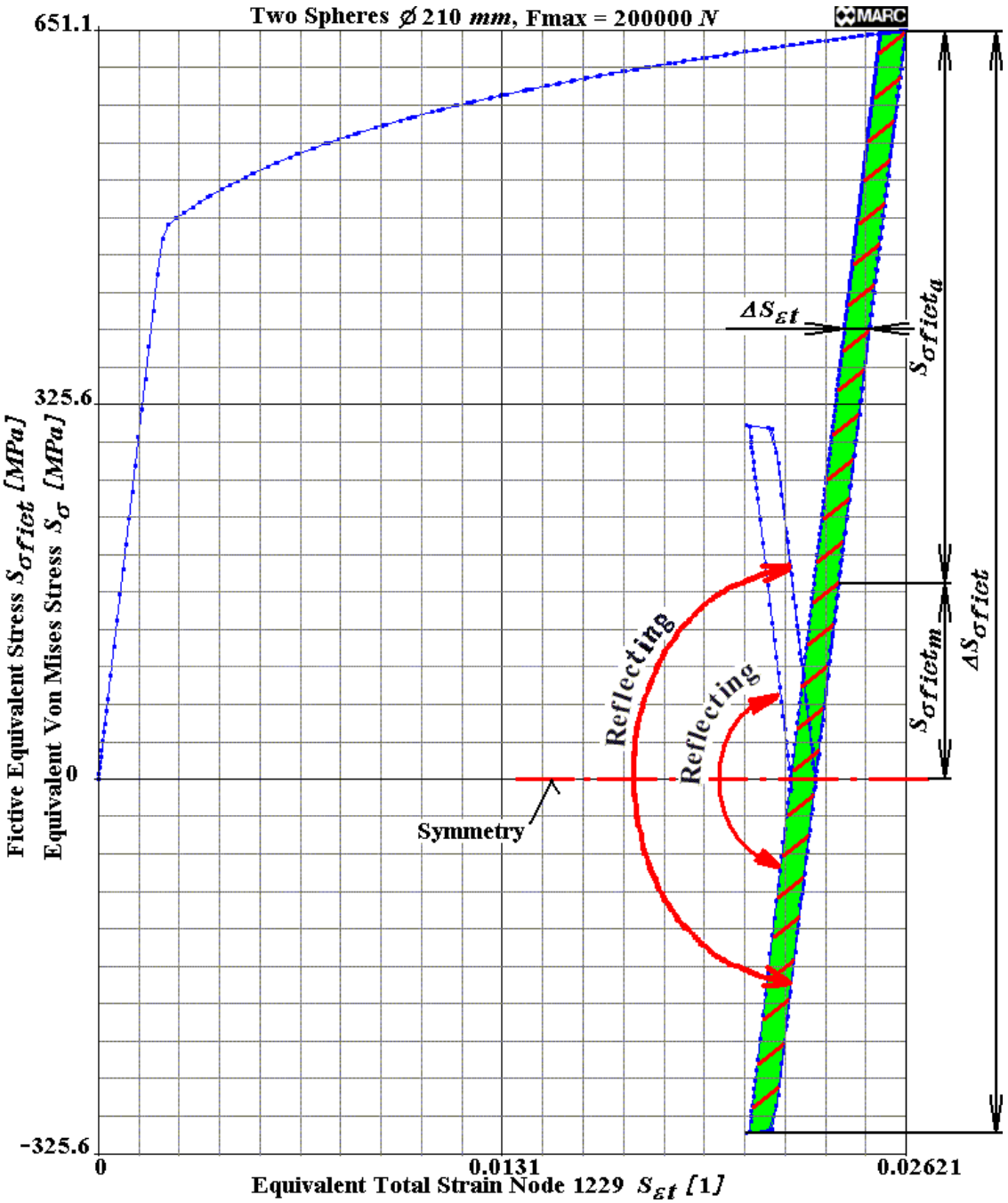

Fig.3 Second proposal model of fictive hysteresis loop. The $S_{\varepsilon t}$ - S_σ and $S_{\varepsilon t}$ - $S_{\sigma\,fict}$ dependencies during the solution.

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.

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, and 3. At this point it is possible to calculate the number of cycles N_f *[*cycle*]* needed for initiation of fatigue cracks.

Hence Fig.2 shows first proposal model of hysteresis loop based on $S_{\varepsilon p}$ - σ_m dependence. This fictive hysteresis loop (shaded area in fig.2) should be important in calculating the number of cycles N_f necessary for fatigue crack initiation via equation:

$$N_f = \frac{1}{2}\left(\frac{\sigma_{m_a}}{\sigma'_f}\right)^{\frac{1}{b}}\left(1-\frac{\sigma_{m_m}}{\sigma'_f}\right)^{\frac{-1}{b}} \tag{1}$$

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

Figure 3 shows second proposal model of fictive hysteresis loop ($S_{\varepsilon t}$ - $S_{\sigma\, fict}$ dependence) based on the ($S_{\varepsilon t}$ - S_{σ} dependence), where $S_{\sigma\, fict}$ is a fictive equivalent stress measured in *[MPa]*. This fictive hysteresis loop (shaded area in fig.3) 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 $S_{\sigma} = 0$ *MPa*.

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

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

3. Realisation of Test Machine for the Research of Contact Fatigue

The test machine for the research of contact fatigue as a complement of the servo-hydraulic machine INOVA 200kN is shown in fig.4. This machine was proposed and realised in the department of mechanics of Materials at VŠB – TECHNICAL University of Ostrava.

This machine will be used:

1. for the solution of quantitative coherence between number of cycles to the origin of fatigue cracks in microstructures of different materials by contact fatigue and number of cycles.

2. for initiation of crack by combination of tensile and pressure stresses in the area of the fatigue of materials.
3. The experimental results will be also important for future numerical solutions

For more details see [2] and [3].

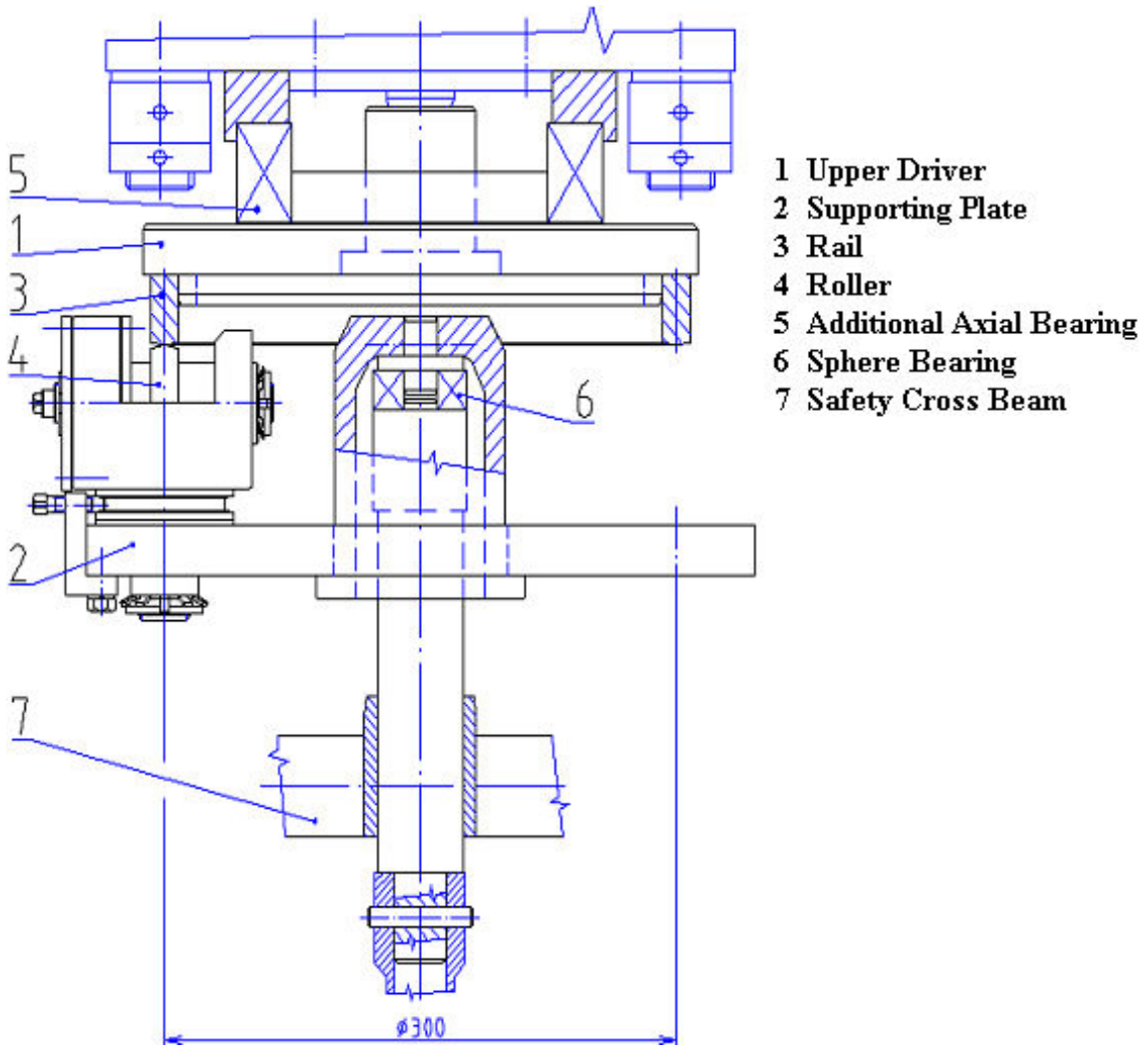

Fig.4 Diagram of the machine for contact fatigue tests.

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 and 3 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) or (2) 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. This paper and the given references show that the FE model can be used to simulate plastic shakedown and ratchetting material responses but experiments are necessary.

The test machine for the research of contact fatigue as complement of the loading test machine INOVA was realised.

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