NUMERICAL METHODS IN THE DEVELOPMENT OF DIE EJECTOR PINS WITH SUFFICIENT LIFE EXPECTANCY

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A die ejector pin used in the pressing of billets for production of roller bearings was developed with numerical analysis support to maximise the tool life expectancy. Quasistatic finite element analysis was used in the diagnostics phase (in combination with metallurgical and surface studies), identifying the stress state and deformation mode of the initial cracks. New pin geometries were then generated numerically, allowing for design constraints, and analysed by simulation of the dynamic penetration of the pin into the billet. Comparative approach to life expectancy analysis is also mentioned.

INTRODUCTION AND OBJECTIVES

The economy of the production of roller bearings is strongly affected by the tool life and the nature of tool failures. The machine cuts billets from a wire, feeds them into the press die (Fig. 1-a, marked 'D') and presses them to the size prepared for grinding the roller into final shape. The billet ejector pin 'E' of the press die has a small protrusion (referred to as 'pip' - 'P') which makes a recess in the centre of the billet base for accurate and firm guidance of the pressed billet during grinding. The machine produces almost five pressed billets per second and the tool life is most often influenced by the life of the pip of the billet ejector pin. When the pip breaks, the machine must be stopped to change the pin and faulty billets can cause further tool damage in subsequent operations.

The main objective of the exercise was therefore to contribute to the reduction of the manufacturing costs by making the ejector pin life as long as possible and by changing the pip failure to a more predictable mode.

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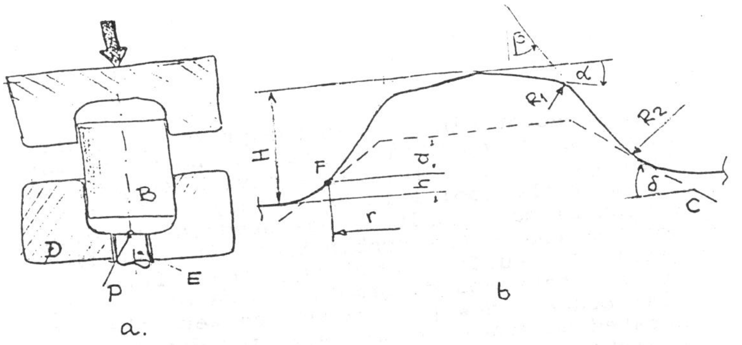

Fig 1 Billet pressing (a) and pip geometry data (b)

NUMERICAL METHODS IN THE PIN FAILURE DIAGNOSTICS

Service life of the ejector pin is influenced by metallurgical aspects of the material and heat treatment, surface finish, pin geometry and service conditions (material, shape and size tolerances of the billets, dynamics of the press operation, mechanism adjustment, etc).

The diagnostics study (1) concentrated on the pin for which sufficient experimental evidence was available and included metallurgical studies of the pin and billet material, microexamination of the pin surface finish and failure mechanism and preliminary finite element stress analysis.

Metallurgical and microexamination studies involved a series of new and fractured pins made of high-strength steel ingot and its powder metallurgical equivalent. The main conclusions were that the pip failures are produced by crack propagation with some plastic material flow also identified and that the initial cracks introduced during pin manufacture were very difficult to eliminate by surface polishing.

Space limits of the paper allow that only a brief selection of the numerical results can be made.

PRELIMINARY - STATIC FINITE ELEMENT ANALYSIS OF THE PIN

The reference pin with dimensions displayed in Fig. 1-b: H = 0.91 mm, R1 = 0.2 mm, R2 = 0.8 mm, $\alpha = 8^{o}$, $\beta = 37^{o}$, centre-tool angle $\delta = 45^{o}$) was also studied numerically, using program NISA with the axi-symmetric model of one half of the pin to a depth of approximately one radius of the pin cylinder (Fig. 2). The initial model was made of 8-noded rectangular parabolic elements, with a total of 1500 degrees of freedom. A more detailed second model included a finer mesh surrounding the varying-length crack to simulate those observed in service.

A quasi-static experimental load-deflection curve of the pip penetration into a billet was used to estimate the approximate level of interface pressures at different penetration depths. The load cases studied were :

1. axisymmetric pressure of 3460 MPa on the pip top,
2. axisymmetric pressure of 2350 Mpa when the penetration almost reaches the pip height,
3. non-axisymmetric pressure with a parabolic variation from 2310 Mpa to zero around one half of the pip, to simulate loading from a very irregular-shape billet.

Most attention was paid to the level and pattern of von Mises equivalent stresses (general level of material stressing), maximum shear stress (important for crack propagation within a compressive stress field), hoop stresses (the highest stress component) and the possible tension stress components (no significant were found).

The quasi-static numerical study established that the pin material is very close to plastic yielding, particularly due to load case 1 (Fig. 2-a and b). As the penetration progresses, the deformation and stress levels and patterns change (Fig. 2-c and d). The non-axisymmetric case, produces a very low stress field on the lower pip radius.

REDESIGNING THE PIP AND DYNAMICS PENETRATION SIMULATION

A new pin-design was developed numerically by a special-purpose program, allowing for the numerous and tight constraints imposed by the pin manufacture and interaction of the pressed billet with the centering tool in the grinding machine.

Numerical simulation of the dynamics of the pip penetration process was then carried out using the explicit formulation program DYNA-2D. The initial and two new candidate geometries were studied with the axisymmetric

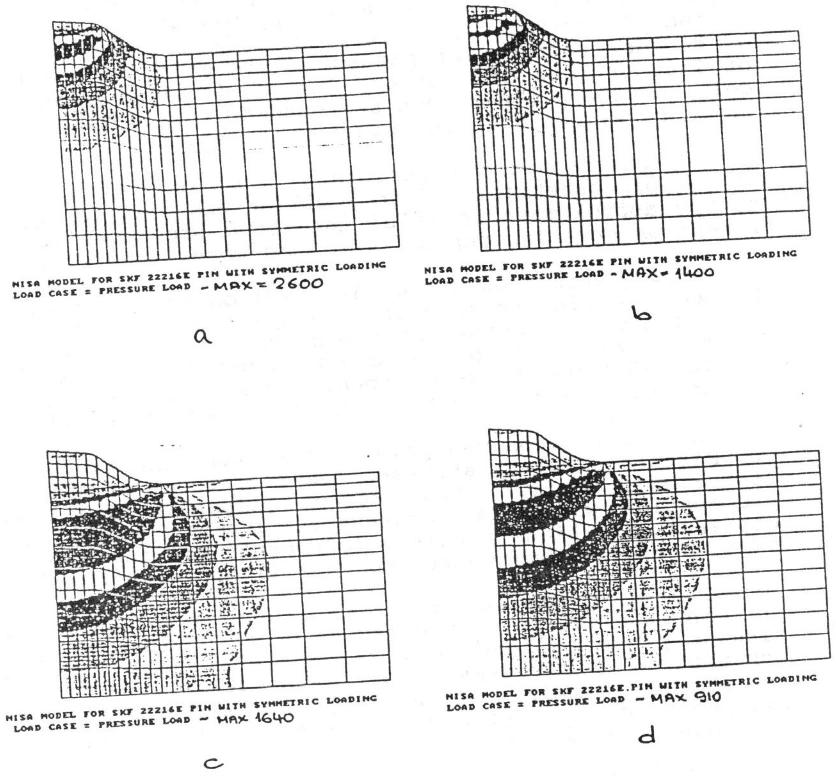

Fig. 2 The von Mises and shear stresses in the pin - load cases 1 ('a' and 'b') and 2 ('c', 'd').

model involving the pin segment, billet and part of the die. The model had approximately 3500 four noded elements for the pin and 10000 elements for the billet (die boundary elements were completely restrained). A reversing linear velocity profile from 1 m/s was applied to the top surface of the billet. The initial, maximum crushing and final states of the original pin geometry model are shown in Fig. 3-a,b and c respectively (elastic spring-back was in excellent agreement with experiment).

Fluctuating stress fields were apparent, combining the dominating effects of the travelling and varying surface pressures, with stress-wave propagation through the pin. The maximum stresses in the original pin design were travelling down the pip, confirming the possibility of crack occurrence at various locations. The interface pressure also varied along the pip with a maximum of 3000 Mpa, and a usual drop on the pin axis to 2300 MPa.

The analysis indicated the need to reduce the angle (δ) of the centre tool. The geometry optimisation program produced two new pip geometries with reduced height and a much bigger lower radius. The maximum stresses at the pip top were reduced by only 5 % . However, the new 'wide' geometry had approximately 35 % lower stresses close to the surface in the area of the lower pip radius (Fig. 3-d,e), where failures are most frequent in service. The new pip also has a potentially longer critical crack and a relatively smoother surface for the same finish.

Lower comparative stresses levels at the original 'critical' location need not imply a major increase in pin life, i.e. the new pin may fail closer to the top, with a similar life expectancy. However, failures close to the top are preferable, since they are much more likely to leave a 'warning' period for tool replacement before complete failure.

A COMPARATIVE ESTIMATE OF FATIGUE LIFE EXTENSION

Work is currently in hand trying to predict the pin life extension by redesign, using the elastic analysis with programs NISA and its fracture-mechanics module ENDURE. Models of the original and recommended geometries are analysed with axi-symmetric crack simulation and with pressure loading taken from the DYNA2D analysis. Close-up of the crack detail in the original model (Fig. 4-1) confirms the assumed shear-mechanism of the crack propagation. This analysis is a comparative one, assuming the same material properties, with the stress-intensity factors calculated from the model with various crack lengths and resulting in the crack propagation diagrams of the type shown in Fig. 4-b (details of this analysis with experimental statistics will also be published).

REF. 1: Rashidy, Pearce, Kecman : Damage assessment of SKI Die Ejector Pin, CIC report to SKF (UK), 1991

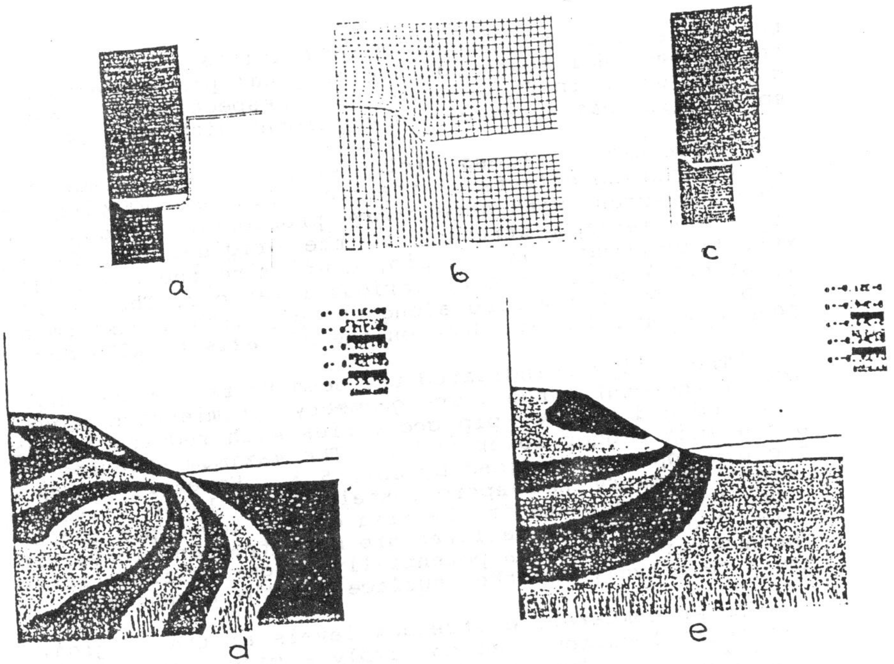

Fig 3 The initial, intermediate crushing (zoom) and final states of the original pin geometry (a,b,c) and vonMises & shear stresses in the new geometry (d,e)

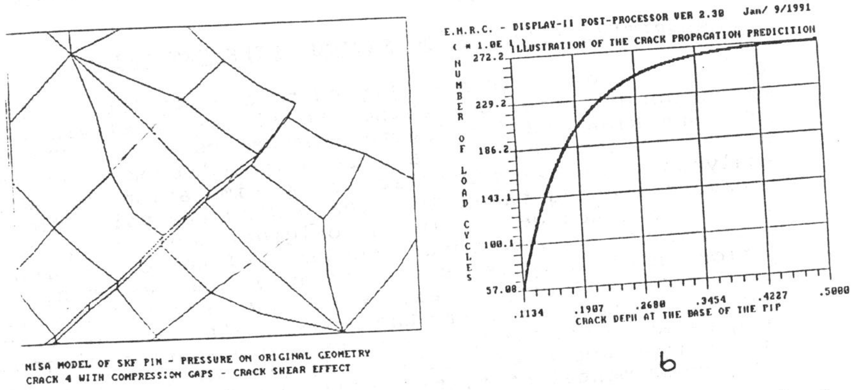

Fig. 4 Crack deformation pattern (a) and a typical (qualitative) crack-propagation curve