

Design of a wear test for hot and warm forging

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Summary

This paper presents a laboratory simulative test for hot and warm forging tools designed and set-up by the Authors with the twofold purpose of (i) verifying the applicability of wear micro-mechanical models in simulation of hot and warm bulk metal forming operations using FEM codes and (ii) evaluating wear parameters by an inverse numerical technique.

Although its configuration is simple, the test embodies many of the tribosystems encountered in industrial forging operations and relevant tool wear and failure mechanisms, such as abrasion, thermal fatigue as well as permanent deformation of tool surface.

The paper focuses on the design of the test configuration and the description of testing and measuring apparatuses.

The research work is part of the workprogramme of a European BRITE-EURAM project aimed at developing a DSS for predicting abrasive and adhesive wear in bulk and sheet forming operations.

Key words: Wear Test; Tool Wear and Failure; Hot and Warm Forging

1. Introduction

Wear is one among the principal causes of tool failure in hot and warm forging. As a consequence it influences, sometimes heavily, production cost of workpieces.

A statistical investigation [1] covering about 100 different forging geometries has showed that different types of wear are the cause for failure of about 60% of tools, as shown in Fig. 1

With the term wear a number of different mechanisms are associated, which lead to loss of substance. In hot forging the most important mechanisms are (i) abrasive wear, (ii) thermal fatigue and (iii) mechanical fatigue. To some extent plastic deformation can be added in the list, even if, strictly speaking, there is not material loss.

Which mechanism develops in a specific situation is depending on the tribological system (hereafter *tribosystem*), consisting of interacting components, such as

material pairs, interfacial elements and environment, and associated with the three groups of parameters [2]:

- *structural parameters* related to physical, chemical and technological properties of the system components;
- *operational parameters*, including the loading, kinematics and temperature conditions, and
- *interaction parameters*, which characterise the action of operational parameters on the structural components of the tribosystem and define contact and lubrication modes.

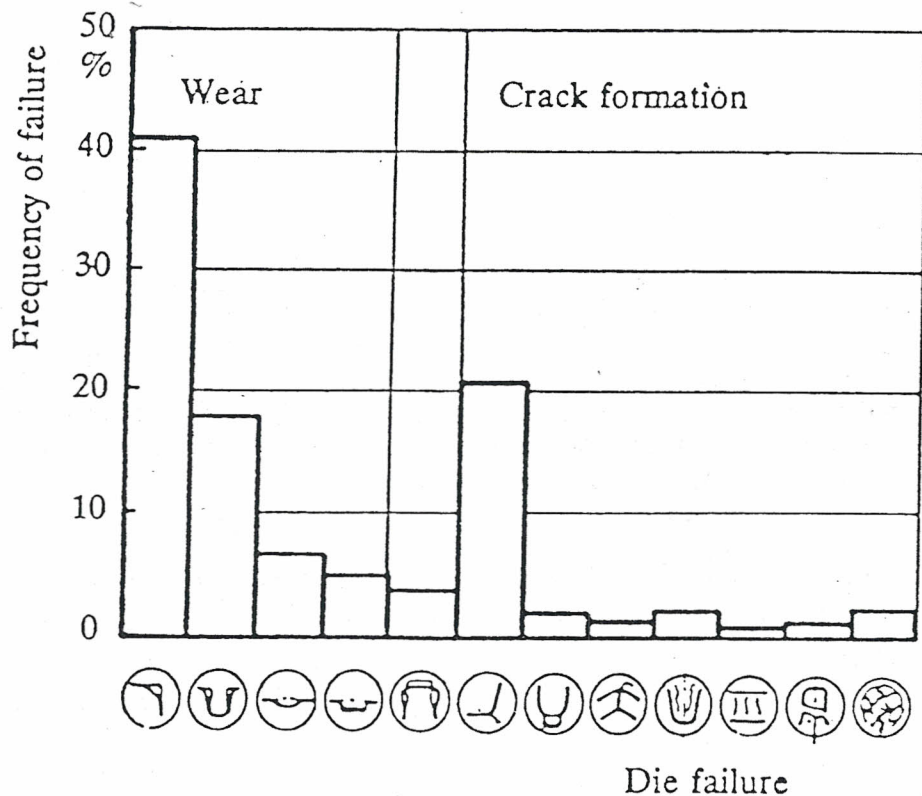


Fig. 1 - Frequency of scrapping of forging dies due to different die failures

No algorithms are at the moment available to predict tool wear, due to the large number of factors affecting it and to the different possible interactions among such parameters, then it is difficult to take wear into account when designing a forging sequence and the relevant tooling system. Attempts to study phenomena connected to wear development has lead to a number of tests which have also been classified into categories [3], depending on dimensions and similarity with industrial processes. Reviews of tribotests related to bulk forming operations are in [4] and [5]. Recently a number of tests addressed to study wear in hot forging have been proposed; examples are presented in [6], [7] and [8].

The work described in this paper is part of a BRITE Project aimed at developing algorithms to predict tool wear in hot and warm forging and sheet forming. Among Authors tasks within the project, the design and setting up of a wear test for hot and

warm forging is presented. This laboratory simulative test has been designed and set-up with the twofold purpose of (i) verifying the applicability of wear micro-mechanical models in simulation of hot and warm bulk metal forming operations using FEM codes and (ii) evaluating wear parameters by an inverse numerical technique.

1st Level	2nd Level	3rd Level	CUSTOM REQUIREMENTS
DESIGN A MEANINGFUL RELIABLE AND ECONOMICAL LABORATORY TEST	TEST SHOULD BE ECONOMICAL	3.1.1	ECONOMICAL SPECIMEN
		3.1.2	ECONOMICAL EQUIPMENT (PRESS, TESTING MACHINE)
		3.1.3	ECONOMICAL TOOLING SYSTEM
		3.1.4	AUTOMATIC SPECIMEN LOADING AND UNLOADING
	TEST OPERATING CONDITIONS MUST BE REPEATABLE	3.2.1	OPERATING CONDITIONS REPEATABLE CYCLE BY CYCLE
		3.2.2	REPEATABILITY OF TESTING CONDITIONS ON DIFFERENT EQUIPMENTS
	WEAR DATA MUST BE EASY TO MEASURE	3.3.1	MEASURING AREA EASY TO ACCESS
		3.3.2	MEASURING AREA WIDE ENOUGH
		3.3.3	MEASURING AREA OF SIMPLE GEOMETRY
	TEST MUST BE EASY TO CARRY ON	3.4.1	EQUIPMENT AND TEST APPARATUS EASY TO SET-UP
		3.4.2	SPECIMEN LOADING EASY AND RELIABLE
		3.4.3	SPECIMEN HEATING EASY TO CONTROL
		3.4.4	FORMING OPERATION EASY TO CONTROL
		3.4.5	SPECIMEN UNLOADING EASY AND RELIABLE
		3.4.6	SPECIMEN EASY TO MANUFACTURE
		3.4.7	TOOLING SYSTEM EASY TO MANUFACTURE AND ASSEMBLY
		3.4.8	SAFETY OF OPERATION CONDITIONS
	TEST CONFIGURATION MUST BE FLEXIBLE	3.5.1	A VARIETY OF OPERATING CONDITIONS (IN TERMS OF WEAR PARAMETERS) CAN BE EASY OBTAINED WITH THE SAME TEST CONFIGURATION

Fig. 2 - A subset of wear test requirements

2. Definition of test requirements

The design and set-up of the laboratory test have been carried out through the following steps:

- Step 1. Identification of a number of industrial tribosystems to be simulated in wear testing.
- Step 2. Conversion of the general commitment into a list of design specifications for the test.
- Step 3. Selection of appropriate test configurations for the test specimens of triboelements. This step and the following will be presented in the next chapters.
- Step 4. Selection of test geometry and specifications of structural and operational parameters.
- Step 5. Design and setting-up of testing equipment and apparatus.

To identify industrial tribosystems (Step 1), contacts with three different companies producing respectively (i) turbine blades, (ii) components for automotive industry and (iii) for earth movers has lead to the identification of a number of products which are at the same time of industrial interest and significant for wear analysis in terms of severity of the process and variety of wear mechanisms. Four main tribosystems have been identified, abrasive wear, thermal fatigue, mechanical fatigue and plastic deformation.

To translate the general commitment into test design specifications (Step 2) a sort of QFD technique has been utilised [9]. Translation has been accomplished in the four main stages: (i) organising test requirements into three levels and assigning importance ratings, a subset being shown in Fig. 2, (ii) establishing design specifications, (iii) determining the relationships between test requirements and design specifications and (iv) establishing target value for design specifications. A survey of existing similar tests determining how they compare in satisfying test specifications is also included.

3. Test geometry definition

Starting from the above considerations, the double combined piercing and upsetting of a cylindrical billet has been selected as test configuration, some of the correspondences between industrial tribosystems wear mechanisms and test configuration being represented in Fig. 3.

The test has been studied using FEM. Simulations were aimed at (i) confirming correctness of choices as concerns the deforming process and (ii) definition of its geometry in detail. From the point of view of wear development, three tribological

features can be identified on the test punches, they are (i) the cone top and edge, (ii) the cone flank and (iii) the flat surface surrounding the cone.

Simulations confirmed that tool surface reaches high temperatures and pressures during the process at the cone top and edge, thermal fatigue and plastic deformation being the mainly expected failure mechanisms in these areas.

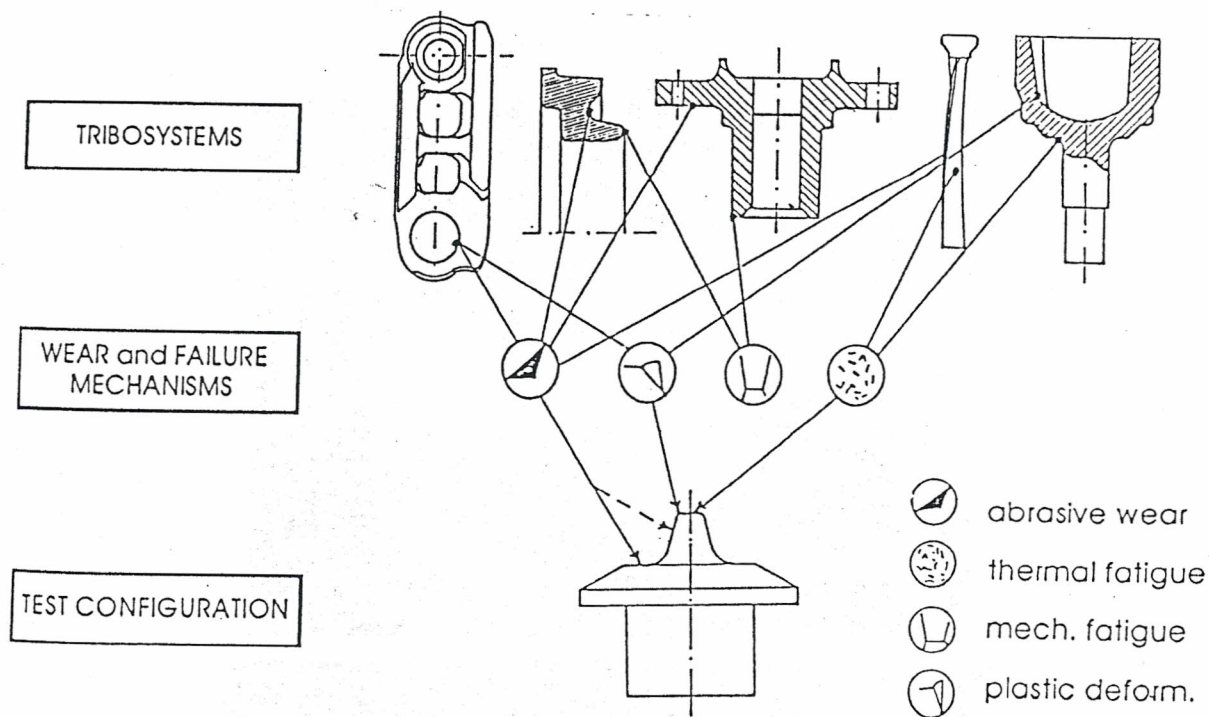


Fig. 3 - Tribosystems, wear and failure mechanisms and test configuration

On the punch flank the contact pressure is relatively low throughout the process and a sharp peak of the potential wear can develop not far from the cone top, mainly due to a long sliding length.

At the cone bottom the work material tends to separate from the punch, whilst on the flat surface a rather high and uniform potential wear develops, mainly with long piercing strokes.

The above tribological behaviour is strongly affected by the geometry of punch and billet, as confirmed by results of a sensitivity analysis based on model-material (lead) and FEM simulations. FEM was then used for a detailed definition of the punch geometry.

The sensitivity analysis has led to the choice to use two different profiles for the two pairs of test punches to study abrasive wear as result of different contact conditions. Fig. 4 shows the results of a couple of simulations with the chosen punches. Both punches are 40 mm large at the maximum diameter, to fit the seat on plates. One cone height is 16 mm, the other 7 mm.

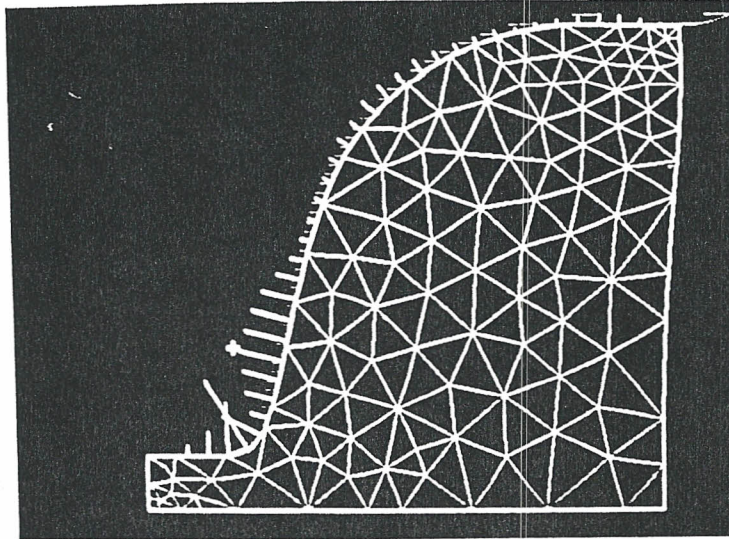
The specimen is a circular cylinder $\Phi 30 \times 48$. The bar diagrams along punch profiles are indications of expected abrasive wear based on the following simplified model:

$$U = \int_0^t \sigma_n * v_t * dt$$

where:

U is the expected abrasive wear,
 σ_n is the normal stress, and
 v_t is the tangential sliding velocity.

a)



b)

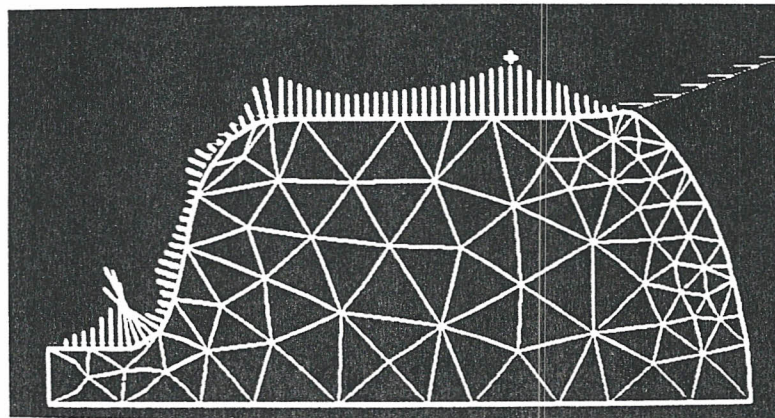


Fig. 4 - FEM predictions of potential wear distribution

On the cone top and edge of the slender punch higher temperatures are reached during the forging cycle. On its flank higher abrasive wear derives from a longer sliding length and relatively low normal pressure (Fig. 4a). On the flat surface surrounding the shorter punch high wear is due to high normal pressure and short sliding length (Fig. 4b).

4. Testing apparatus, equipment and procedure

The test has been designed to be conducted on a Gleeble 2000 testing apparatus. Gleeble 2000 (Fig. 5) is a device capable of a wide set of tests for data generation and step-by-step process replication in the area of material forming technology. In

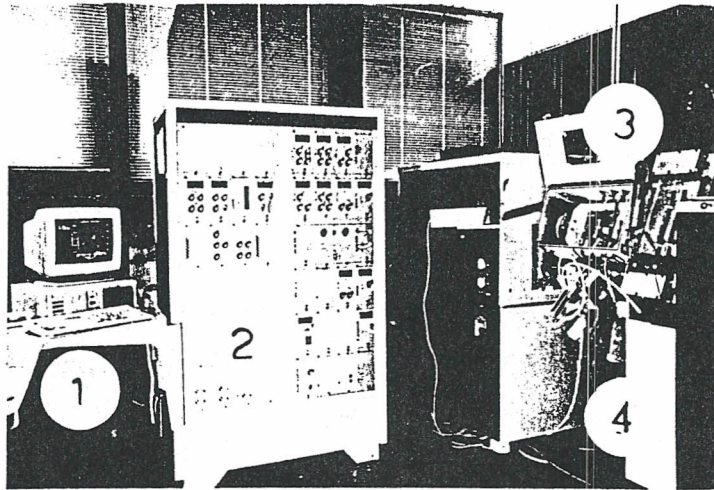


Fig. 5 - The Gleeble 2000 System. (1) Computer control and acquisition console, (2) manual control console, (3) testing unit, (4) hydrowedge unit.

the specific field of metal forming process the testing capability of the System includes tests to measure true stress - true strain curves at different temperatures and strain rates, workability, friction and heat-transfer coefficient at workpiece-die interface. As concerns thermal/mechanical cycle replication, the Gleeble Hydrowedge combo permits precise reproducing, under computer control, of strain, strain rates, temperatures and forces.

The general characteristics of Gleeble 2000 system can be summarised as follows:

- maximum force available to apply to specimen : 200 kN
- maximum stroke rate: 2 m/s
- maximum power available for specimen heating: 150 kW
- maximum punch stroke: 100 mm
- maximum counter-punch stroke: 30 mm

The general testing apparatus consists of the following subsystems:

- a furnace, to heat specimens to the test temperature,
- the Gleeble system, and
- auxiliary devices for loading and unloading of specimens.

Fig. 6 shows the loading and deforming equipments

The wear test cycle consists of the following five stages:

- *Stage A: Heating* The specimen is heated at the prescribed temperature in an extra furnace. The furnace temperature is set slightly above the work material forging temperature to take into account the transfer time to the Gleeble System.
- *Stage B: Lubrication and loading* The two plates supporting the forming punches are in the backward position. Lubricant is sprayed on punches and, at the same time, the specimen is loaded from the feeder between punches.

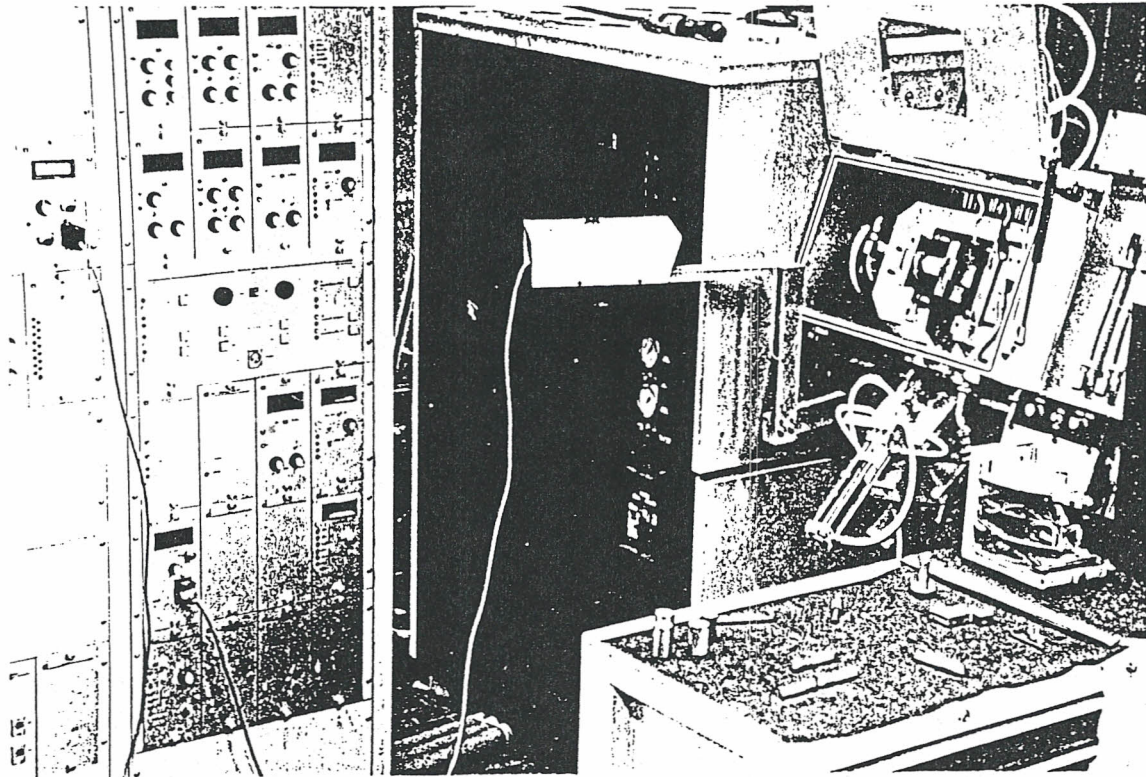


Fig. 6 - The loading and deforming equipments

- *Stage C: Deformation.* The specimen is deformed at the prescribed strain and strain rate between the two punches. Punch and counter-punch are controlled independently by the stroke unit and hydrowedge unit respectively.
- *Stage D: Unloading.* The specimen is ejected by the ejection plate during the return stroke of the forming punches and then unloaded.

During the test the following process parameters are measured: temperatures of both specimen and punch, strokes of punches and force. To measure surface temperature of punches, type K thermocouples are embedded into one punch at several near-surface locations. Surface temperatures are reconstructed using an inverse numerical technique.

5. Preliminary results

Some tests have been conducted. Preliminary series have been mainly aimed at assessing reliability of the testing apparatus and at tuning FEM simulations. In the second phase some sets of specimen have been deformed; at the moment an electric furnace is used to heat specimens, in the definitive configuration an induction furnace will be used to assure higher repeatability and faster heating. Test Work material is UNI C53, punch material is X37CrMoV5.

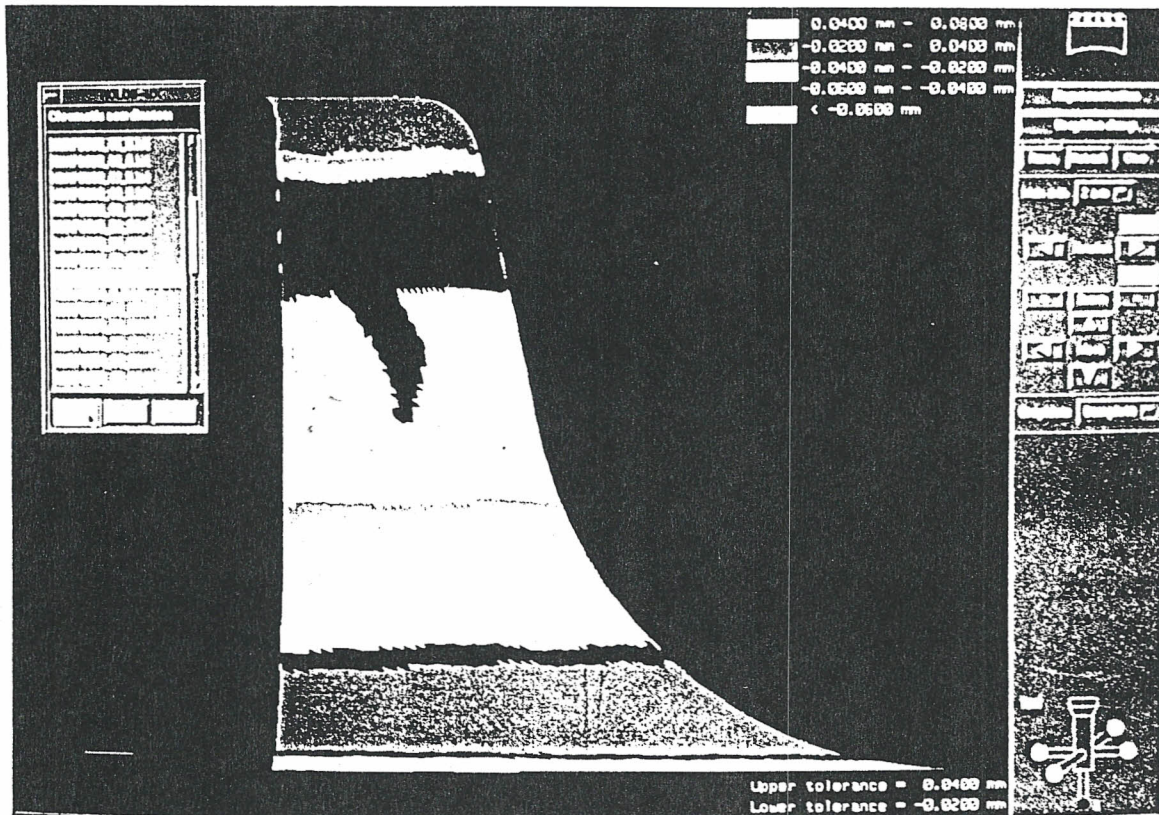


Fig. 7 - Evaluation of punch profile changes

A UMM 550 Zeiss Coordinate Measuring Machine is used to measure dimensional changes after tests. Dimensions will be evaluated on specimens at fixed intervals of punch life in order to study effects of wear development on deformation. At the moment some preliminar measurements have been conducted on punches to analyse profile modifications, some results being presented in Fig. 7.

6. Conclusions

A simulative wear test for hot and warm forging tools has been developed with the twofold purpose of (i) verifying the applicability of wear micromechanical models in simulation of hot and warm bulk metal forming operations using FEM codes and (ii) evaluating wear parameters by an inverse numerical technique.

Test configuration is simple and embodies many of the tribosystems encountered in industrial forging operations and relevant tool wear and failure mechanisms, such as abrasion, thermal and mechanical fatigue as well as permanent deformation of tool surface.

Acknowledgements

The work presented in this paper is part of the BRITE-EURAM research project No. BE-5248-92 sponsored by the European Union. The authors wish to thank the Italian forging companies Berco SpA, Carraro SpA, Pietro Rosa TBM and Teksid Spa for their collaboration in providing data on industrial tribosystems. The European Union is gratefully acknowledged for the financial support.

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