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CHARACTERIZATION OF Ti AND Ni ALLOYS FOR HOT FORGING : SETTING-UP OF AN EXPERIMENTAL PROCEDURE.

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ABSTRACT:
There is a growing interest in the application of Titanium and Nickel alloys forged components in the aerospace and Hi-Tech industry.
Hot forging of these alloys requires a precise definition and control of operating parameters, such as forging temperature, punch speed and lubricant.
A procedure is presented to obtain true stress true strain curves for Ti and Ni alloys at hot forging conditions, that is especially designed to guarantee homogeneity at deformation and temperature in the specimen during the overall compression test.

1. INTRODUCTION

Materials sensitivity to the temperature and strain rate should be carefully considered when forming processes are designed, due to the high influence of these parameters on a successful and correct production. From an industrial point of view, forming processes require, as much as possible,

- high rates of working, which are desirable for reason of economy and to minimise heat transfer ,
- high temperature, in order to reduce material's resistance to deformation.

The knowledge of the behaviour of metals as a function of temperature, strain and strain rate is a basic step for (i) optimising the industrial process and (ii) dimensioning the forming machines tooling-set. To obtain data on the characteristics of the materials it is important that temperature, strain and strain rate replicate the parameters of the real process.
The precise characterisation of the material is a fundamental step when the forming process is designed for Ti and Ni alloys components, which have a growing applications in hi-tech industry (aerospace and aeronautics). These alloys present a narrow range of temperature, strain and strain rate for the formability. For these reasons a particular care should be taken in fine controlling these parameters during the test.
This paper is focused on the optimisation of a procedure for determining the behaviour of these alloys at forging condition. The procedure should be set-up in order to:

- assure homogeneity of deformation and temperature in the specimen during the whole compression test;
- evaluate true stress-true strain curves of Titanium and Nickel alloys in hot forging condition.

2. **THE EQUIPMENT IN PHYSICAL SIMULATION**

Methods and equipment used in physical simulation depend upon the process to be studied. The physical simulator should offers a wide range for thermal and mechanical parameters, in order to replicate the operating condition of the real process. When these requirements are satisfied, it is possible to replicate the thermal mechanical history on the specimen and to determine the effects of thermal (temperature and heating/cooling rate) and mechanical parameters (strain and strain rate) on material and process.
There are different kinds of testing machine [l]:

- *servohydraulic loadframe connected to a furnace or an induction heater.* This system is satisfactory for process applications where the temperature is changing slowly during the process;
- *cam plastometer*. The simulation takes place at one defined temperature. It can be considered a single 'hit' device. Multiple 'hit' programs are possible in principle, but the time to change strain rates and temperature, usually make the replication of multy stage forming processes very difficult or impossible;
- *torsion testing machine*. The tester provides shear data for simulation in a wide range of strain rates (up to 100 1/second) and strains. The most notable benefits of torsion testing are the large amount of strain possible without necking or barrelling, typically up to strain of 5.0. The temperature is usually hold constant or may be changed at slow rates.

A GLEEBLE 2000© system installed at DIMEG's lab in Padua, has been utilised to conduct the tests presented in the paper. It is an electronically controlled, hydraulically operated testing machine used for:

- thermal and mechanical analysis of materials for research,
- quality control,
- process simulation, and
- a wide variety of metallurgical studies.

Accurate temperature control is the significant characteristic of the Gleeble machine.

Specimen temperature is monitored by a thermocouple spot welded on the specimen surface and the heat input and rate are controlled according to a predetermined programmed cycle chosen by the researcher. The system can be consider as a sophisticated *universal testing machine* capable of heating rates of 10.000 °C/s, speed of 2000 mm/s with a maximum load of 20 tons. The two servo hydraulic systems can assure precise strain and strain rate even in a multiple-hit test. Strain can be measured by means of either a crosswise gauge or a lengthwise gauge; in both cases stress evaluation is based on the assumption of constant volume and section area. To satisfy this condition no barrelling should develop during the test. At this regard, it should be noted that barrelling is influenced by axial gradient of temperature, as well as by friction at the interface specimen-anvils. In order to reduce the barrelling effect [3] friction at the interfaces and temperature axial gradient should be minimised, as well as slenderness ratio (l/d) should be optimised.

3. THE TESTS

Most metalworking processes involve compressive deformation: for this reason the uniaxial compression test [4,5] has been widely used for studying metals workability and characteristics.

In the present work, Titanium and Nickel alloys behaviour, in forging conditions, is studied. Due to the high sensitivity of these alloys to the working temperature, strain and strain rate, some difficulties may arise in the hot upsetting [6] of a cylindrical specimen:

- axial temperature gradient;
- specimen end surfaces cooler than mid section;
- non uniform deformation during the test.

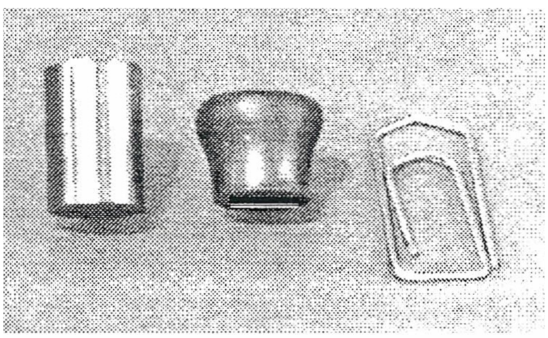


Fig. 1

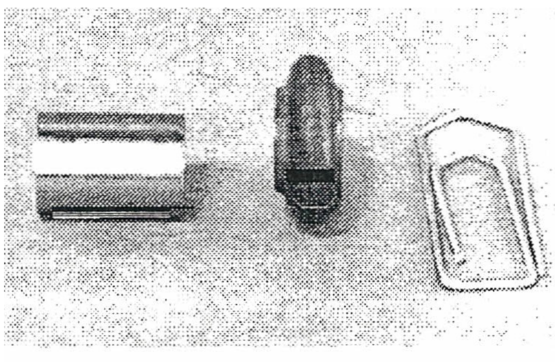


Fig. 2

Fig. 1 shows a Ti-6Al-4V specimen that presented a non uniform temperature distribution along the axis ; in Fig. 2 it is evident the final deformation of a specimen (same alloy) with the end surfaces cooler than mid section.

The Gleeble heating systems is based on Joule effect: the current passes through the specimen and heat it up. With this system isothermal planes are obtained in the specimen, but an axial gradient is introduced due to the cooling effect induced by the punches. In order to reduce the axial gradient the following measures should be adopted:

- reducing heat loss from the end surfaces with a thermal barrier;
- increasing electrical resistance of the surfaces in order to increase temperature;
- reducing mass ratio between punches and specimen.

The system is equipped with several adjustments, which allow to operate on a wide range of specimen, as concerns size, shape and resistivity. Thermal power should be selected according to the requirements relevant to specimen size, heating rate and thermal distribution. The combination of nine transformer taps with a switch for four different specimen sizes provides the most suitable power range depending on the specimen characteristics; the best switches combination gives the minimum thermal gradient along the specimen axis.
The following three kinds of test [7] have been conducted to reduce barrelling:

(i) heating tests for selecting the right thermal power of the system;
(ii) tests with conventional lubricant;
(iii) tests with different layers of lubricant.

(i) heating tests for selecting the right thermal power of the system

Several tests have been conducted on Φ12x14 mm long specimens heated in the range 600-900 ° C without lubricant (scheme in Fig. 3). The measurement of the specimen axial gradient has been done in steady conditions (60 seconds after reaching the programmed temperature).
Four thermocouples were spot welded inside four

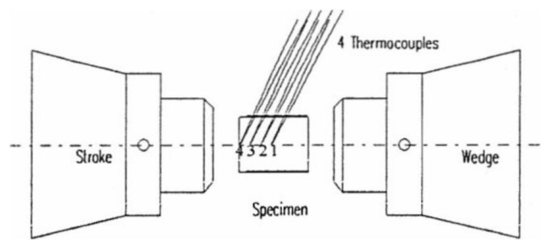
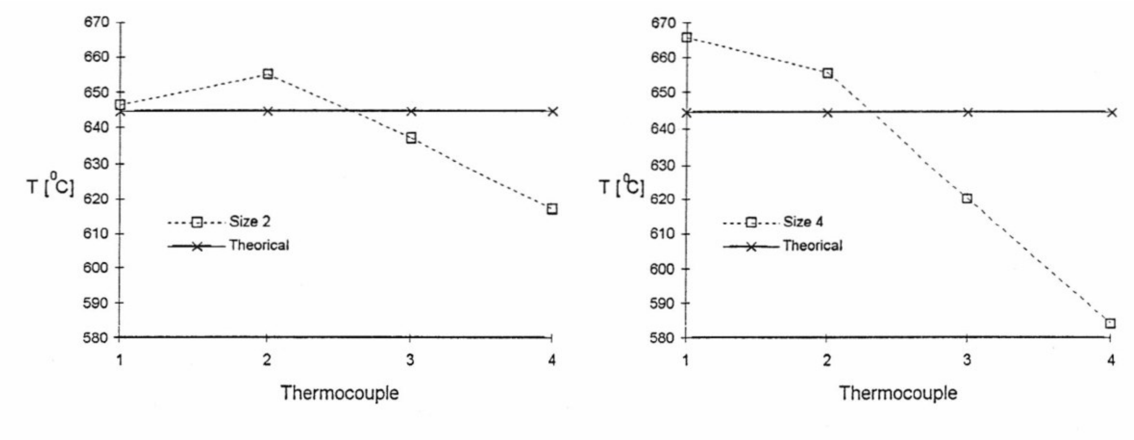


Fig. 3

drilled holes to place them at the specimen core. Best combination of switch positions and taps have been investigated. Fig. 4 (a) and (b) show respectively the result of measurements at 645 ºC in the best and in the worst condition. It is evident that even in the best situation (a) the maximum Δt, close to 35 °C, is not acceptable.

(ii) tests with conventional lubricant

Isothermal conditions are important in flow stress measurement. When a thermal gradient exist along the axis of the specimen, barrelling occurs during deformation, no matter what lubricant is used (Fig. 5).



(a) *Fig. 4* (b)

Three different lubricants, MoS_2 powder, graphite foil and tantalum foil have been tested [8] with the twofold aim to reduce:

- friction at high temperature;
- heat loss introducing a thermal barrier.

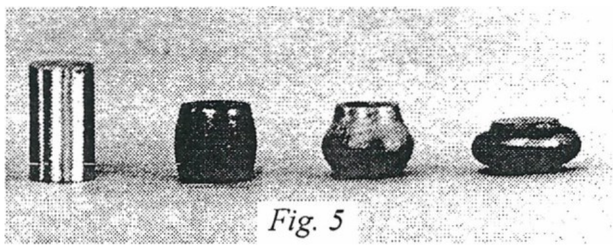


Fig. 5

MoS_2 powder is relatively simple to use when mixed with alcohol, but some difficulties may arise during heating because of the bad electric contact between specimen and punch surfaces. It is usually applied at a temperature below 600 ^{0}C, above which it breaks into the Mo oxide.

Graphite foil can be used above 600 °C, but only if the diffusion does not become a problem. During tests at high temperature a piece of tantalum foil can be utilised between the specimen and the graphite foil as a diffusion barrier and to protect graphite from high temperature, avoiding self burning.

Tantalum foil is used for two reasons: it is a good thermal barrier and, due to its resistivity, increases the electrical high resistance at the punch-specimen interface.

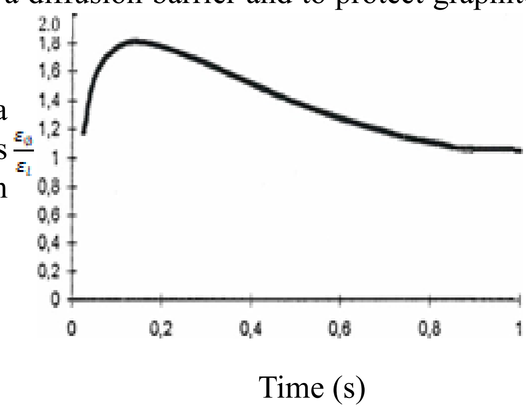


Fig. 6

The best results have been obtained with tantalum-graphite foils, but they aren't acceptable in term of temperature distribution and final deformation : barrelling is still evident in Fig. 6 that shows the ratio between $\varepsilon_{\emptyset}$ (strain calculated with a crosswise gauge) and ε_{l} (calculated with a lengthwise gauge).
In an ideal condition, assumed volume constancy and uniform deformation, the ratio should be equal to 1 during the whole test.

(iii) tests with different layers of lubricant

The solution tested by the authors is a kind of "sandwich" of lubricants. It has been noticed that using tantalum-graphite foils, the thermal gradient along the specimen axis is reduced.

Several tests with different combinations of Thermocouples lubricants have been performed. Fig. 7shows the final solution:

- MoS_2 applied on the specimen surface,
- a sandwich with two graphite foils with two tantalum foils on each side of the specimen.

This configuration gives the best results as concerns temperature and deformation uniformity.

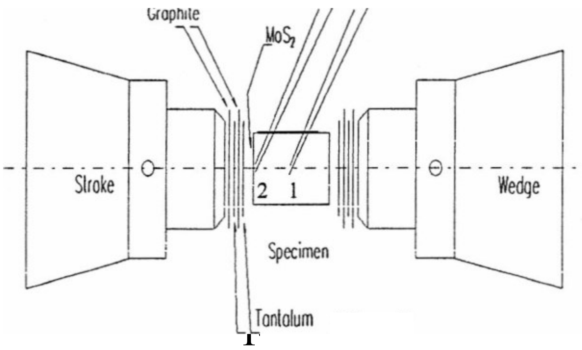
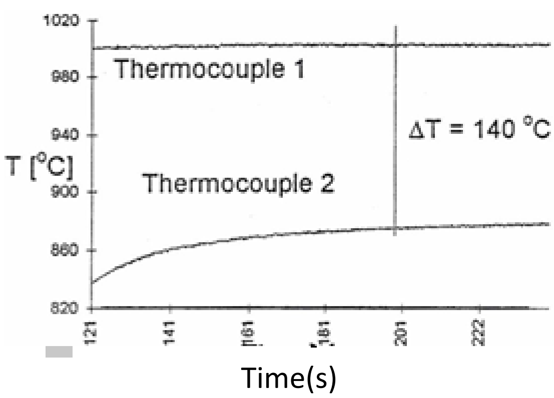
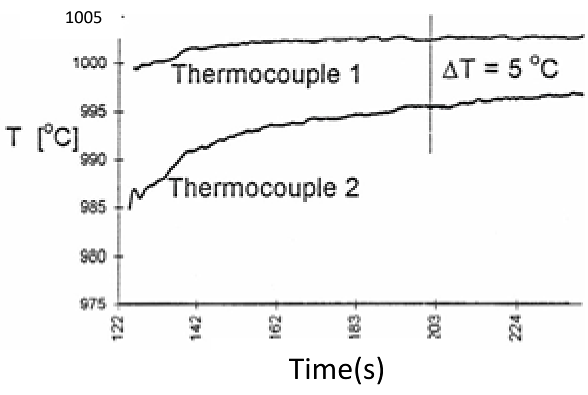


Fig. 7

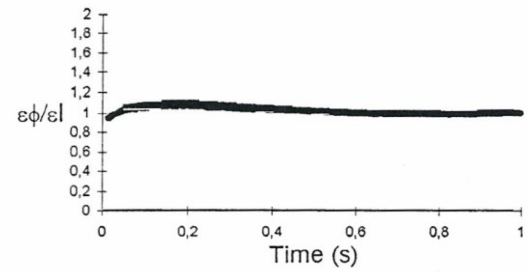
As concerns temperature, the gradient is highly reduced: Fig. 8 shows the difference of the measured temperature between thermocouple 1 and 2 (see Fig. 7) after 200 s from the beginning of test: (a) is relevant to the test with both graphite and tantalum foils, (b) the same test with the multy-layered "sandwich". It can be noticed that in the second configuration the temperature gradient is reduced to 5 degrees.





(a) Fig. 8 (b)

Good results have been obtained even in terms of deformation using the "sandwich". Fig. 9 presents the $\frac{\varepsilon_\phi}{\varepsilon_l}$ ratio during the test, which is almost constant and close to 1 (ideal condition). Fig. 10 shows the deformation of the specimen during the test where barrelling can be neglected.



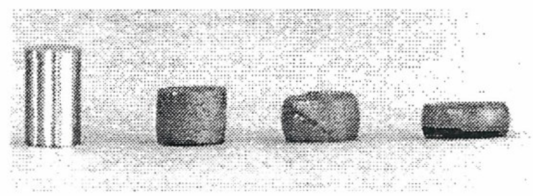


Fig. 9 Fig. 10

4. CHARACTERISATION OF Ti AND Ni ALLOYS

The developed test configuration allowed the characterisation of materials which present high sensitivity to temperature and strain rate[8].
True stress - true strain curves have been calculated for Ti-6Al-4V in the following conditions:

- Temperature 850, 880, 910 ºC
- Strain rate 1, 3, 5, 7, 9 1/s

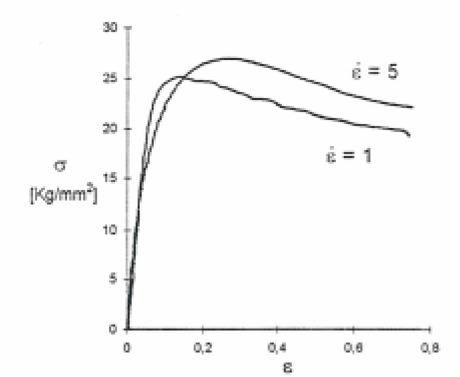


Fig. 11

As example of this characterisation two true-stress vs. true-strain curves at 850 ºC are presented in Fig. 11.
Operating conditions relevant to a complete forging sequence have been simulated for Nimonic 80A alloy. The test has been focused on the evaluation of the material response to forming operations where small amount of deformation per step has been performed at strain rates in the range of 4-10 1/s:

- heating up to 1150 ºC in 1 minute;
- soak time at temperature for 30 s;
- deformation at 4 1/s with 2.3 as amount strain;
- holding specimen for 15 s;
- re-heating up to 1150 ° C for the next deformation.

Four stages as described above have been performed at strain rate of 4, 5, 7, 9 (1/s). Fig 12 shows the four curves at different stages of strain.

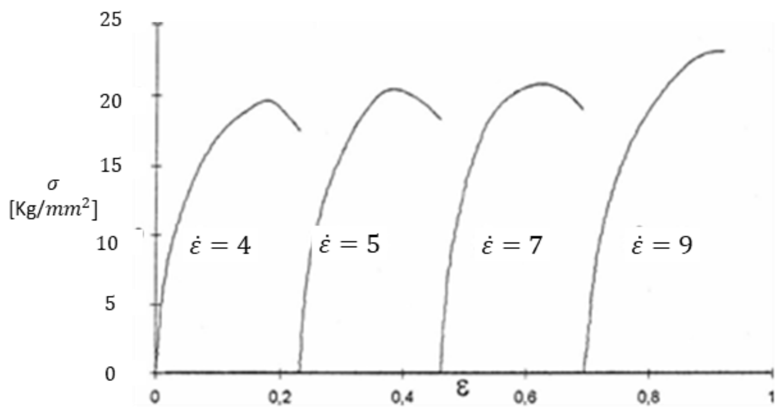


Fig. 12

5. CONCLUSIONS

Some progress in the setting-up of the procedure to characterise materials such as Ti and Ni alloys have been presented. Effects of different lubricants as concern temperature uniformity and barrelling have been investigated. A multi-layered lubricant, tantalum, graphite and MoS_2, has been tested giving good results due to its effects (thermal and diffusion barrier, lubricant, local increase of resistivity). Using this sandwich the Ti-6Al-4V and Nimonic 80A materials have been characterised.

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