DIGITAL IMAGING CORRELATION AS A USEFUL TOOL OF ANALYSIS OF HOT CUTTING PROCESS

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ABSTRACT: This study deals with the use of Digital Image Correlation (DIC) to investigate the physical phenomena taking place during the orthogonal cutting of a SG iron specimen at high temperature (around 1,000 °C). After having recalled the scientific and industrial context, the experimental procedure developed to record the pictures of the tool covered with a speckle pattern at a frequency of 10,000 Hz (thanks to a high speed camera) is explained. The quantitative exploitation of these recordings is leading to a first set of results showing how the cutting speed and the rake angle of the tool have an influence on the physics of the cutting operation.

1. INTRODUCTION - CONTEXT

In the very competitive context in automotive industry, suppliers are trying to develop new materials and processes that can fit the requirements of the desired applications while being cheaper. This is the case of the production of rods that are traditionally forged. Some efforts are currently made to try to produce cheaper rods by casting, taking advantage of the high mechanical properties of ADI products (austempered ductile iron). These products are made from SG cast iron submitted to a specific thermo-mechanical treatment leading to the high properties of ADI. In particular, these products are isothermally heat treated in austenitization temperature range (around 1,000 °C) for stability of the austenite phase. To reduce costs, efforts are made to perform the spruing operation (separation of the feeder head of the product from the finished part itself) just after the austenitization heat treatment, without waiting for the product to cool. Nevertheless, this spruing operation sometimes induces unacceptable deep cracking damages on the rods (Fig. 1).

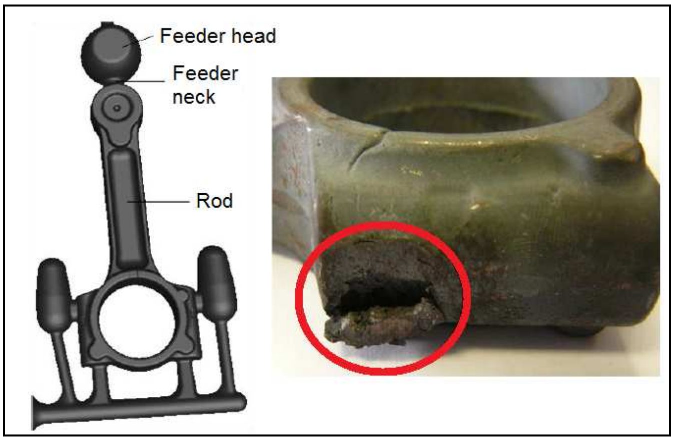

Figure 1- Cast rod before and after the spruing operation that has induced a deep cracking damage (surrounded zone) [1].

A first study has identified that the existence or absence of dynamic recrystallization during the cutting (as a microstructural transformation) explains the quality of the cut surface and has drawn a first set of experimental recommendations for manufacturers to avoid defects [1]. As a continuation, an investigation of the tool/material interaction has been carried out in the present study by the exploitation of the digital image correlation (DIC) in accordance with the previous study.

2. EXPERIMENTAL PROCEDURE

To experimentally reproduce the physics of the spruing operation, a hot cutting test bench has been designed. It consists in an orthogonal cutting device on which a simple parallelepipedic specimen with a pin element of diameter Φ and height h (reproducing the feeder neck) is clamped and machined at an austenitization temperature range (around 1,000 °C).

As the temperature of the specimen during the test does not allow putting a valuable and optically contrasted pattern onto it in order to directly measure its displacements and strains, the idea has been to study the displacements of the tool during its interaction with the specimen to get some relevant information.

To perform the full-field measurement, the digital image correlation has been set up. This well-known technique consists in calculating the displacements of joined regions of interest (the "subsets") between an initial and a deformed state by maximizing a correlation coefficient [2]. To perform this, the observed area has to be textured with some random pattern. In the present study, this pattern has been simply obtained by spraying some black painting onto the surface of the tool previously uniformly painted in white. Due to the dynamic nature of the test, the pictures have been recorded at a frame rate of 10,000 images per second thanks to a high speed camera (Photron Fastcam SA5). Several cutting configurations have been tested, changing the two main influent parameters: the cutting speed (three tested: 0.8, 1.2 and 1.7 m.s^{-1}) and the rake angle of the tool (three tested: -10°, 0° and +10°).

To sum up the arrangement of the experimental bench, a schematic view of the experimental setup is shown in Fig. 2.

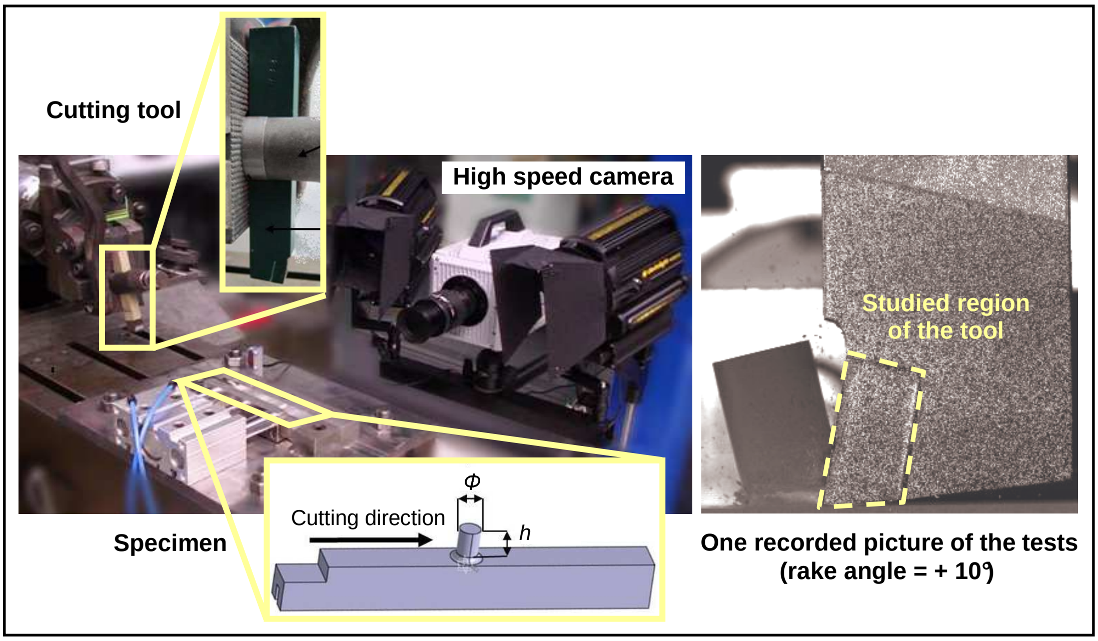

Figure 2- Schematic view of the experimental setup

3. RESULTS AND DISCUSSION

From the recorded pictures, the displacements have been computed by the DIC algorithm over the surface of the tip of the tool that is constituted by an insert in cobalt base superalloy ("studied region of the tool' on Fig.2). Assuming that this insert is not submitted to large strains (apart from its tip) and, thus, that its displacement is more or less uniform, the maps are then averaged all over the surface to get a single value of $U_x(t)$ and of $U_y(t)$ with a better resolution (since the averaging increases the signal/noise ratio).

Fig. 3 shows the $U_y = f(U_x)$ curves got for the different testing configurations. The curves start with the beginning of the interaction between the tool and the specimen ($U_x = 0$) and finish with the ejection of the pin element (the max value of the U_x scale corresponds to the value of Φ). These curves can be interpreted as the trajectory of the tool tip within the specimen.

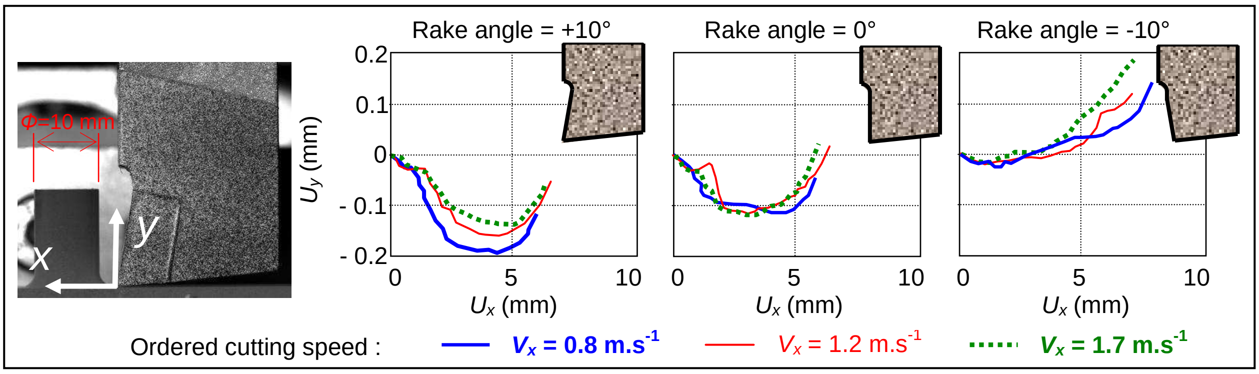

Figure 3- $U_y = f(U_x)$ curves for the tool within the specimen for the different testing configurations

It can be seen that there are several functioning regimes. In particular, the rake angle completely conditions the way the tool interacts with the specimen:

- For a positive (+10°) or a null rake angle, the to ol tip first penetrates within the material with a negative value of U_y (the tool goes down within the specimen) before ejecting the pin element after a short increasing of U_y (the tool goes back up). The pin element is finally ejected after a crossing of the tool within the material of about 60 % of the width of the pin element. The difference between the two rake angles is that the penetration is deeper with the positive rake angle.

- For a negative rake angle (-10°), the tool never goes down within the material. It monotonically goes up leading to a bending of the pin element (as the cutting edge of the tool is not the first to hit the specimen due to the negative rake angle) before its ejection after a crossing length of about 75 % of its width.

The difference of mechanisms induced by the rake angle (pure shear with the positive or the null rake angles and bending of the pin element before its shear with the negative one) has already been observed in [1]. The damaging of the cut surface appears only for a negative rake angle with a relatively high cutting speed (1.7 $m.s^{-1}$).

On the curves plotted in Fig. 3, the effect of the cutting speed is quite obvious for the +10° rake angle: the lower the speed, the deeper the penetration. This can be explained by a switching between a quasi-static regime, for which the tool has “plenty of time” to deform to accommodate the solicitation, and a dynamic regime for which it is not the case anymore. This is less obvious for the other angles.

Nevertheless, for the - 10° rake angle, after a traveled distance of 50 % within the specimen (*i.e.* U_x = 5 mm) for which the three curves are superimposed, they are separated and one can see that the higher the speed, the higher the U_y. This observation can bring some qualitative explanation for the effect of the speed: for higher cutting speed values, the tool is going upper and this induces (for an identical cutting force) a higher bending moment. As the solicitation at the base of the pin element is composed of both shear and tensile stresses (due to the bending), when the tension becomes overriding, the fracture mechanism changes: it is not anymore ductile fracture by shearing but brittle fracture by tensile stresses leading to some wrenching inducing a damaged cut surface showing a deep crater (Fig. 4).

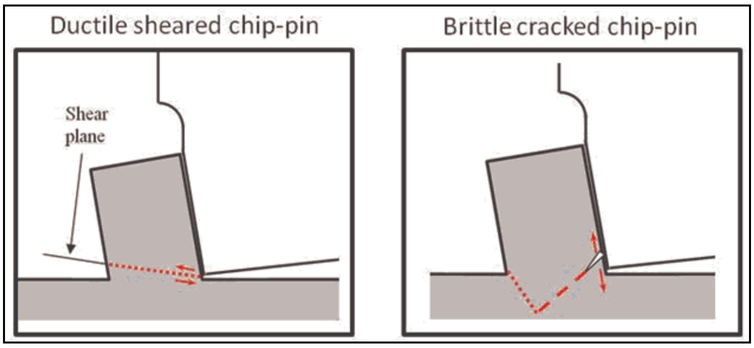

Figure 4- Fracture mechanisms for a negative rake angle of the tool (from [1])

4. CONCLUSION

This study has shown the interest of studying the displacement of the tool during the hot cutting operation of a SG iron specimen to better understand the damaging process of the obtained cut surface. Indeed, this approach has demonstrated its capacity to confirm and give confidence to the conclusions previously made on the same experimental configuration and to explain the physical influence of the cutting speed on the fracture mechanisms observed.

This work will be continued in two main ways:

- The results obtained from the displacements of the tool will be compared with the ones coming from load measurements;
- The temperature of the specimen will be changed (over a range going from 500 to 1,000°C) to try to characterize the thermo-mechanical behaviour of SG cast iron during a cutting operation.

5. REFERENCES

1. Fouilland, L. and El Mansori, M. (2012) Experimental study of the brittle–ductile transition in hot cutting of SG iron specimens. *Journal of Materials Processing Technology*, doi:10.1016/j.jmatprotec.2012.08.012
2. Sutton, M.A., Orteu, J.-J. and Schreier, H. W. (2009) *Image Correlation for Shape, Motion and Deformation Measurements*, Springer