# Chapter 15
# Dynamic VFM to Identify Viscoplastic Parameters. Analysis of Impact Tests on Titanium Alloy

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**Abstract** The present work aims at identifying an elastic-viscoplastic material behavior over a wide plastic strain and plastic strain-rate range (up to 0.1 and 1000 $s^{-1}$ respectively), using the Virtual Fields Method. Image-Based Inertial Impact tests have been performed on the Ti6Al4V titanium alloy. The strain-rate dependency of the material has been identified with the results provided by these tests and compared to references.

**Keywords** Titanium alloy · Johnson-Cook · Virtual fields method · Full-field measurement · Viscoplasticity

## Introduction

Normalized tensile tests performed at different constant strain rates are regularly used to study the strain-rate dependency of the mechanical behavior of metallic materials. The strain-stress responses are successfully used to identify parameters of hardening and viscoplastic models. However, the method is costly due to the large number of specimens to be tested to investigate a wide range of strain rates, mostly because of the required hypothesis of constant stain rate during loading. In addition, a very limited number of loading directions are usually studied with the method. The present work aims at identifying viscoplastic model parameters over a large plastic strain and strain-rate range using the dynamic Virtual Fields Method (dynamic VFM). The dynamic VFM is a very promising method to identify material model parameters based on an inverse approach and full-field measurements of displacements only (no contact measurement). It can be based on a limited number of impact tests thanks to the full exploitation of non-homogeneous strain, strain-rate and stress state generated in the specimen. The complete experimental setup was designed using simulated image-based numerical process (e.g., specimen shape, impact conditions, spatial and temporal regularization parameters). In the present work, the experimental set-up is presented, the impact tests performed on a titanium alloy are described, the results are discussed, and an identification of a viscoplastic model is proposed with the dynamic VFM.

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## Image-Based Intertial Impact Tests

Image-Based Inertial Impact (IBII) method has been recently proposed [1, 2] to take advantage of the dynamic VFM. Among existing inverse methods, the dynamic VFM enables the identification of material parameters with the sole knowledge of the strain and acceleration fields (Eq. 15.1). In particular, the dynamic VFM does not require the knowledge of any external loads, thus avoiding the use of an intrusive sensor (e.g., accelerometer, strain gauge, …) which was proven to be problematic for high strain rate tests.

$$\underbrace{\int_V \underline{\underline{\sigma}}\left[\underline{X}\right] : \underline{\underline{\varepsilon}}^* dV}_{W^*_{\text{int}}} + \underbrace{\int_V \rho \underline{\gamma} . \underline{u} * dV}_{W^*_{acc}} = 0 \tag{15.1}$$

The design of the tests has been performed using finite element analysis (FEA) to generate virtual images that were processed with the same toolchain that will be used to analyse the tests results. This work has been presented in [3]. As non-linear viscoplastic behavior might need a lot of material parameters to be described, it is necessary to explore more extensively the design space in order to optimize the procedure of identification, in particular for a high yield stress material such as Ti6Al4V (973 MPa [4]). From this process three different kinds of specimen geometry (i.e., rectangular, with notches, and with a hole) have been selected. The full-field measurements are obtained over the specimen surface using the grid method and pictures recorded with an ultra-high speed camera. The strain rate dependency has been identified. Figure 15.1 shows an example of the plastic strain computed for the last stage recorded during an IBII test on a rectangular specimen.

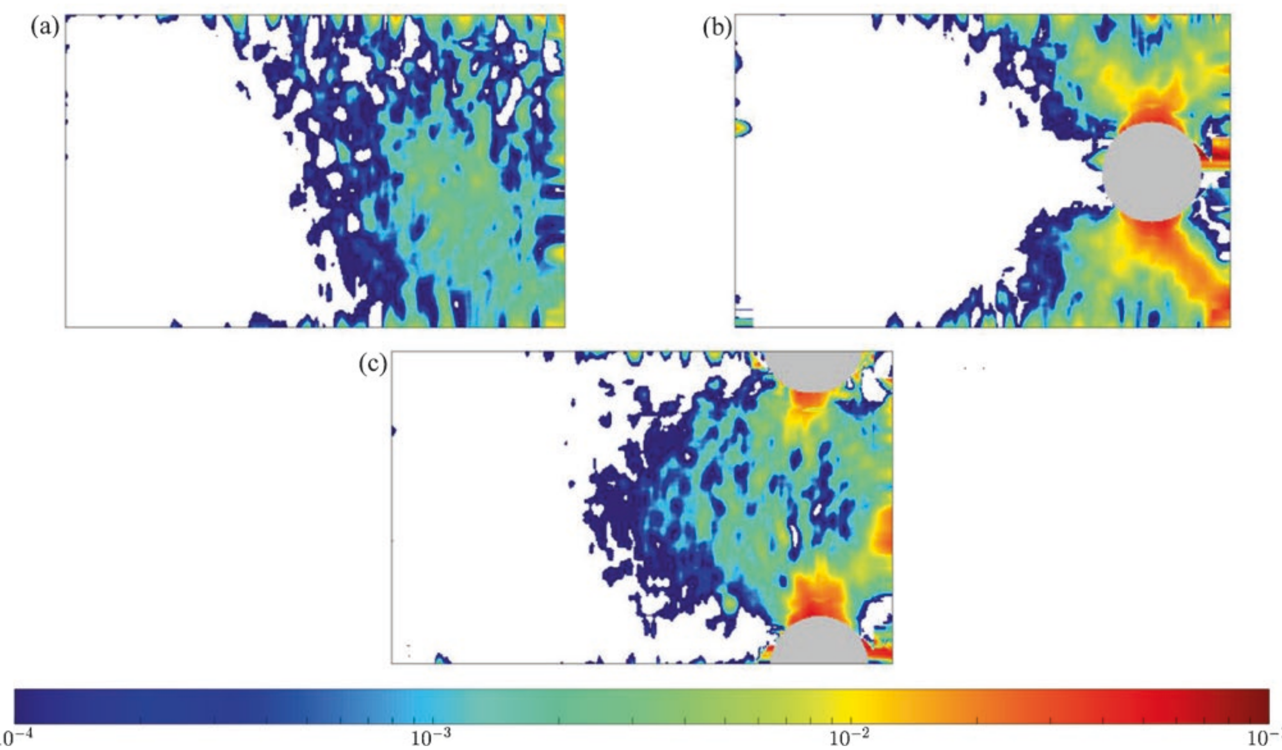


**Fig. 15.1** Typical longitudinal plastic strain at the last stage recorded during the IBII test (**a**) rectangular specimen, (**b**) specimen with a hole, (**c**) specimen with two notches

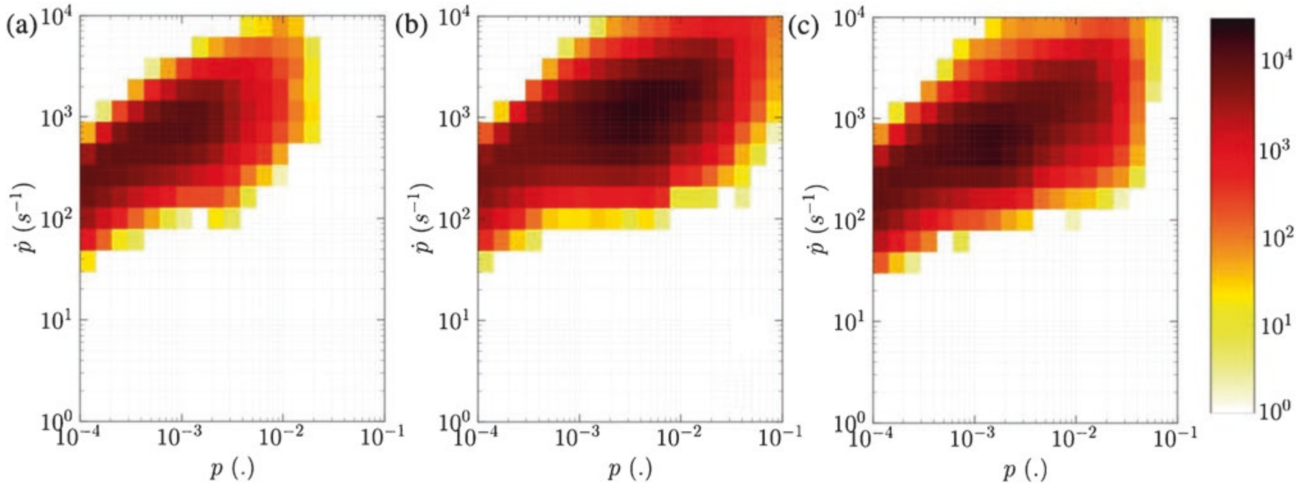


**Fig. 15.2** Viscoplasticity histogram contour at the last step recorded in the IBII experiments. (**a**) Rectangular specimen, (**b**) holed specimen, (**c**) notched specimen

## Viscoplastic Spectra Covered By the IBII Tests

One advantage in inverse methods such as the Virtual Fields Method is that inhomogeneous tests can be performed to generate a wider range of experimental data than the one that could be obtained from "standard" tests. Figure 15.2 illustrates spectra in terms of plastic strain/plastic strain rate typically recorded for each specimen geometry. It can be seen that a large spectrum is covered using only one IBII test. In terms of plastic strain rate it is mainly between 30 $s^{-1}$ to $2 \times 10^3$ $s^{-1}$ for the rectangular specimen. Also, for the same impact speed the specimens including stress concentrating geometries enable to cover a larger spectrum (between 30 $s^{-1}$ to over $10^4$ $s^{-1}$ for the specimen geometry including a hole for instance).

## Conclusion

In this study the strain rate dependency of Ti6Al4V has been successfully identified using the dynamic VFM. Very high strain rate (over $10^4$ $s^{-1}$) have been reached in the IBII tests. The next step is to compare the experimental results with those predicted by the numerical approach to better understand the sources of possible differences in the toolchain used.

## References

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