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## Axial fatigue tests on aluminum specimens with impact-induced damage

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### Abstract

The present study investigates the axial fatigue behavior of hourglass-shaped specimens made of 7075-T6 aluminum alloy subjected to localized impact damage. The specimens were impacted at different speeds using a steel sphere and subsequently tested under axial fatigue loading. The results of the experimental tests reveal similar fatigue strengths across the investigated impact speeds, with a non-monotonic trend. The data suggest that impact speed does not have a significant influence on fatigue performance within the tested range.

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### 1. Introduction

Impact damage is a critical concern in aerospace and aircraft engineering, where structural components are typically manufactured from lightweight alloys or composite materials (Starke and Staley, 1996; Boyer, 1996; Kastratović et al., 2021; Grbović et al., 2022). The collision of foreign objects with such components can produce surface dents, that are associated with the appearance of stress concentrations, residual stresses, microdamage and even material removal in the case of high-speed impacts (Peters et al., 2000; Boyce et al., 2001; Duò et al., 2007; Riccio et al., 2014; Zhu et al., 2023). These phenomena influence fatigue strength by promoting early crack initiation and accelerating crack

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propagation, leading to premature failure, as demonstrated for impact damage by Peters and Ritchie (2000), Oakley and Nowell (2007) and Martinez et al. (2002) and in other engineering situations by Kim et al. (2013), Baragetti and Villa (2015), Lepitre et al. (2024), Babić et al. (2018) and Calvo-García et al. (2025).

To support structural integrity assessments, several analyses on fatigue behavior have been proposed across various general applications (Božić et al., 2012; Milovanović et al., 2020; Basan et al., 2025; Cazin et al., 2020; Mlikota et al., 2021). Specific investigations on impact damage are present in Symons and Davis (2000), Mall et al. (2001), Ding et al. (2007), Fleury and Nowell (2017) and Zhu et al. (2019).

This study is a continuation of the previous research activities conducted by the authors. In Arcieri and Baragetti (2024) and Arcieri et al. (2021, 2022, 2023, 2025) the fatigue behavior of hourglass specimens made of 7075-T6 aluminum alloy subjected to impact damage and then to rotating bending was investigated principally through finite element analysis. In the present work, the fatigue strength of the same aluminum alloy and geometry is experimentally investigated under axial fatigue loading after impact damage. Hourglass-shaped specimens were selected due to their different curvature in orthogonal planes, which introduces a stress distribution different from that of commonly studied flat or airfoil geometries (see Frankel et al., 2012; Zhang et al., 2023; Yin et al., 2023). The global aim is to provide an evaluation of fatigue behavior in the presence of geometric complexity and localized damage. According to the experimental results obtained from the axial tests, similar fatigue strengths were observed for the different impact speeds.

### Nomenclature

|       |  |
|-------|--|
| $N_f$ | number of cycles completed in the failure load block     |
| $N_i$ | target fatigue life                                      |
| $R$   | stress ratio   |
| $L^*$ | estimated limit load range for a determined fatigue life |
| $L_f$ | load range at failure within the final load block        |
| $L_p$ | load range applied in the load block preceding failure   |

## 2. Materials and methods

Prior to fatigue testing, each 7075-T6 specimen was impacted by a steel sphere with a diameter of 5 mm and a hardness of HRC40. The impacts were applied perpendicularly to the external surface at the specimen minimum cross section using an air gun setup (Fig. 1). The impact speed was calculated using two OMRON-E3XNA11 fiber optic amplifiers and a Tektronix TBS1102C oscilloscope, used to measure the time lapse between the signals from the amplifiers. The hourglass-shaped specimen geometry was designed in accordance with ISO 1143 standard (2021). The dimensions of the specimens are reported in previous studies (Arcieri et al., 2021, 2022).

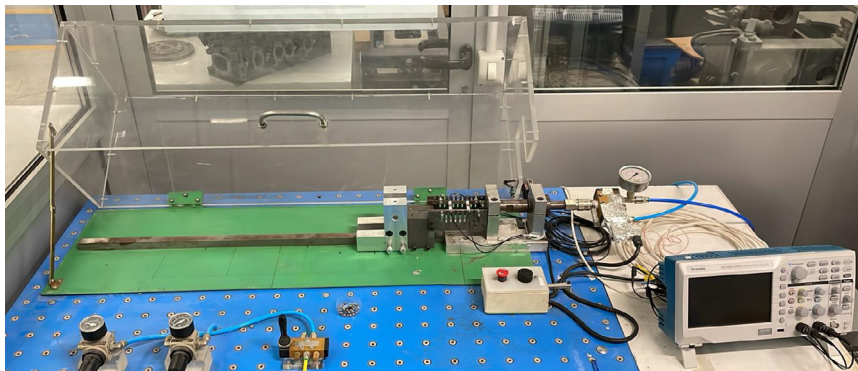


Fig. 1. Experimental setup for impact tests.

Axial fatigue tests were conducted using a servo-hydraulic testing machine. The experiments were performed at a frequency of 10 Hz, with a stress ratio  $R \sim 0$ , following the step loading method proposed by Nicholas (2002) and applied by Baragetti and Villa (2015) and Baragetti et al. (2016). This procedure consists of applying a sequence of constant-amplitude load blocks of  $N_i$  cycles, where  $N_i$  is the target fatigue life, here set to 200,000 cycles. If the specimen runs out in a given load block, a higher load amplitude is applied in the next one. The limit load range  $L^*$  for the fatigue life of  $N_i$  cycles is computed as reported in equation 1, where  $L_f$  is the load range at failure,  $N_f$  is the number of cycles completed by the specimen in the failure load block and  $L_p$  is the load range in the preceding block:

$$L^* = L_p + \frac{N_f}{N_i} (L_f - L_p) \quad (1)$$

This experimental technique provides preliminary results and is particularly suitable in the presence of rapid crack growth. The initiation of cracks in a load block prior to specimen failure may alter the internal stress distribution, thereby influencing the fatigue response of the specimen. The first load block was applied with a minimum force of 0.1 kN and a maximum force of 1.4 kN. In the following load blocks, the minimum force was kept constant while the maximum force was incremented by 0.2 kN.

### 3. Results and discussion

The results of the conducted axial fatigue tests are summarized in Table 1. Similar fatigue strengths were observed for the different impact speeds, with the highest value observed at 87.5 m/s. Therefore, impact speed does not appear to markedly influence fatigue performance within the analyzed range. However, due to the intrinsic scatter typical of fatigue experimental results, a larger number of specimens should be tested to obtain more robust conclusions. To better clarify the influence of impact speed, future studies should explore a broader range of impact conditions. Finally, the contribution of residual stresses and notch effect in influencing the fatigue strength of the hourglass specimens subjected to impact damage and subsequent cyclic axial loading should be determined.

Table 1. Results of the fatigue tests.

| Impact speed (m/s) | Maximum force in failure load block (kN) | Cumulative number of cycles at failure | Limit load according to step-loading procedure (kN) |
|--------------------|--|--|---|
| 70                 | 4.4                                      | 3,200,000                              | 4.4   |
| 87.5               | 4.6                                      | 3,300,000                              | 4.5   |
| 130                | 4.4                                      | 3,028,000                              | 4.2   |

### 4. Conclusions

Axial fatigue tests were conducted on 7075-T6 aluminum hourglass specimens with impact-induced damage. The fatigue strengths observed at the three investigated impact speeds are similar. To better understand the influence of impact speed on fatigue strength, further studies are needed on a broader range of impact speeds. Additionally, the influence of residual stress and notch effects on the fatigue life and the involved failure mechanisms should be assessed.

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