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Why does necking ignore notches in dynamic tension?

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ABSTRACT

Recent experimental work has revealed that notched tensile specimens, subjected to dynamic loading, may fail by growing a neck outside of the notched region. This apparent lack of sensitivity to a classical stress concentration case was reported but not explained or modeled.

The present paper combines experimental and numerical work to address this issue. Specifically, it is shown that the dynamic tensile failure locus is dictated by both the applied velocity boundary condition and the material mechanical properties, specifically strain-rate sensitivity and strain-rate hardening.

It is shown that at sufficiently high impact velocities, the flows stress in the notch vicinity becomes quite higher than in the rest of the specimen, so that while the former resists deformation, it transfers the load to the latter. The result will be the formation of a local neck and failure away from the notch.

This effect is shown to be active when the material properties are perturbed only at the local level, as in the case of machining of the notch, which in itself may again be sufficient to stabilize the structure under local failure until a neck forms elsewhere.

While the physical observations are quite counterintuitive with respect to the engineering views of stress concentrator's effect, the present work rationalizes those observations and also provides information for the designers of dynamically tensioned structures that may contain notches or similar flaws.

1. Introduction

The mechanical response of a structural element under external loads may be strongly influenced by the presence of geometrical discontinuities such as fillets, grooves, threads, or alike. The local geometrical perturbation (or discontinuity) amounts to a local increase in the stress field surrounding it. The role of stress concentrators on the deformation process is of prime importance in the field of mechanical design. Classical works, which are constantly used by structural engineers, can be found in Norton (2004), Roark and Young (1975), Budynas and Nisbett (2008), Inglis (1997), where the emphasis is mostly on elastic stress concentration problems. The importance of notched members under tension has led to a vast body of works focusing on evaluating the stress intensity factors around geometrical discontinuities (Coker et al., 1919; Howland, 1930; Strandberg, 2001; Zappalorto and Lazzarin, 2011), and specifically the differences between quasi-static and dynamic loading scenarios (James and North, 1969; Nakayama et al., 1998; Matsumoto et al., 1990).

An underlying assumption in all of the above-mentioned studies is that the fracture locus will be that of the geometrical

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imperfection, or any other given flaw. The same assumption is implicitly extended to dynamic loading situations, where inertia plays an important role. Other material heterogeneities related to the manufacturing process are ignored in the vast majority of works, or are considered secondary with respect to the presence of the dominant flaw.

It was recently shown that under dynamic loading conditions, the location of neck in a smooth bar subjected to tensile loading, is a deterministic event resulting from the applied boundary conditions (Osovski et al., 2013). Furthermore, it was shown experimentally that the necking location, as dictated by the applied boundary conditions, may prevail even in the presence of a geometrical perturbation which was deliberately introduced as a notch. The results of Rittel et al., (2014) imply that the presence (or pre-assumption) of a structural flaw, cannot be considered as the dominant factor in determining the locus of the dynamic structural failure. In other words, those results show that *the presence of a geometrical imperfection will not necessarily dictate the dynamic failure locus, as commonly assumed in the literature*.

Therefore, one standing issue is the identification of the physical factors controlling the dynamic failure locus in the presence of a geometrical imperfection. In consistence with our previous work (Rittel et al., 2014), the geometrical imperfection considered here is a notch, rather than the usual smooth variations of a characteristic dimension (e.g. diameter) found in the literature (El Maï et al., 2014) and references within.

The present study, of a hybrid experimental–numerical character, examines several potent factors responsible for the selection of the dynamic failure locus, as follows.

First, the methods used for the above-mentioned investigation are detailed. The experimental setup used for the dynamic tests, as well as the tested materials and specimens' geometry are described, followed by a detailed description of the numerical model used to study the potential factors. The experimental results are then presented, from which a critical notch size is extracted. The critical notch size is defined as the notch depth for which the majority of the specimens fail statically, within the notch. Next, new results for dynamic tensile tests of notched 15-5 PH (annealed) and 4340 steel specimens are presented. Finally numerical simulations are used to examine the role of the material's rate dependence as well as the local hardening stemming from the manufacturing process on the competition between the potential failure sites. We then discuss and summarize the main findings of this work.

2. Experimental setup

2.1. Materials and specimens

Two materials were tested: 15-5 PH steel (condition A) and 4340 H&T, supplied as 12.7 mm diameter bars, and tested in the as-received condition. Tensile cylindrical specimens with end threads were machined from the bars. The dimensions of the specimen are shown in Fig. 1. A summary of the characteristic dimensions used for static and dynamic tests is presented in Table 1. For the dynamic tensile experiments, two types of specimens were manufactured, namely long (36 mm gauge length), and short (12 mm gauge length) specimens, both having a diameter of 3 mm. In addition, the specimens were grooved circumferentially, using a machining thread tool knife, to a specific depth and geometry as listed in Table 2. Note that, while the dynamic specimens were notched at mid-gauge length, the static ones were notched at 1/3 of the length to avoid any possible confusion with potential symmetrical failure (necking).

A total of 90 specimens were tested to ensure repeatability of the results (Table 3). In addition we tested 40 specimens of 7075-T6 aluminum alloy. Those yielded the same qualitative results as those reported in the sequel, and therefore will not be presented here for the sake of brevity.

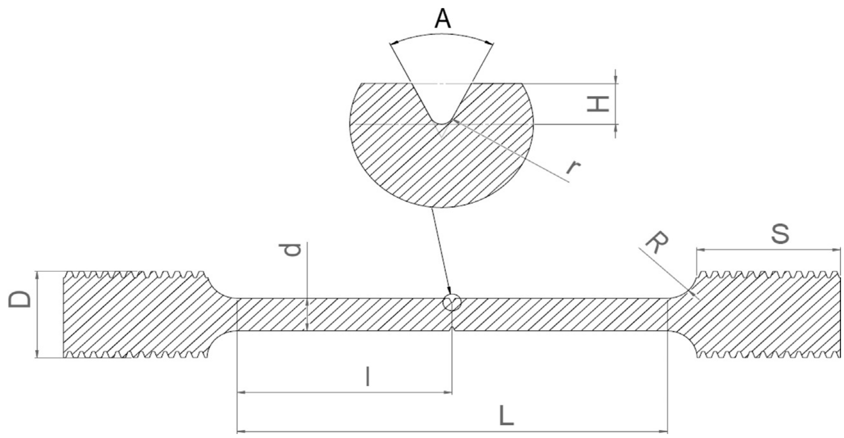

Fig. 1. Static and dynamic tensile specimens' geometry.