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Measurement and prediction of compressive properties of polymers at high strain rate loading

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ABSTRACT

Strain-rate effect is widely recognized as a crucial factor that influences the mechanical properties of material. Despite the acknowledge importance, the understanding of how such factor interact with the sensitivity of the polymers in terms of mechanical properties is still less reported. In this study, an experimental technique, based on the compression split Hopkinson pressure bar, was introduced to perform high strain rate testing, whereas, a conventional universal testing machine was used to perform static compression testing, to experimentally investigate the independent and interactive effects of strain rates towards mechanical properties of various polymers. Based on the experimental results, we parameterized two equation models, which were used to predict the yield behavior of tested polymer samplings. The experimental results indicate that, the yield stress, compression modulus, compressive strength, strain rate sensitivity and strain energy increased significantly with increasing strain rates for all tested polymers. Meanwhile, the yield strain and the thermal activation volume exhibit contrary trend to the increasing strain rates. Interestingly, the proposed constitutive models were almost agreed well with experimental results over a wide range of strain rate investigated. Of the three polymers, polypropylene shows the highest strain rate sensitivity at static and quasi-static region. On the other hand, at dynamic region, polycarbonate shows the highest strain rate sensitivity than that of polypropylene and polyethylene. Overall, both experimental and numerical models proved that the mechanical properties of polymer show significant sensitivity and dependency towards applied strain rates up to certain extent.

1. Introduction

The demands of light material have continuously increased for the past few years. A lot of funds and works have been invested to create lighter material without scarifying its initial performances. To date, polymer is one of the promising materials that completely satisfied the lenient requirements with added excellent balance between impact resistance and weight. For these reasons, it has received remarkable attention from both industrial and educational sectors. Although polymer consists a lot of excellent abilities, their mechanical characteristics have become the primary criteria which determine the overall performances [1,2]. Recently, many sophisticated techniques exist to characterize the mechanical properties of polymers. Nevertheless, the techniques are totally different between static and dynamic assessments. As Omar et al. [3] pointed out; the universal testing machine (UTM) used in static properties measurement, would not be relevance for dynamic measurement, due to its difficulties to provide high strain rate condition to the specimen. Therefore, unique dynamic facility was first introduced by Kolsky [4], in 1949, to fulfill and satisfy the high strain rate testing requirements which is the split Hopkinson pressure bar (SHPB) apparatus. Year by year, the apparatus has experienced magnificent evolution by the following researchers [5–7], where now, it has become the standard method of measuring material dynamic mechanical properties, in the range of $10\ s^2$–$10\ s^4$ strain rates [8,9].

In polymer, things like chain structures, type of branching and molecular weight might be key drivers that affect their mechanical characteristic [10–12]. Apart from internal issues, it is believed that external factor like strain-rate effect may also cause huge impacts to the mechanical behavior of polymers. Since the applications of polymers have been extended from conservative to various engineering applications, the strain rate factor should not be neglected and need extra attention from the researchers. For the past few years, several experimental approaches have been performed to study the strain-rate effect towards the mechanical properties of polymers [13–15]. However, understanding on how loading rates manipulate the sensitivity of polymer is presently unclear and remains a major challenge in dynamic perspective. In addition, numerical studies on dynamic mechanical properties of polymers are also infrequently reported

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