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A Note on the Fracture Propagation and Time-Dependent Behavior of Rocks in Uniaxial Tension

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Specimens of Berea sandstone, Barre granite, Tennessee marble, and Valder limestone were tested at various strain rates under uniaxial tension. The strengths increased with strain rates but the rates of increase and the shapes of postfailure region of the complete load-deformation curves varied. Sequential pictures were also taken along the complete load-deformation curves of Berea sandstone and Tennessee marble tested under uniaxial tension. Final fracture resulted from coalescence of cracks and 'advanced' cracks along more or less a single plane.

INTRODUCTION

In previous publications [1, 2], the time-dependent behavior and fracture propagation of rock subjected to uniaxial compression by a servocontrolled hydraulic testing machine were investigated. Due to its versatility, the machine was able to provide data on relaxation behavior, strain rate effect and the sequential events of fracture propagation along the complete load-deformation curves.

It remains unexplored as to whether same phenomena exist in uniaxial tension. This note will illustrate the strain rate effect of complete load-deformation curves and the characteristics of fracture propagation under uniaxial tension.

MATERIALS AND TESTING TECHNIQUE

Four rock types (i.e. Barre granite, Berea sandstone, Tennessee marble and Valder limestone) were used. The description of these rocks can be found elsewhere [2, 3]. Specimens used were prismatic with dimensions of 2·54 × 1·27 × 5·08 cm.

In preparation for uniaxial tensile testing specimens were cemented at the ends to special fixtures that can be connected to the machine plateans rather easily. Two clip-on gages of one-inch gage length were set at the middle of the specimen, but in opposite sides of the diametrical plane. A servocontrolled testing machine was used and all tests were conducted under strain (or deformation) control. For complete description of the testing technique, the readers are urged to consult a previous publication by Krech [4].

In strain rate study, at least three tests were performed for each strain rate to check the reproducibility. In the fracture propagation analysis, pictures of the specimen surfaces were taken at various points along the complete load-deformation curves. These pictures were enlarged approximately six times for analysis of crack propagation characteristics. Open cracks in the pictures were then traced on the transparencies overlaid on the enlarged pictures. Any open fissure which had high aspect ratio was considered as a crack. Only one test was conducted for each rock type. During testing, both Valder limestone and Barre granite failed abruptly because fracture initiated besides the gage length area and no data were collected.

EXPERIMENTAL RESULTS AND DISCUSSION

A. *Strain rate effect*

Figures 1–3 show the complete load-deformation curves of various strain rates for Barre granite, Berea sandstone, and Valder limestone, respectively. Each curve represents the typical curve obtained for that strain rate. Generally, the uniaxial tensile strengths increase with strain rates. The rate of strength increase, however, not only differs for each rock type, but also varies in a given rock. Berea sandstone shows the widest

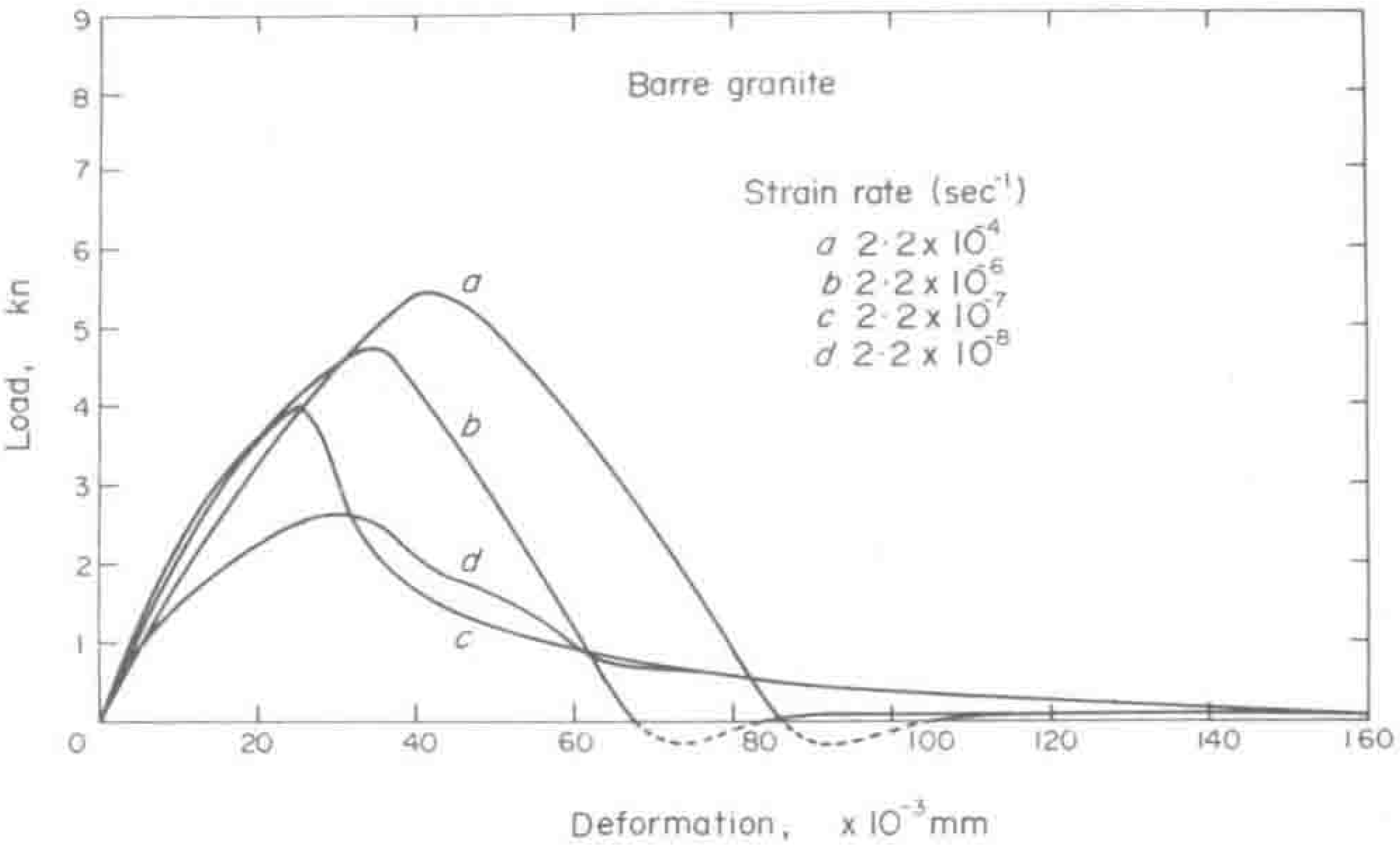

Fig. 1. Complete load-deformation curves for Barre granite tested under various strain rates in uniaxial tension.

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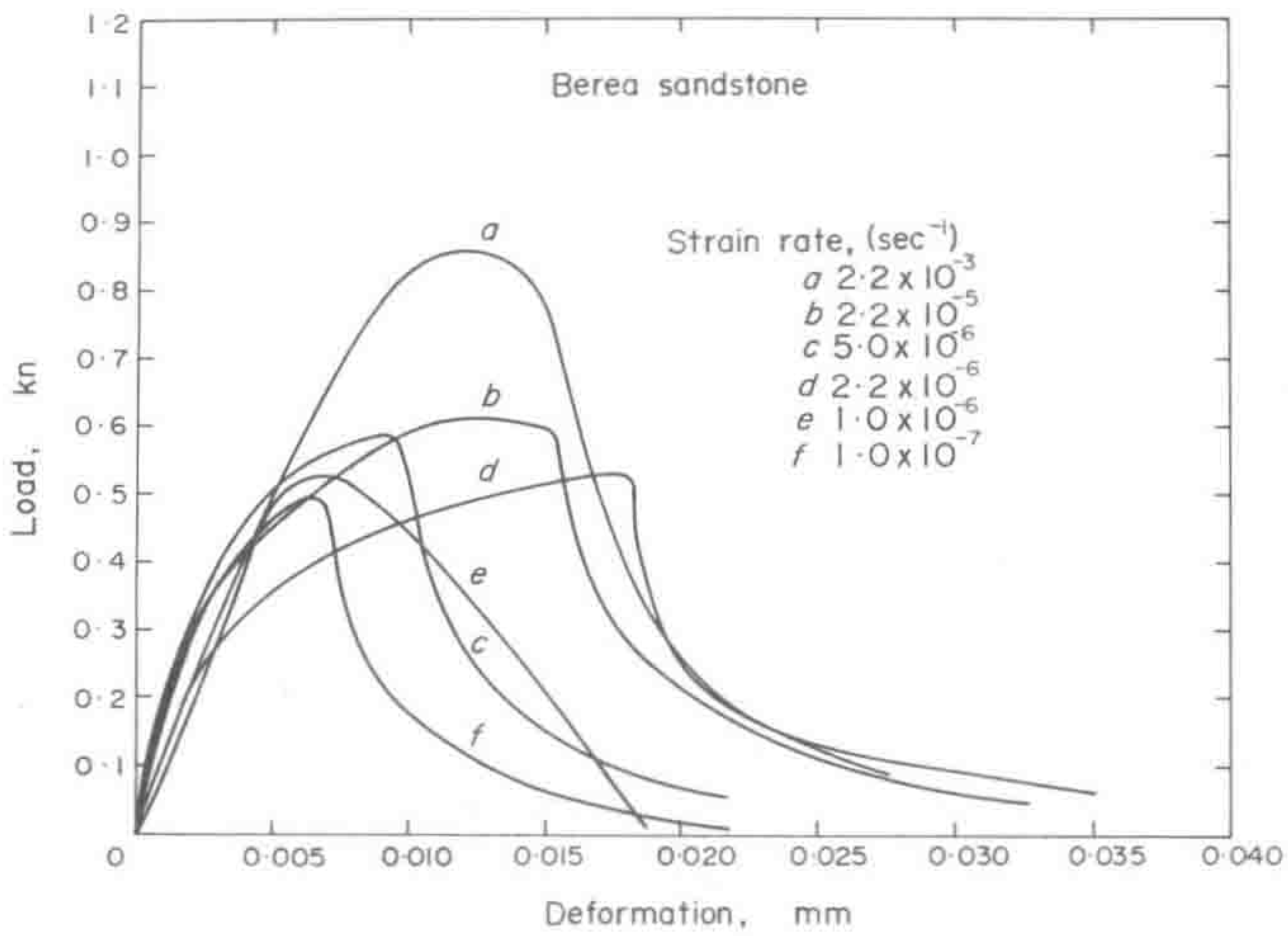

Fig. 2. Complete load-deformation curves for Berea sandstone tested under various strain rates in uniaxial tension.

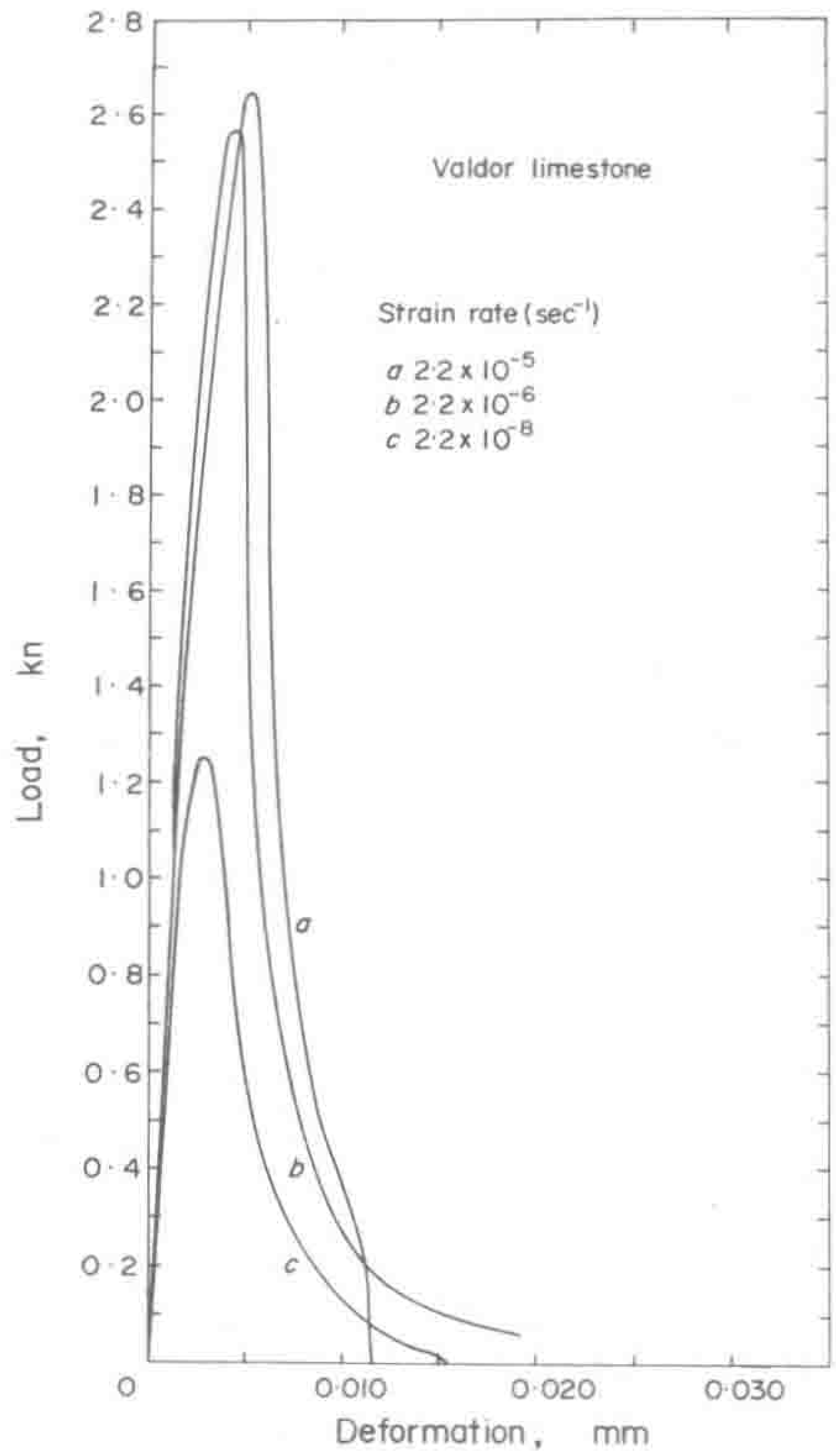

Fig. 3. Complete load-deformation curves for Valder limestone tested under various strain rates in uniaxial tension.

spread whereas Valder limestone, the least. The shapes of the postfailure region also differ widely for Berea sandstone and Barre granite while those for Valder limestone show similar shape. Under uniaxial compression, the slopes of the prefailure portion of the complete load-deformation curve were found insensitive to strain rate effect and the post-failure region followed a good generalized trend [1]. These features were not present for results obtained in uniaxial tension mainly due to the fact that tensile fracture was concentrated to a single plane which depended very much on local microstructures. Accordingly, a number of tests are needed for uniaxial tension to average out individual characteristics.

B. *Fracture propagation*

Figures 4 and 5 show the fracture propagation of Berea sandstone and Tennessee marble, respectively. The complete load-deformation curves are shown in the upper left-hand corner and the letters on the curves indicated the positions where the sequential pictures were taken. The first visible crack did not appear until the applied load reached above 90% of the ultimate load. In Berea sandstone, first crack started at the left edge of the specimen but did not propagate far when a second crack was initiated in advance but not connected to the first

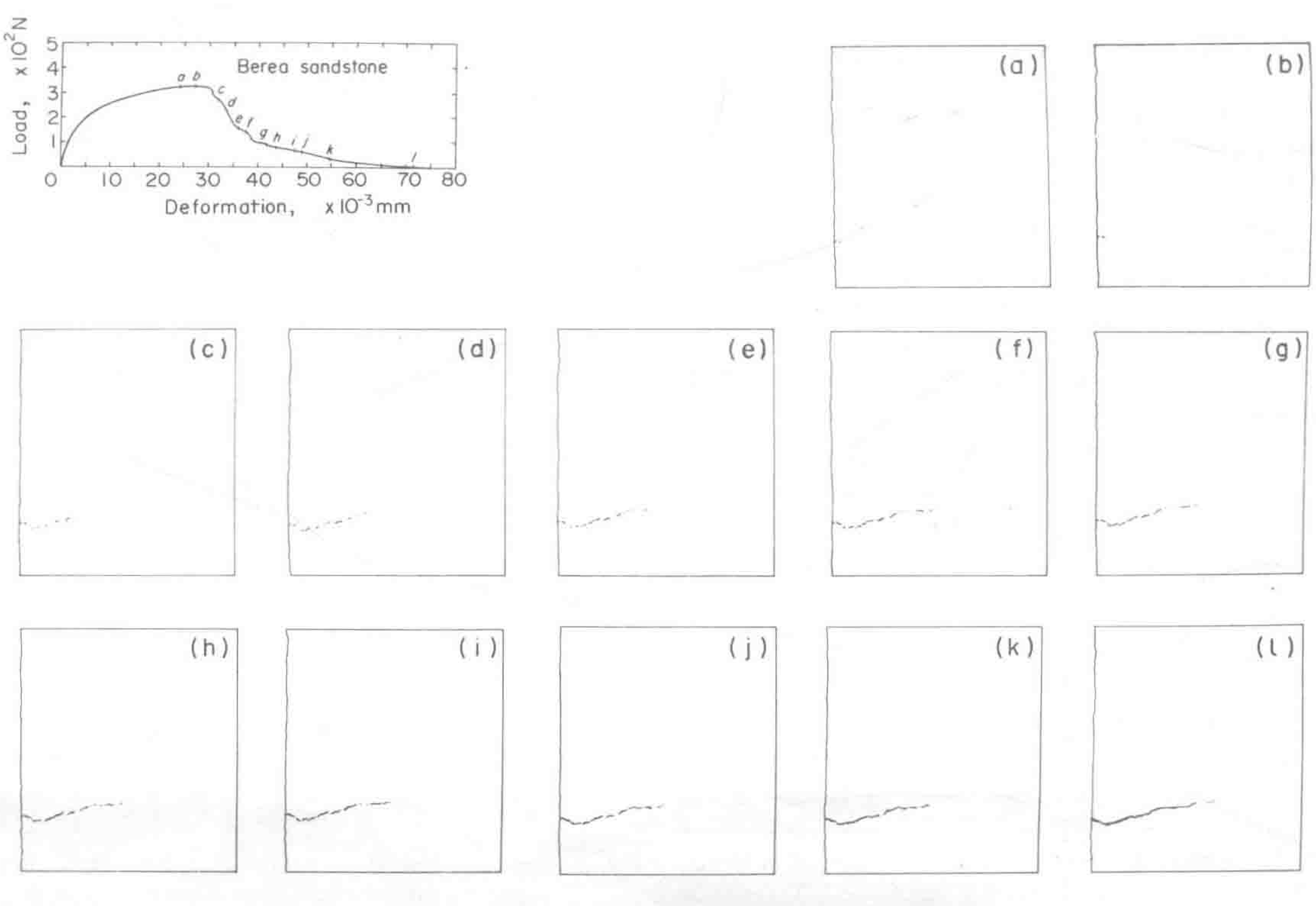

Fig. 4. Fracture propagation of Berea sandstone in uniaxial tension.

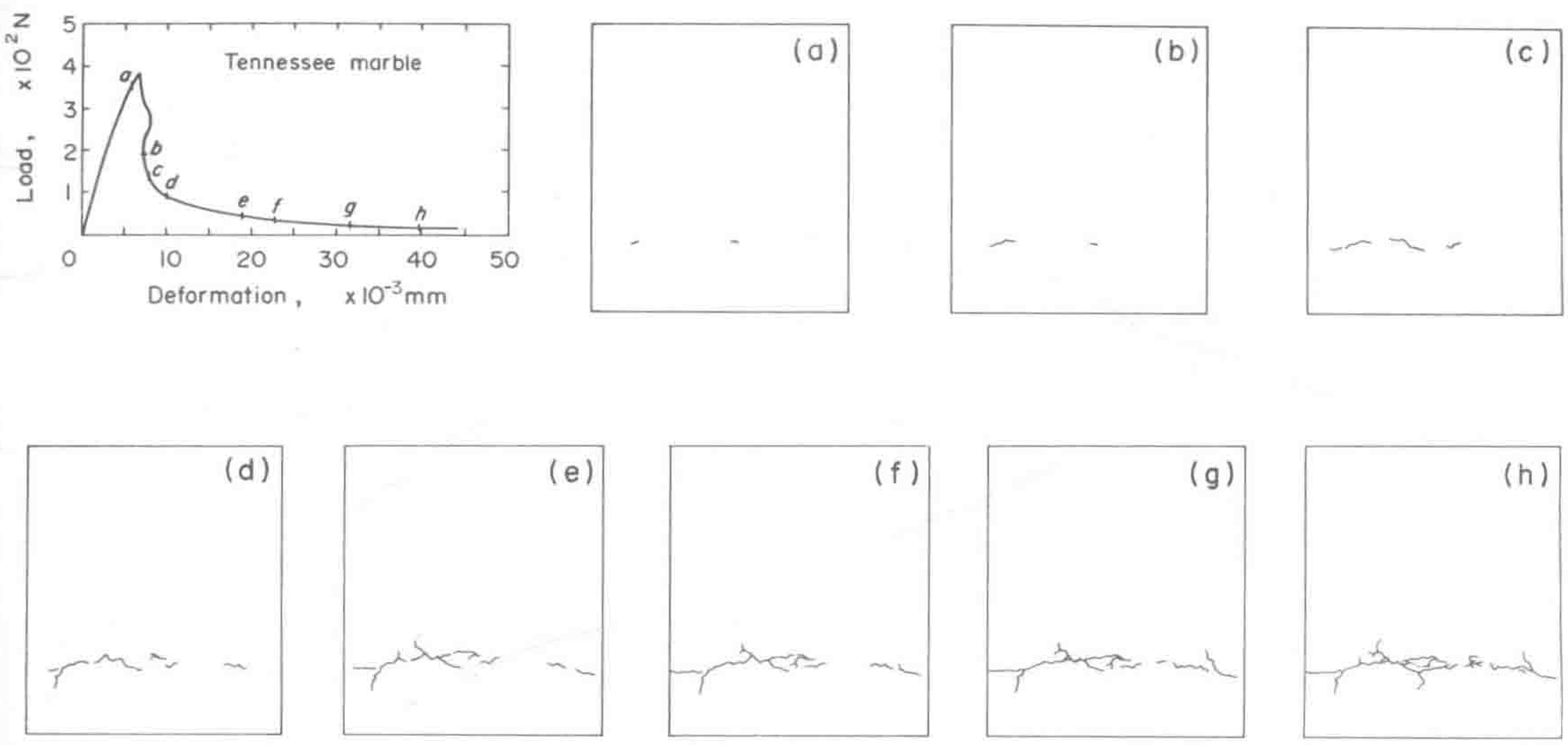

Fig. 5. Fracture propagation of Tennessee marble in uniaxial tension.

one (see a and b of Fig. 4). The third crack initiated in front of the second one before the second one started further propagation. This process continues as applied deformation increases. However, the coalescence of these cracks does not necessarily follow the sequence of crack growth. For example, the fifth and sixth crack coalesed at position d (Fig. 4) while the first and second crack did not coalese, until it reached position i. Upon complete unloading (position l), all cracks joined and became a big crack starting from the left edge and extended approximately half of the specimen. The specimen can be pulled apart along the big crack with little effort. (Notice that there is a small crack ahead of the big crack in position l). The fact that one could break the specimen at position l very easily raised the possibility that small microcracks might have developed ahead of the big crack all the way to the right edge. Brady [5] applied dye-penetrate to the specimen and observed a cracked zone ahead of the big crack and called it crack inclusion and that the propagation of the crack inclusion caused the final fracture. Unfortunately, all the pictures taken for this research were not of such quality for further enlargement to substantiate the existence of microcracks. It is therefore recommended that the same testing technique should be used for studying tensile fracture propagation but with pictures capable of showing detailed microstructural and microcrack features in advance of main cracks.

In Tennessee marble, two cracks appeared at two discrete locations at position a (Fig. 5) which is about 92% of the ultimate load. The left crack propagated right away while the right side one remained unpropagated (position b of Fig. 5). At position c, a large crack developed between them while the left crack had a small but discrete crack ahead it and the right crack was joined by its 'advanced' crack. At position d, two more cracks, one at each side toward the edge, were developed. These five cracks acted as source and generated 'advanced' cracks ahead of them until it finally reached position h when cracks extended about 97% of the potential fracture plane. Contrary to Berea sandstone, quite a few cracks branched off from the main crack in Tennessee marble and often followed grain boundaries.

CONCLUSIONS

Contrary to results from uniaxial compression by a servocontrolled test machine, the shapes of the complete load-deformation curves in uniaxial tension varied irregularly with strain rates and ultimate fractures were caused by the coalescence of cracks and 'advanced' cracks in more or less a single plane. However, strengths increased with strain rates and fracture could be controlled as in uniaxial compression.

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