Accurate Strain Distribution Measurement during Large Deformations via Image Scaling Technique

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Abstract. A full-field strain measurement is a powerful tool for assessing diverse materials' mechanical properties and fracture characteristics. Imaging methodologies like digital image correlation (DIC) and sampling moiré (SM) methods leverage digital cameras and grating patterns, offering substantial efficacy and versatility. Here, we propose an improved SM method using an image scaling technique tailored for comprehensive strain analysis across varying deformations. Using the proposed method, we investigated the necking behaviour in CFRP angle-ply specimens subjected to substantial deformation, demonstrating its effectiveness and versatility.

Introduction

Full-field strain measurement [1] is a potent tool for assessing the mechanical strength and understanding fracture behaviours across diverse materials, spanning metals, composites [2], and solid polymers. Over the past half-century, numerous optical methodologies, notably digital image correlation (DIC) [3] and sampling moiré (SM) [4-6], have undergone extensive investigation. These approaches enable the precise measurement of small strain distributions within the elastic region through the derivation of displacement data. However, the measurement accuracy of large strains in plastic regions could be dramatically decreased. To overcome this problem, in this study, we proposed an enhanced strain measurement based on the sampling moiré method using an image scaling technique. The effectiveness of our proposed method was demonstrated by investigating the necking behaviour observed in CFRP angle-ply specimens.

Principle

Problem of the sampling moiré method. The sampling moiré method encounters several challenges when analysing strain for large deformations: Firstly, in the sampling moiré method, strain is derived from the phase difference of moiré patterns before and after deformations. Hence, in instances where neither image exhibits a periodic pattern before or after deformations, moiré fringe fails to occur, impeding strain calculation. Secondly, the strain measurement points at identical pixels experience substantial displacement following significant deformation, necessitating the tracking of strain values corresponding to the initial target measurement points. Thirdly, discrepancies between the grating pitch (P) and the sampling pitch (T) lead to substantial periodic errors, as theoretically reported in our previous study [7].

New approach to measure strain for large deformation. To address these concurrent issues simultaneously, the principle and procedure of an enhanced strain analysis technique based the sampling moiré method is illustrated in **Fig. 1(a)**. The deformed image is nearly scaled to match its dimensions with the grating pattern area in the pre-transformed image. The scaling factor is determined by the alteration in the grating pitch before and after deformations. Then, the strain distribution is determined through the conventional sampling moiré method, which incorporates both before-deformation and after-deformation images adjusted through image scaling. Finally, the computed strain is transformed into the actual strain value by applying the image scaling factor.

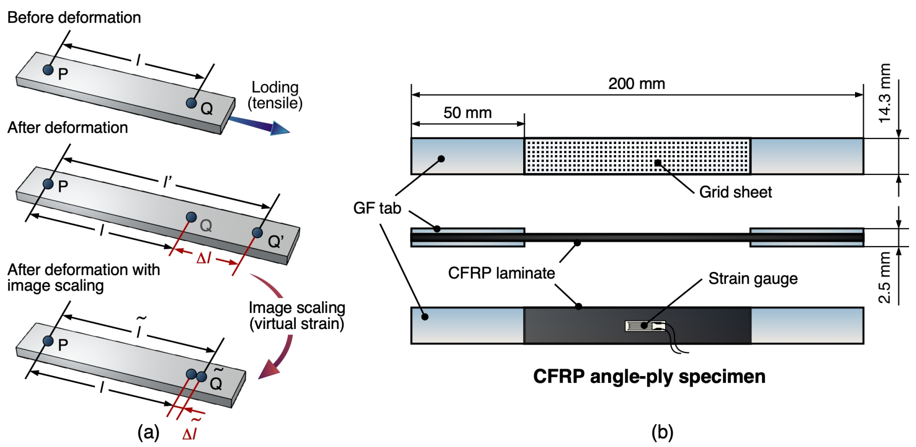

Fig. 1 (a) Principle of strain measurement for large deformation and (b) CFRP angle-ply specimen used in this study.

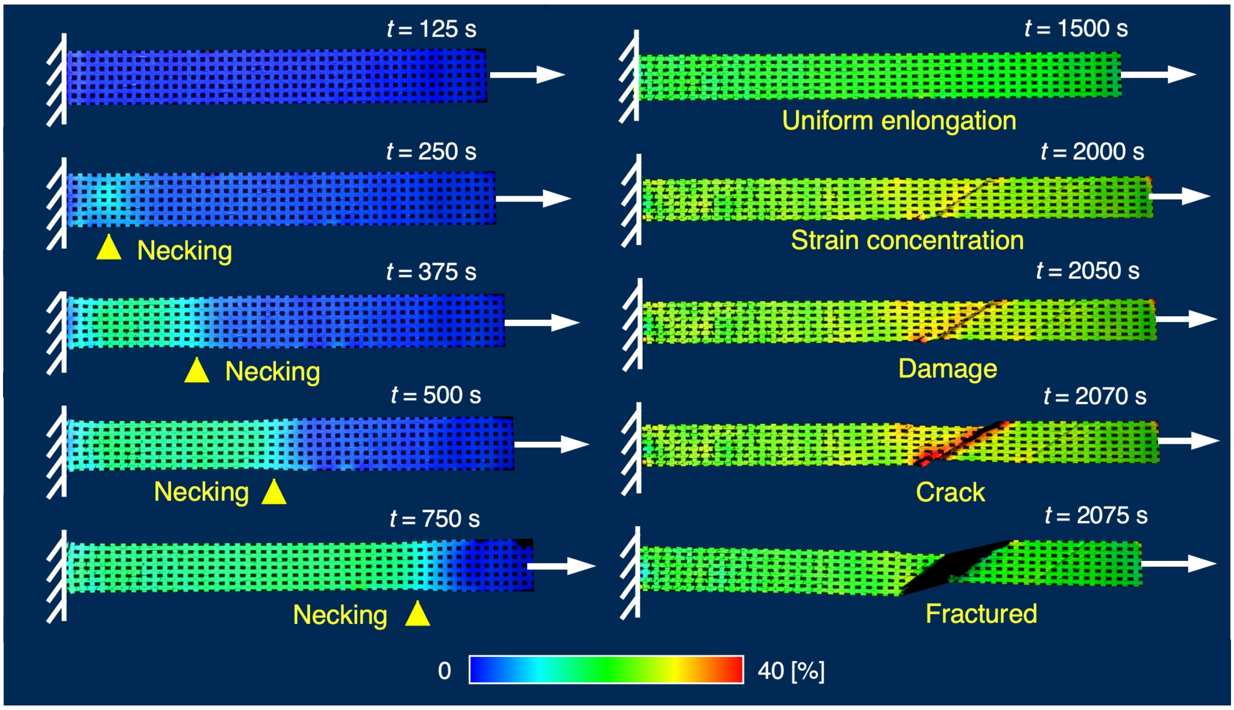

Fig. 2 Experimental results of strain distribution measurement by the improved SM method using an image scaling technique.

Experimental Results

Specimens of CFRP angle-ply laminates with a lamination composition of [±50]4s, as shown in **Fig. 1(b)**, were fabricated by autoclave moulding, and tensile tests were conducted at a longitudinal tensile rate of 1 mm/min until the specimens ruptured. An elastic and adhesive grid sheet with a pitch interval *P* of 2 mm was attached to one side of the specimen to enable strain analysis using the sampling moiré method, and an industrial camera continuously imaged its surface at a rate of 1 fps during the test. For reference, a biaxial strain gauge was attached to the centre of the back surface to measure the normal strain.

Figure 2 shows the experimental results of strain distribution analysed using the improved sampling moiré method. The specimen elongated significantly in the longitudinal loading direction and deformed elongated before rupture. Furthermore, necking occurred during the tensile test, and the specimen ruptured after the necking propagated to the entire specimen. It is considered that the vertical strain changed significantly locally at the necking points. Besides, the strain change until the necking propagation was relatively small except at the necking initiation point. The specimens ruptured after the propagation was completed and the strain changed uniformly. The strains at the beginning of necking are nearly 3-4% in the vertical direction of tensile strain and 2-3% in the horizontal direction of compressive strain, and the strains at the end of necking are about 15% in both directions.

Conclusion

This study presents an enhanced sampling moiré technique augmented with an image scaling approach for measuring a wide range of strain distributions. The efficacy of the proposed method was validated by quantifying the necking deformation exhibited by a CFRP angle-ply specimen. The proposed method is helpful in addressing fundamental issues relating to evaluating the strength of diverse materials and failure and fracture phenomena.

References

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