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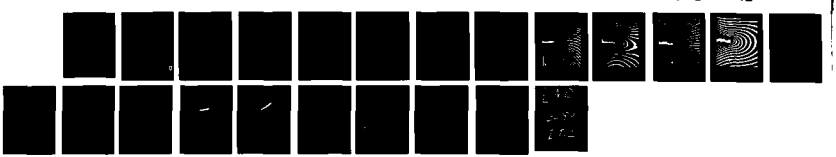

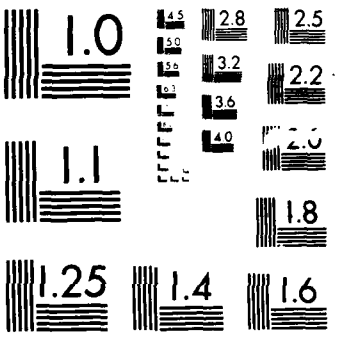

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Technical Report No. UWA/DME/TR-89/63

HRR FIELD IN AN ALUMINUM SEN SPECIMEN

by

M.S. Dadkhah and A.S. Kobayashi

April 1989

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HRR FIELD IN AN ALUMINUM SEN SPECIMEN

Mahyar Dadkhah* and Albert S. Kobayashi**

ABSTRACT

Moire interferometry was used to record simultaneously the vertical and horizontal displacements associated with stable crack growth in single edge notched, 2024-0 aluminum specimens. For a small stable crack growth of 1.5 mm, the vertical displacement showed the dominance of the HRR field but the horizontal displacement deviated from the HRR field at the early stage of loading.

INTRODUCTION

During the past two years, the authors and their colleagues have used an improved moire interferometry technique [1] to study the path independency and the validity of the HRR [2,3] field in single edge notched, 2024-T3, 2024-0, and 5052-H32 aluminum alloy specimens subjected to uniaxial and biaxial loadings [4,5,6]. One of the objectives of this series of investigations was to study the biaxial effect on the ductile fracture criterion and thus a special cruciform specimen [4] was tested in a special biaxial testing machine [7]. The biaxiality ratio, B, was varied from the uniaxial state of $B = 0$ to the highly biaxial loading of $B = 2$. It was thought by some that the built-in bending stiffness of the cruciform specimen simulated the crack-tip state of stress found in a central notched tension specimen for which previous numerical analysis [8] showed a smaller J-dominated region. Thus the authors' previous findings that the HRR field was virtually nonexistent, except for the 2024-T3 specimens with a relatively smaller plastic yield zone, could have been attributed to the particular specimen configuration used in our studies. In particular, Shih et al. [8] has shown through numerical analysis, that a large J-dominated region existed in a single edge-notched (SEN) specimen with large scale yielding subjected to tensile and bend loadings.

The objective of this study is to determine the extent of the HRR zone in an ASTM-type single edge notched, (SEN) 2024-0 aluminum specimen.

PROCEDURES

The experimental procedure and the procedure for evaluating the J-integral have been described in detail [1,3,4] and will not be repeated for the sake of brevity. The SEN specimen used in this study is shown in Figure 1. This specimen is identical in geometry with the cruciform specimen, which was used in previous studies, with the exception that it lacks the horizontal tabs.

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and the secondary normal strains in the directions perpendicular and parallel to the crack, respectively.

One SEN 2024-0 specimen was analyzed using the procedures described in previous publications. Figures 3 and 4 show the fringe patterns which represent the dominant v- and secondary u-displacement field, respectively, of the SEN specimen. Figure 5 and 6 show the v- and u-displacement fields, with the contours used in the J-integral calculation, of a cruciform specimen under uniaxial tension or B = 0. A comparison of Figures 3 and 5 and Figures 4 and 6 indicate that the v- and u-displacement fields of the SEN and uniaxially loaded cruciform specimens are identical. Figure 7 and 8 indeed show that at a reference point of r = 1.2 mm and θ = 45, the v- and u-displacements do coincide. The u-displacement for the biaxially loaded, B = 2, cruciform specimen, however, differs significantly with those of the SEN and uniaxially loaded cruciform specimen.

The coincidence of the v- and u-displacement fields of the SEN and the uniaxially loaded cruciform specimens allowed the use of the J-integral values of an uniaxially loaded cruciform specimen as an estimate of the J-values of a SEN specimen. This estimation was accomplished by relating the J-value of the SEN specimen with the corresponding J-value, as shown in Figure 9, at the same vertical load of the uniaxially loaded cruciform specimen. Also shown in Figure 9 is the variation in J-values with increasing load in the biaxially loaded cruciform specimen. Despite the difference in the u-displacement field, as shown in Figure 8, the J-values for the uniaxially and biaxially loaded cruciform specimens coincide up to an applied load of 4,000 N.

Figures 11 and 12 show typical log-log plots of the variations of the v-and u-displacement, respectively with angular orientation, θ, and radial distance, r, for a load of 3290 N at which load the plastic region had penetrated the remaining ligament of the specimen. The slope of these displacement plots in the HRR region should be 0.2. The dominant v-displacement field exhibits a slope of 0.2 in a limited region circumscribing the crack tip as indicated in Figure 11. The u-displacement field, which is smaller than the v-displacement field, has an average slope of 0.51 as shown in Figure 12. The nonlinear region for the u-displacement field is considerably smaller than that of the v-displacement field.

The J-integral values shown in Figure 10 were used together with the power hardening coefficients in Figure 2 to evaluate the v- and u-displacements associated with the HRR field [2,3]. The crack tip displacements for a linearly elastic aluminum SEN specimen was also computed. Figures 13 and 14 show the measured and the computed HRR and LEFM v- and u-displacement variations, at a location of r = 1.2 mm and θ = 45 from the crack tip, with increasing crack extension in the SEN and the cruciform specimens, respectively. The fitted curves through the measured v- and u-displacement data accentuate the closeness or difference with the HRR of LEFM displacement. The v-displacement initially followed the LEFM displacement but changed to the corresponding HRR component at higher loadings in all three specimens. The u-displacement for the SEN and uniaxially loaded cruciform specimen, on the other hand, followed the corresponding LEFM component while that of the biaxially loaded cruciform specimen followed the HRR component at the initial phase of loading.

CONCLUSION

The displacement fields near the crack tip in the cruciform and the SEN specimens used in this study were identical for all practical purposes. Thus the results generated

previously for the uniaxially loaded cruciform specimens are also applicable to the SEN specimens. As shown previously, the v-displacement followed the corresponding component of the HRR field but the u-displacement followed the corresponding component of a LEFM field for the SEN and uniaxially loaded cruciform specimens as well as during the latter phase of the biaxially loaded cruciform specimens.

DISCUSSIONS

This and previous studies [4,5,6] have consistently shown that the v-displacement outside of the nonlinear region but in the vicinity of the crack tip essentially followed the HRR field for much of the loading. The u-displacement, except for the early stage of loading in 2024-T3 specimens and biaxially loaded cruciform specimens, did not follow the HRR field and was closer or identical to the corresponding LEFM component. Thus the far-field J-integral, which was shown to be identical to the crack tip J-integral, cannot be used to characterize the crack tip states of displacement and strain. The physical significance of the J-integral from the fracture mechanics view point is therefore in need of a redefinition.

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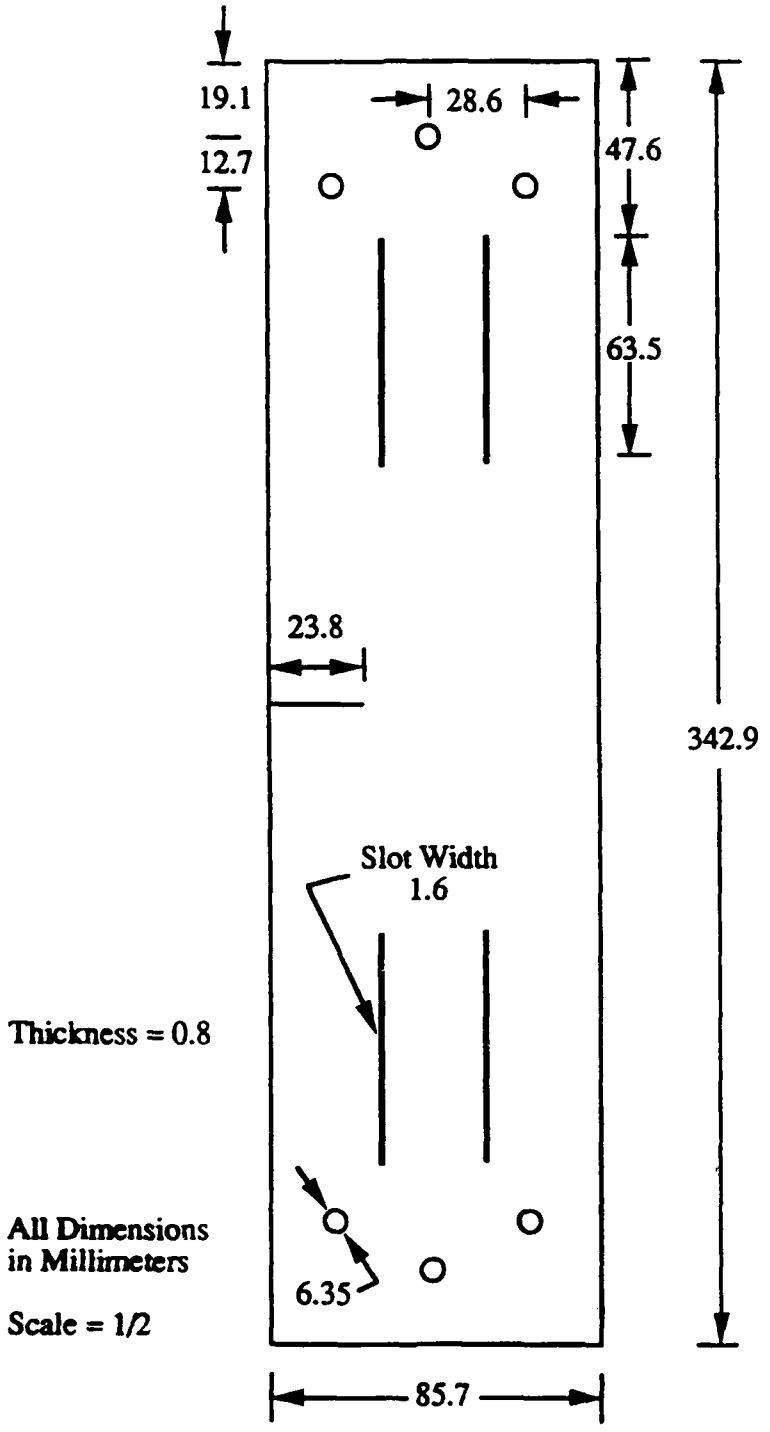


Figure 1 SEN Specimen Configuration.

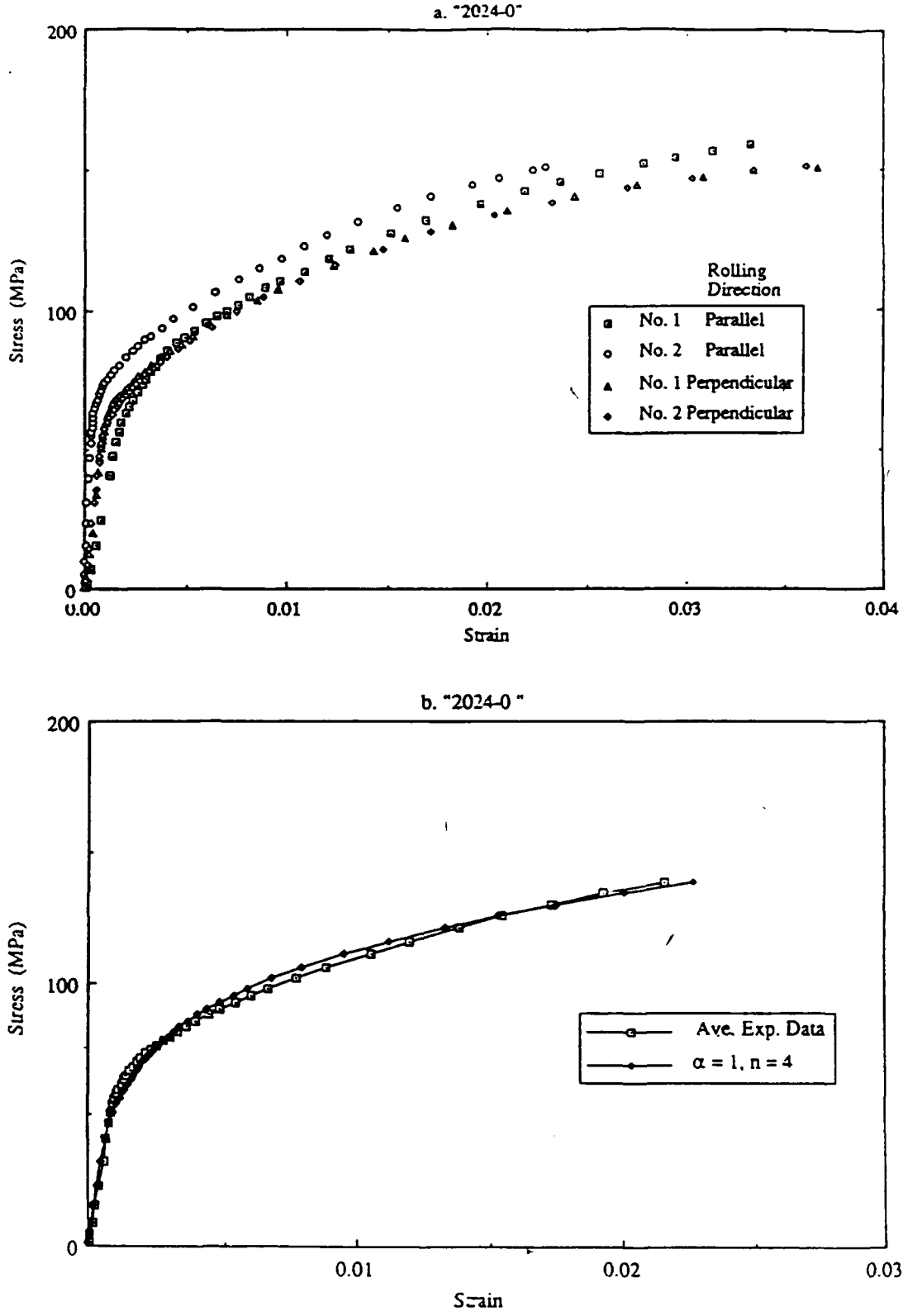


Figure 2 Uniaxial Stress-Strain Curve for 2024-0.

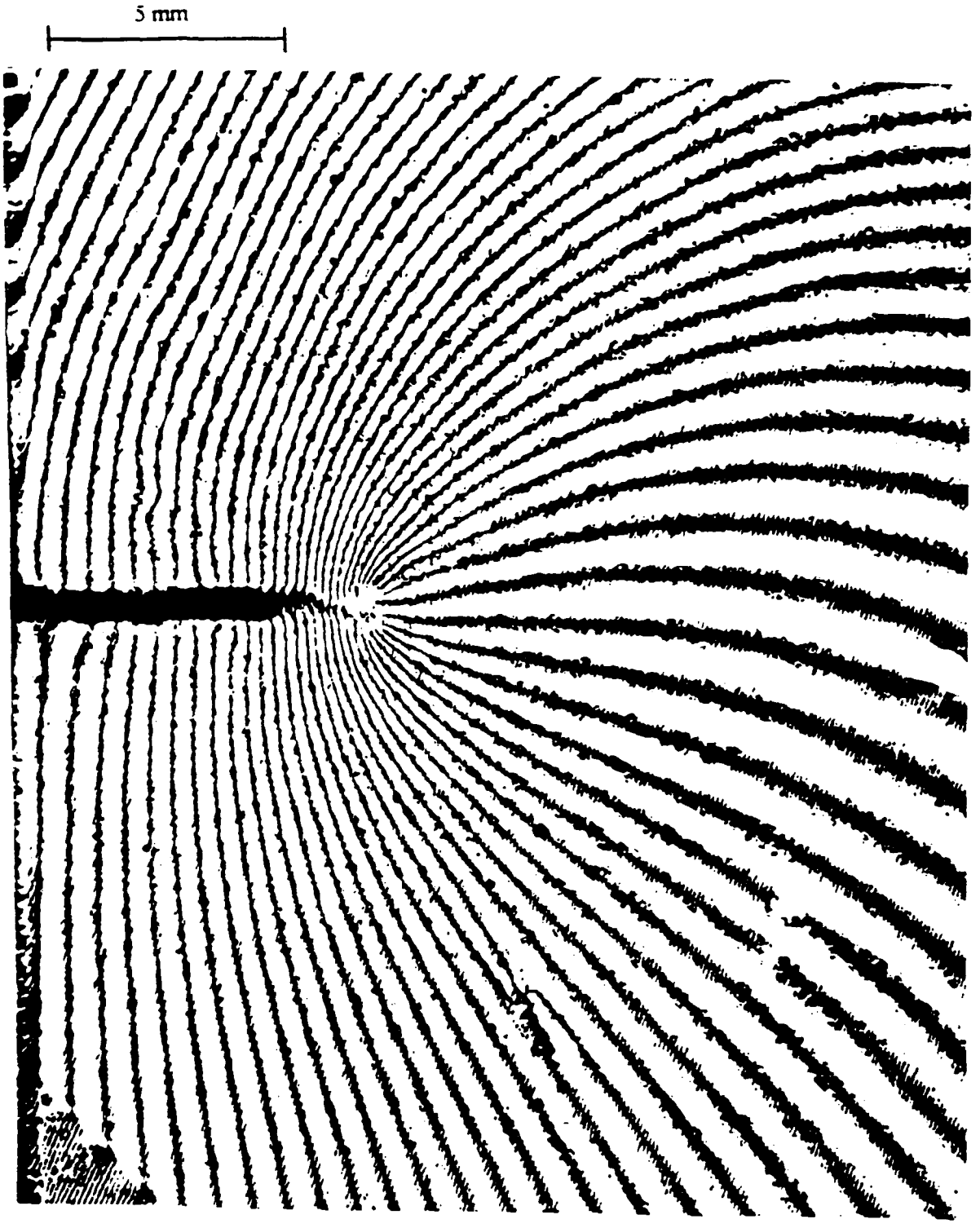


Figure 3. v-Displacement in SEN 2024-0 Aluminum Specimen. MD101988. F_y = 1890 N.

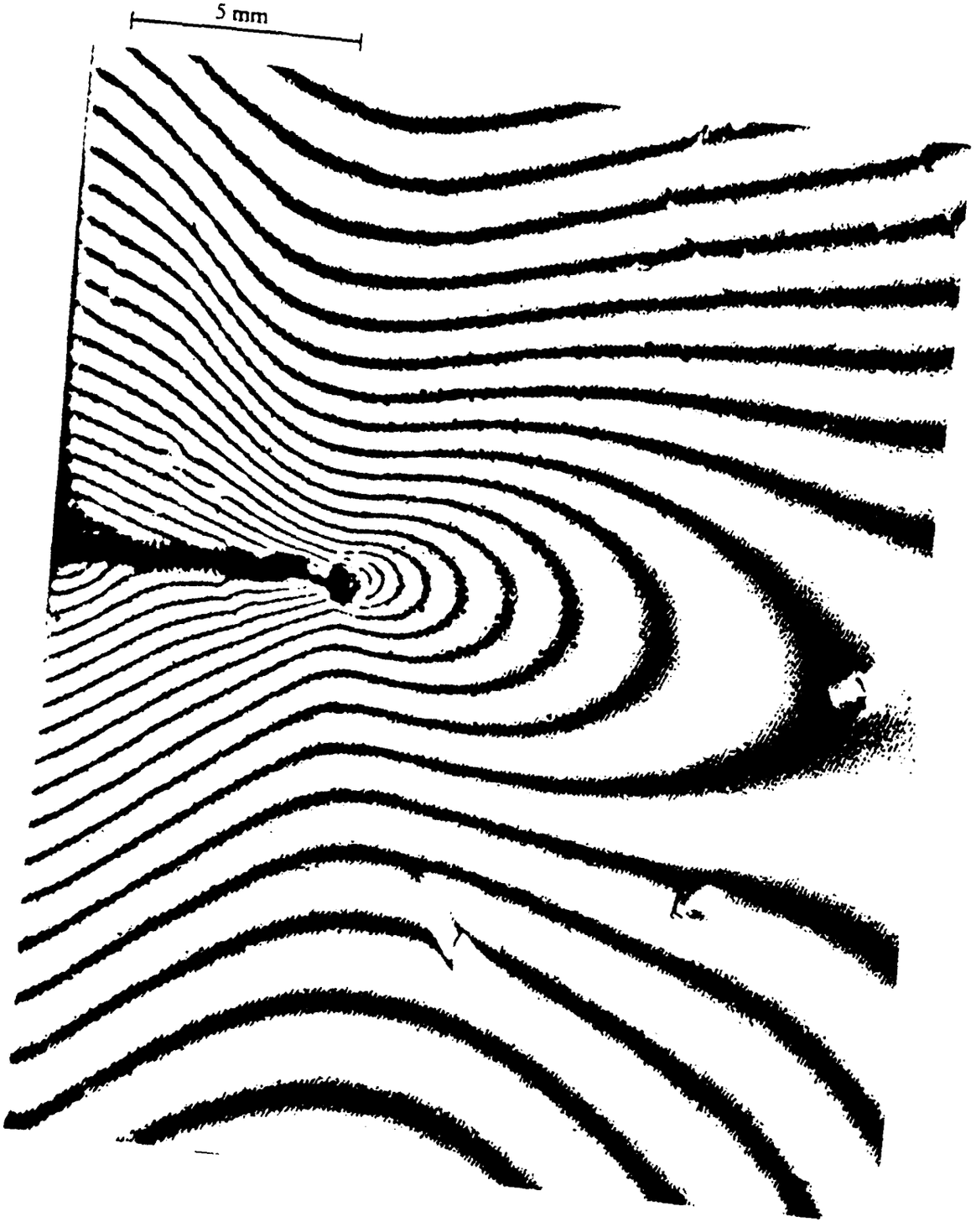


Figure 4. u-Displacement in SEN 2024-0 Aluminum Specimen. MD101988. F_y = 1890 N.

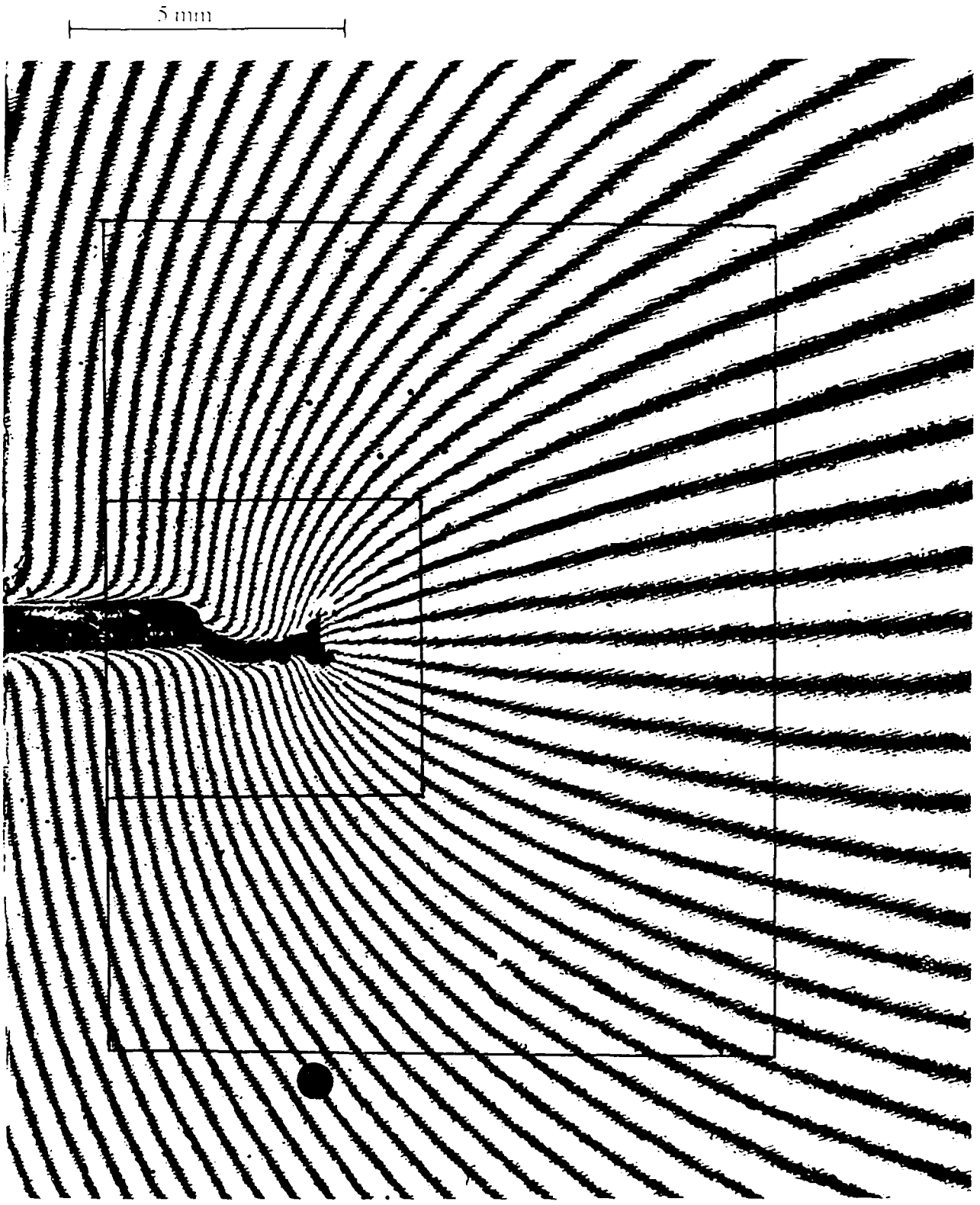


Figure 5. v-Displacement in Cruciform 2024-0 Aluminum Specimen. MD050288. B = 0. F_x= 0, F_y = 1695 N.

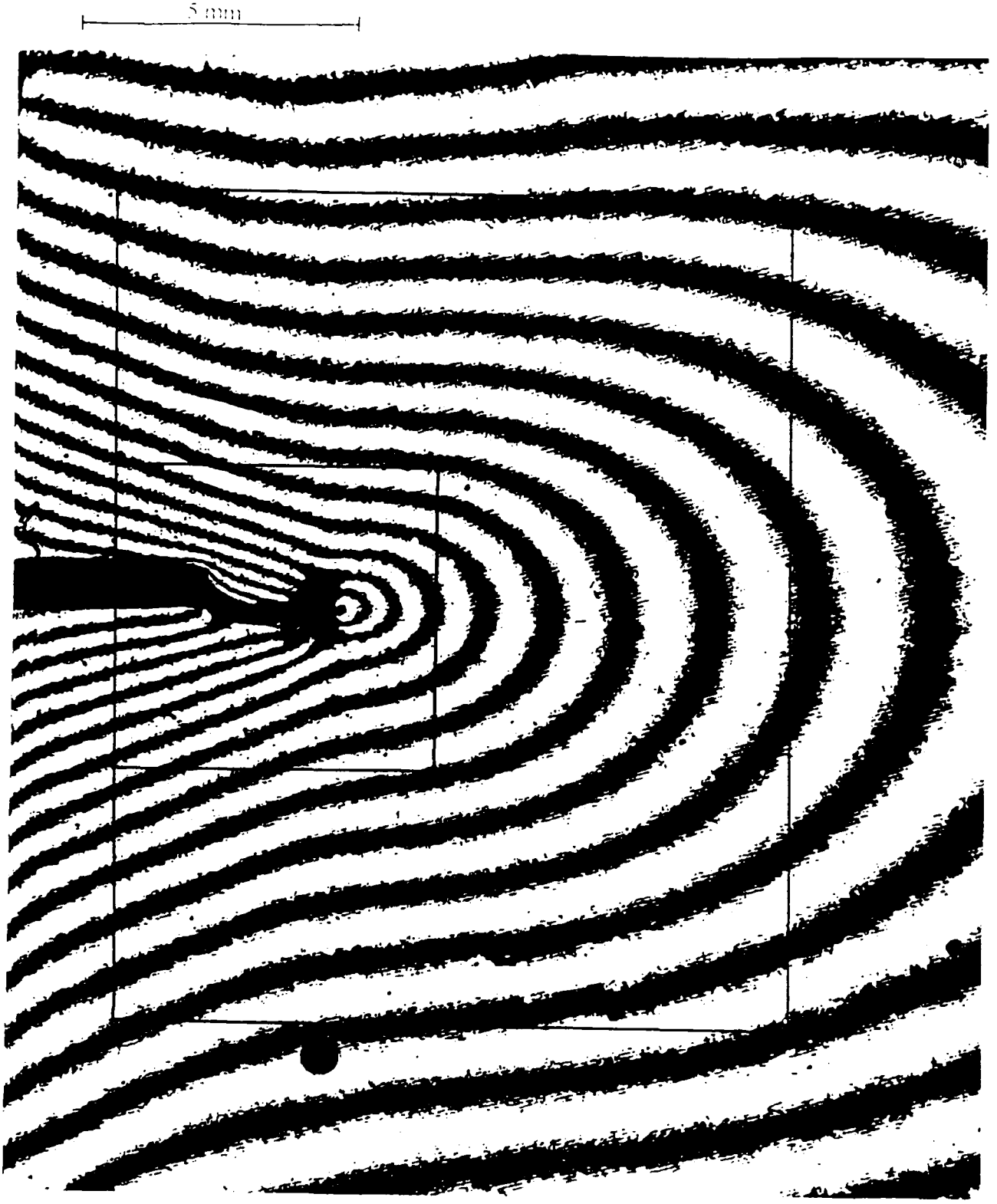


Figure 6. u-Displacement in Cruciform 2024-0 Aluminum Specimen. MD050288. B = 0. $F_x = 0$, $F_y = 1695$ N.

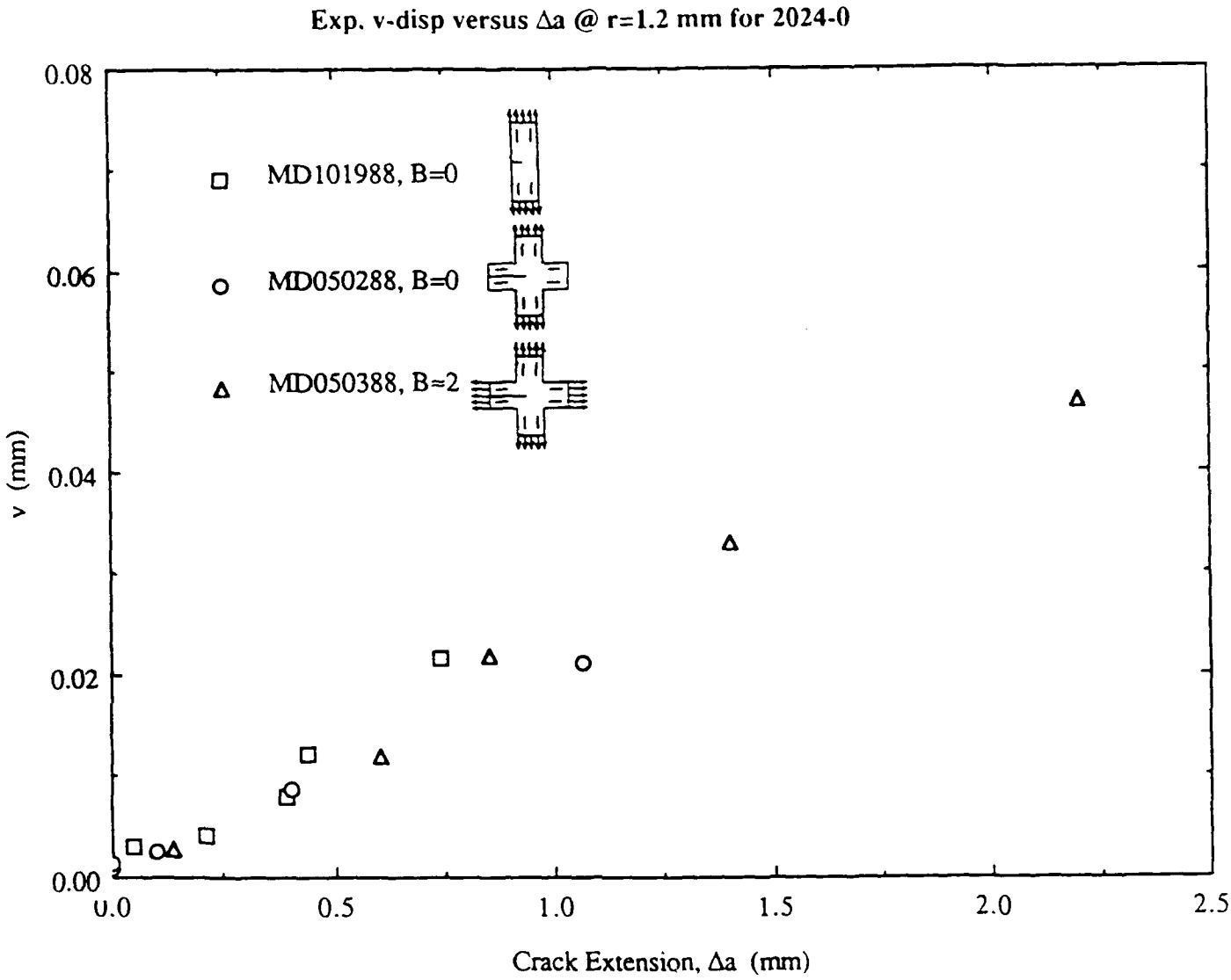
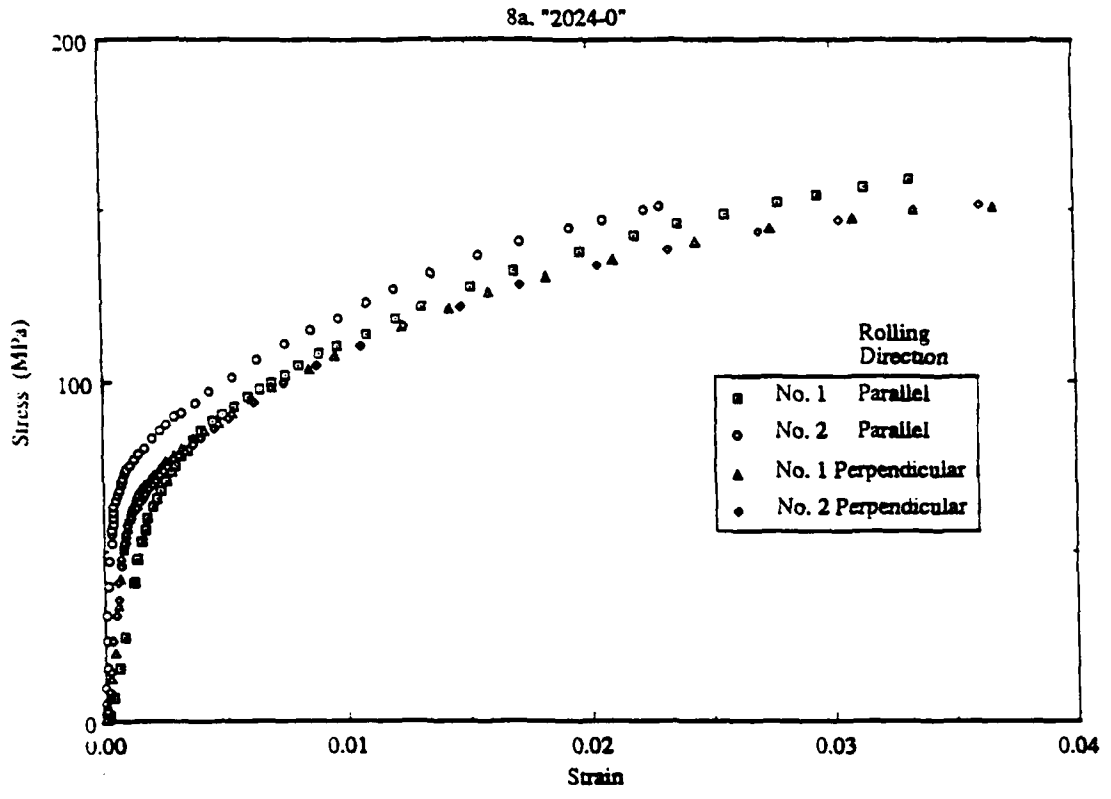


Figure 7 v-Displacement in SEN and Cruciform Specimens 2024-0 Aluminum. r = 1.2 mm, θ = 45°.



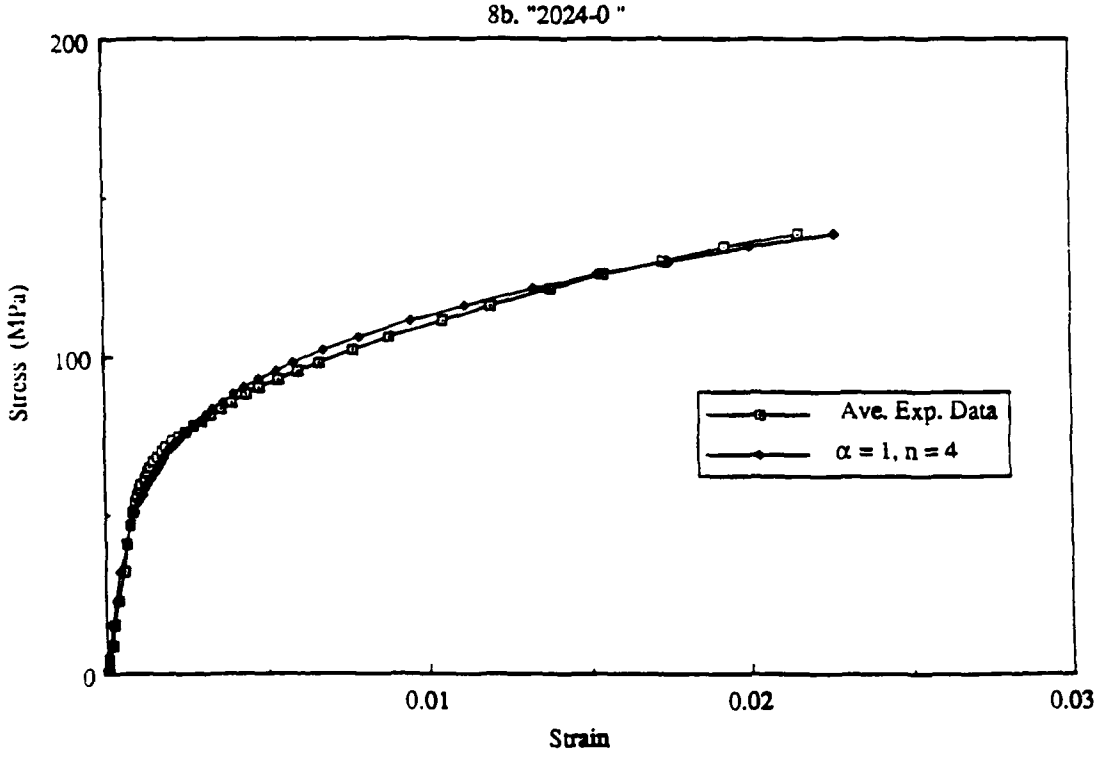


Figure 8 Uniaxial Stress-Strain Curve for 2024-0.

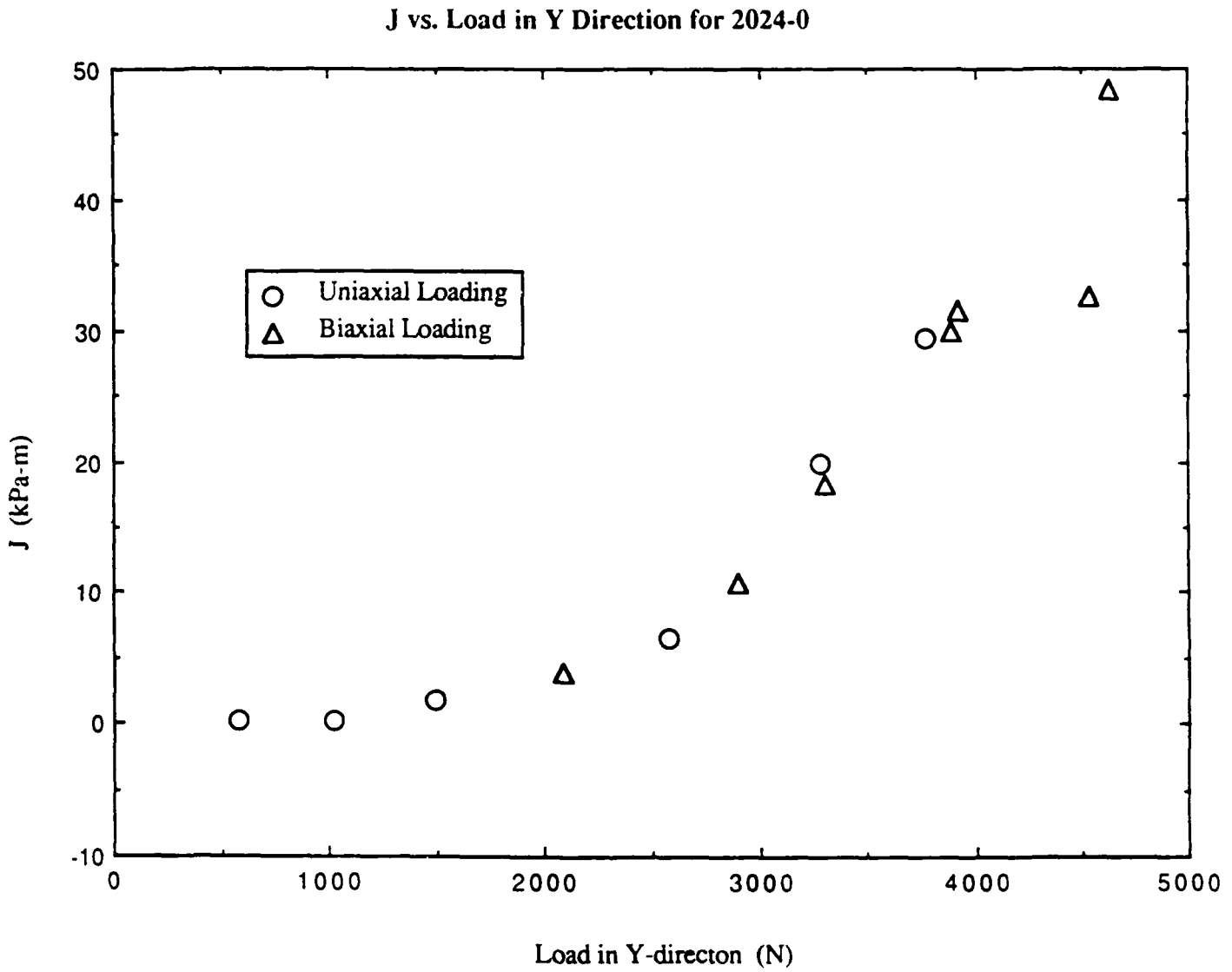


Figure 9 J Versus Applied Vertical Load, F_y, for Uniaxially and Biaxially Loaded Cruciform, 2024-0 Aluminum Specimens.

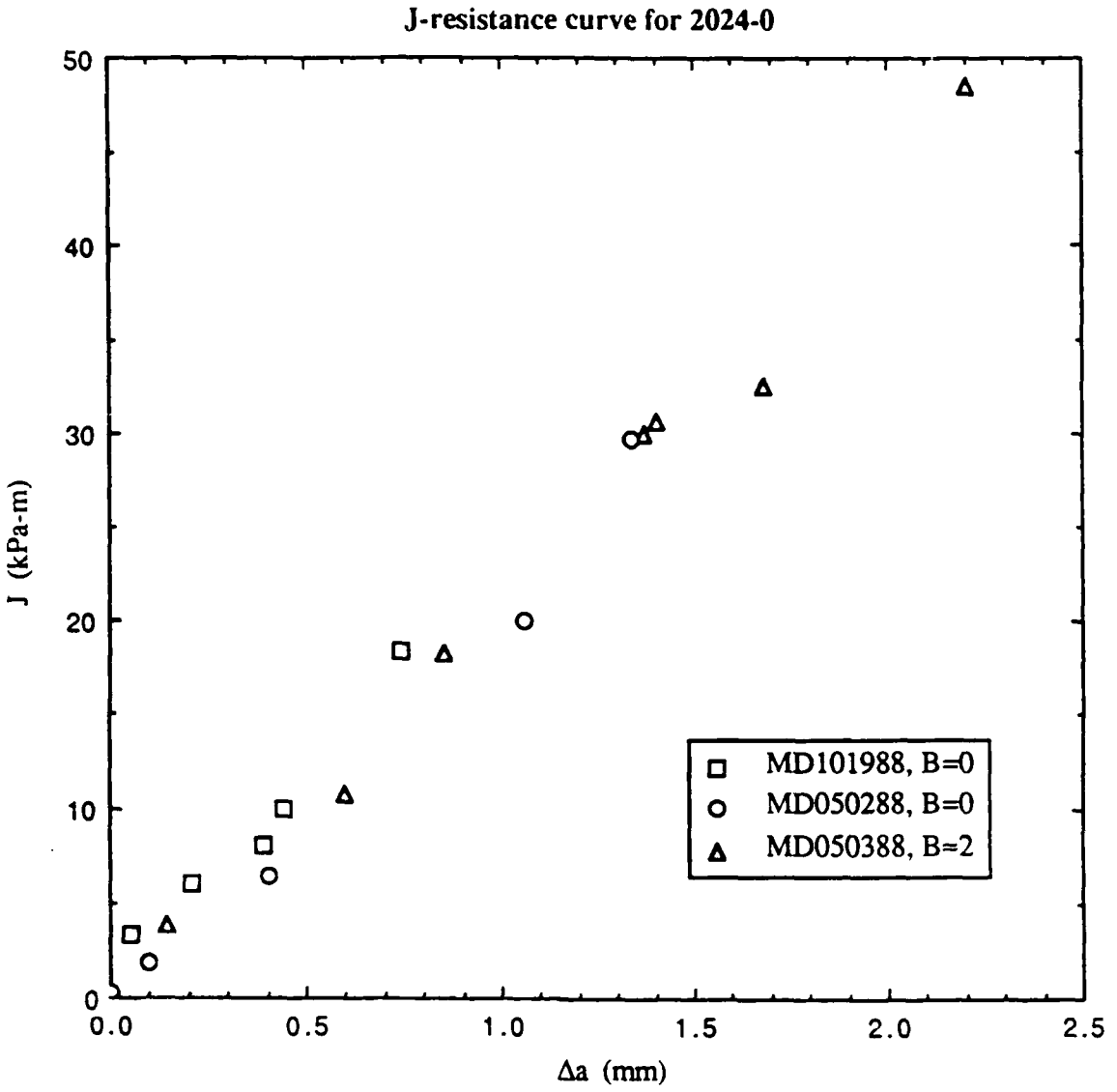


Figure 10 J-Resistance Curves for SEN and Cruciform 2024-0 Aluminum specimens.

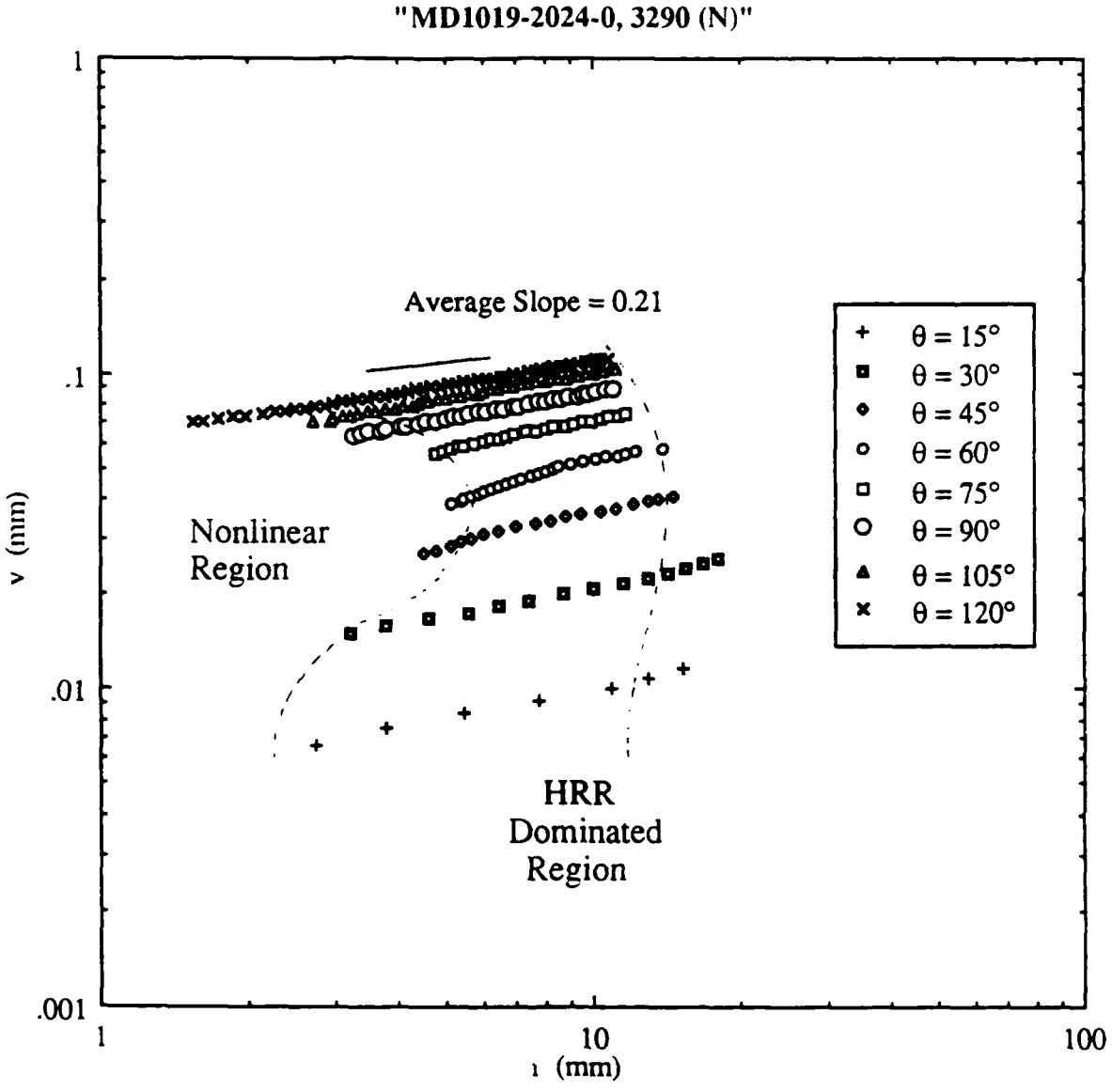


Figure 11 v-Displacement Versus r Relation for Various θ SEN 2024-0 Aluminum Specimen. Δa =0.74 mm, F_y = 3290 N.

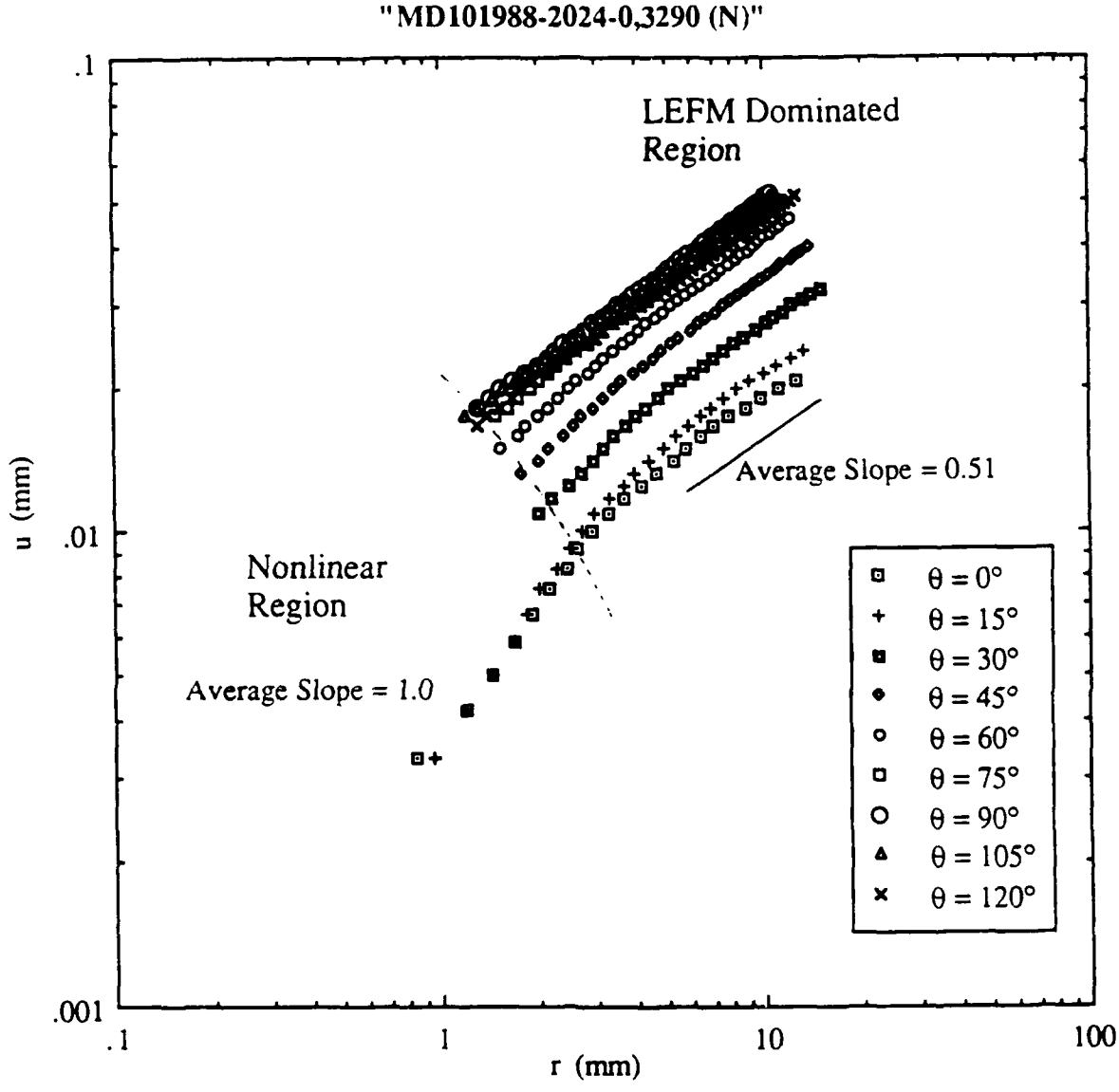


Figure 12 u-Displacement Versus r Relation for Various θ SEN 2024-0 Aluminum Specimen. Δa =0.74 mm, F_y = 3290 N.

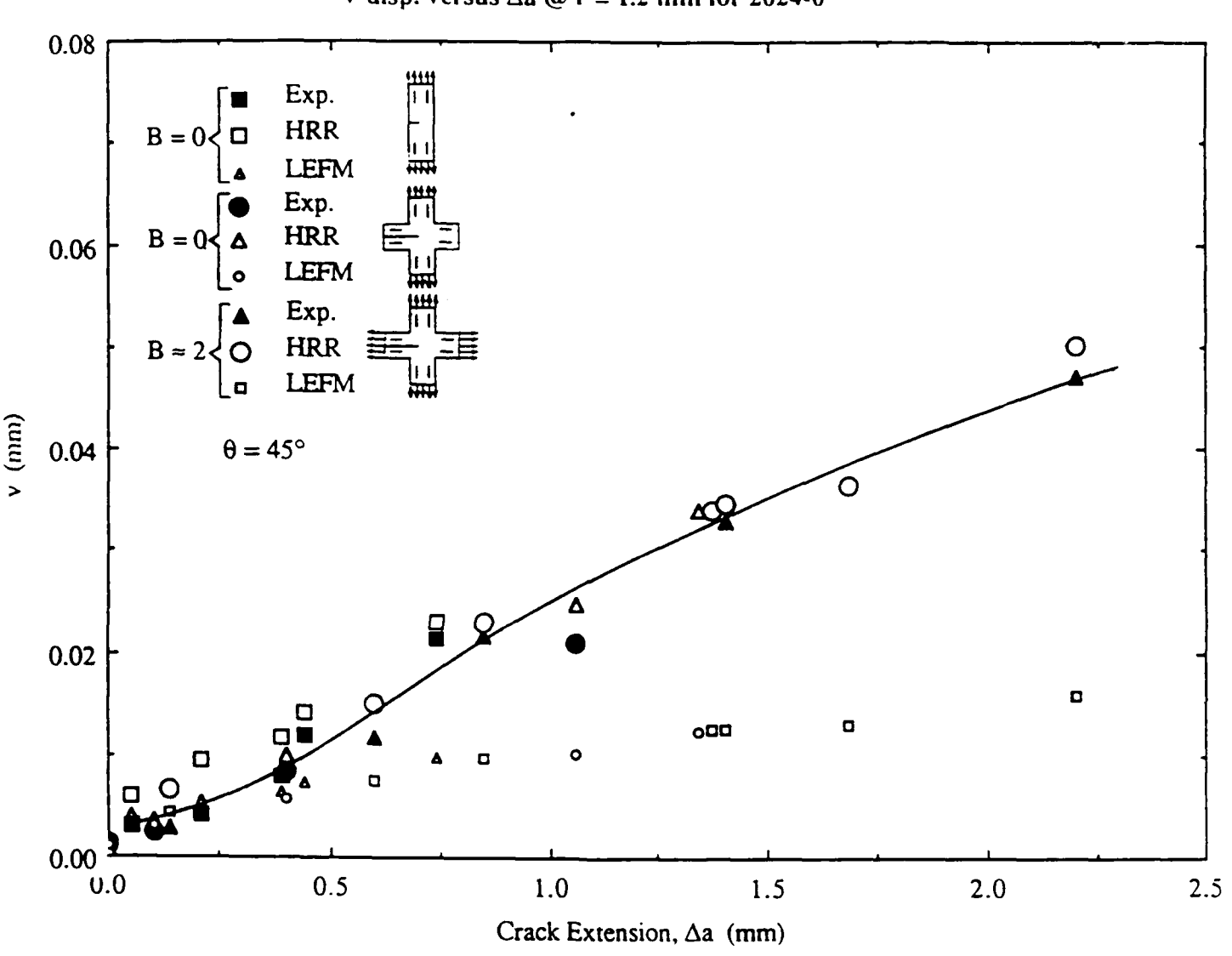


Figure 13 v-Displacements in SEN and Cruciform 2024-0 Aluminum Specimens. r = 1.2 mm, θ = 45°.

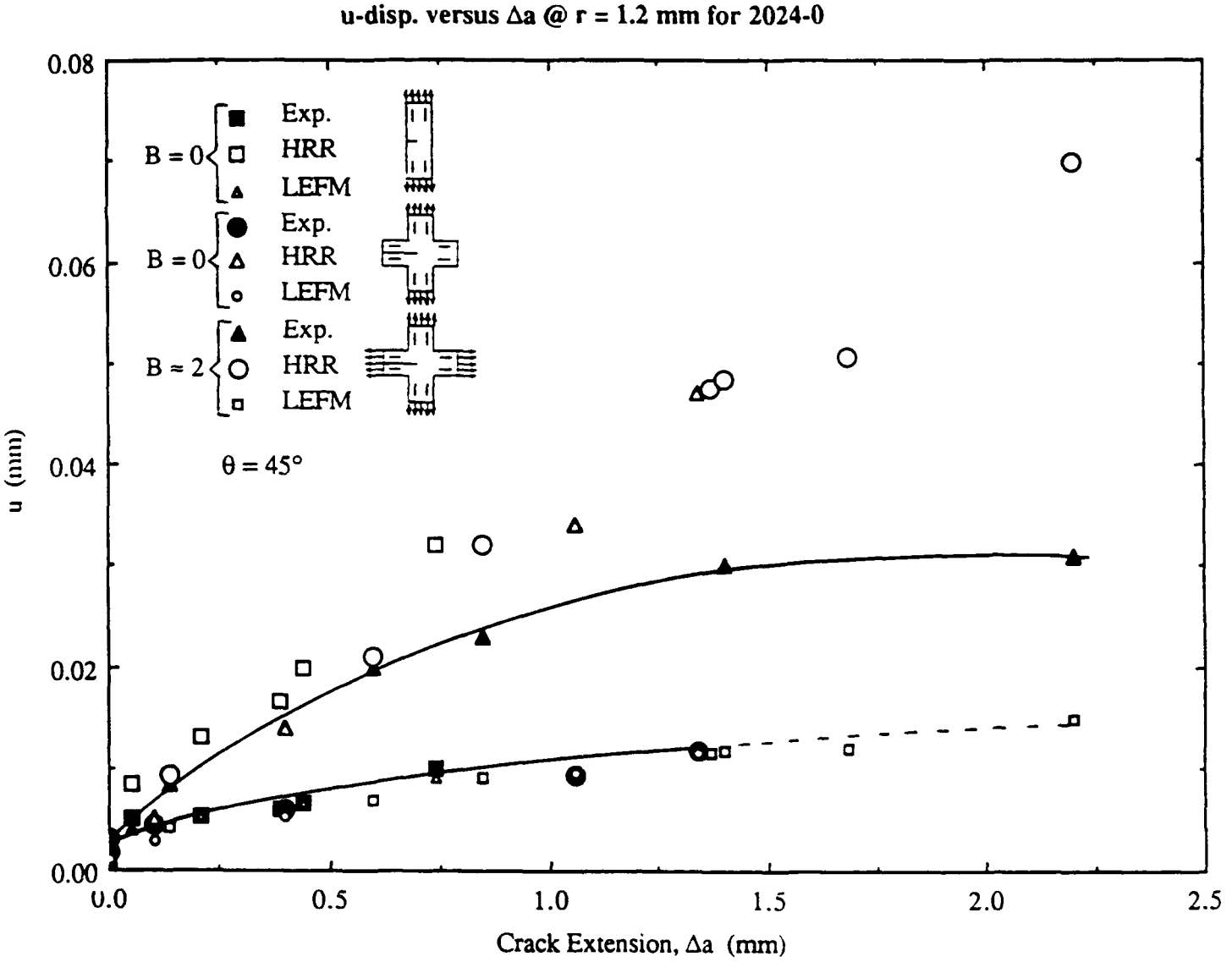


Figure 14 u-Displacements in SEN and Cruciform 2024-0 Aluminum Specimens. r = 1.2 mm, θ = 45°.

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Moire interferometry was used to record simultaneously the vertical and horizontal displacements associated with stable crack growth in single edge notched, 2024-0 Aluminum specimens. For a small stable crack growth of 1.5 mm, the vertical displacement showed the dominance of the HRR field but the horizontal displacement deviated from the HRR field at the early stage of loading.

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