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Performance Evaluation of Barlat's and BBC Yield Criteria based on Directionalities of R-values and Yield Stresses

Y. Lou, G. Bae, C. Lee, C. Park, H. Huh

Abstract

This paper deals with the performance evaluation of Barlat's and BBC yield criteria by the directional variation prediction of the yield stresses and the R-values. For the evaluation of yield criteria, three kinds of Aluminum alloys and two kinds of steels were selected and their material properties are from Stoughton and Yoon's work. The experimental data required for the parameter evaluation included the uniaxial yield stresses and R-values (width-to-thickness strain ratio in uniaxial tension) measured in rolling direction, diaganol direction and the transverse direction, the equibiaxial yield stress and the R-value of equibiaxial tension. The optimization method, the Downhill Simplex method, was selected for the coefficient identification of Barlat91, Barlat97 and Barlat2000 yield criteria. Yield surface shapes, yield stress and R-value directionalities of Barlat's and BBC yield criteria were investigated and compared with the experimental data. Barlat2000 and BBC yield criteria were extremely qualified for the shape of the yield surface and the directionality of the yield stresses and the R-values.

Key Words: Yield criterion, R-value, Planar anisotropy, Sheet metal forming, Downhill simplex method

1. INTRODUCTION

Yield functions define the onset of the yielding or the start of plastic deformation. The performance of a yield function is one of the key issues for the sheet metal forming. Over the last 100 years, many yield criteria were developed for the description of sheet metal behaviors especially for accurate modeling of anisotropy, for instance, Hill's (48, 79, 90, 93) yield criteria [1-4] and Hosford79 yield criterion [5,6]. Barlat's [7-10] and BBC2000 [11, 12] yield criteria are the recent developed ones for highly anisotropic materials. All Barlat's yield criteria and BBC2000 yield criteria can be viewed as members of Hosford's family yield criteria, which are based on the different kinds of linear transformation.

This paper deals with the performance of Barlat's and BBC yield criteria mainly by their ability of precise prediction of the R-value and yield stress directionalities. For the evaluation of yield criteria, three kinds of Aluminum alloys and two kinds of steels are selected and their material properties are from literature [16].

2. PARAMETER EVALUATION

2.1 Barlat's and BBC2000 Yield Criteria

Barlat89, Barlat91, Barlat97 and Barlat2000 yield criteria were described in detail in Barlat's papers [7-10] while the detail the explanation of BBC2000 yield function can be found in the paper of Banabic and coworkers [11]. More detailed explanation of Barlat97 yield criterion of plane stress conditions were provided by Yoon et al. [13] and Abedrabbo et al. [14].

2.2 Downhill Simplex Method

The Downhill Simplex method, proposed by Nelder and Mead [15], is a nonlinear optimization algorithm that requires only function evaluations, but not calculation of derivatives. In the N-dimensional space, a simplex is a polyhedron with N+1vertices. The method iteratively updates the worst point by four operations: reflection, expansion, one-dimensional contraction and multiple contractions.

1. 한국과학기술원
2. 기계항공시스템학부
교신저자: 허훈, E-mail: hhuh@kaist.ac.kr

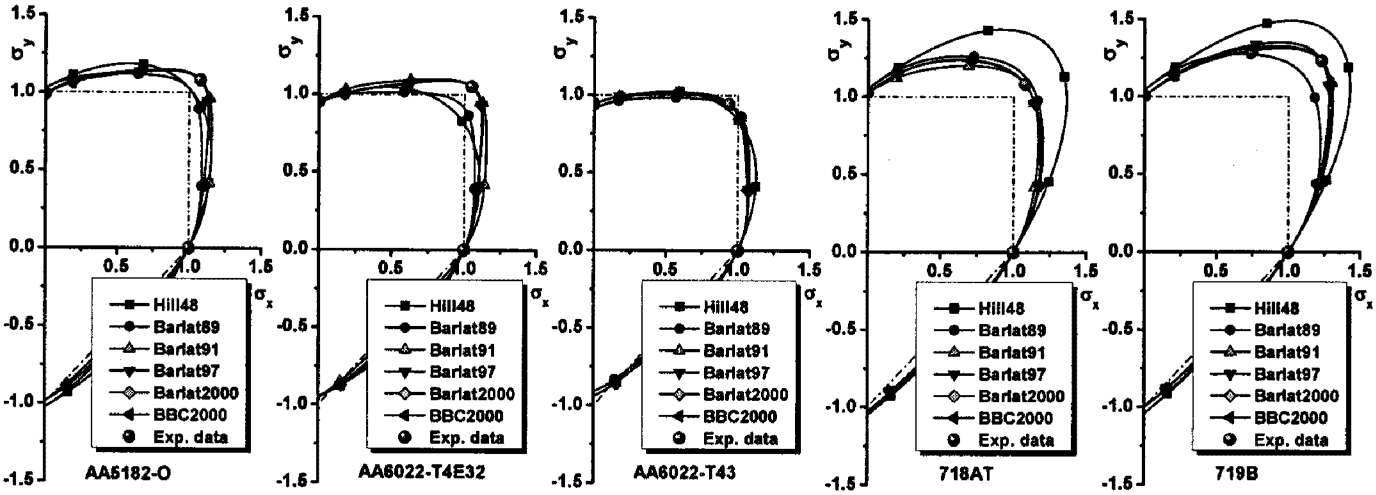

Fig. 1 Yield surfaces of five materials with respect to different yield criteria.

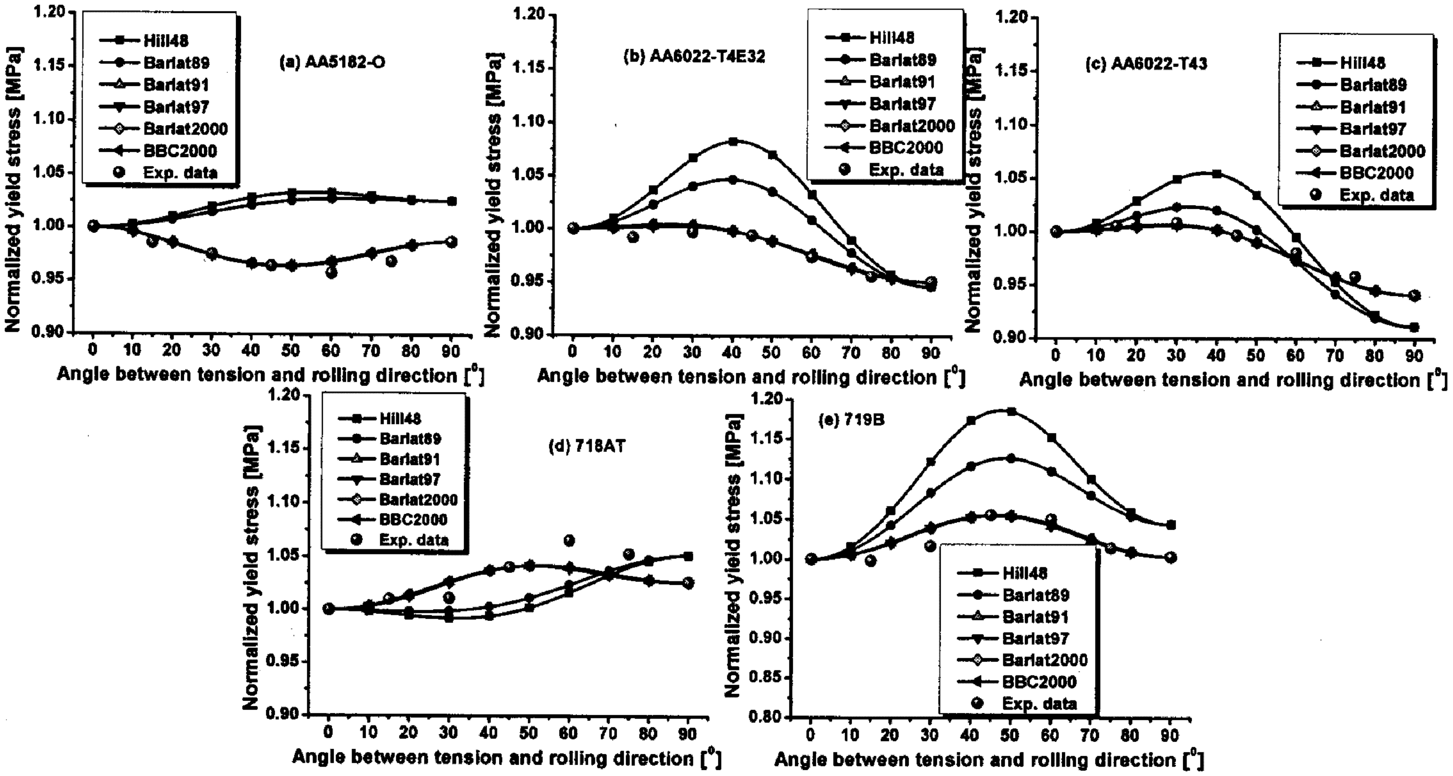

Fig. 2 Directionality comparison of the yield stresses with respect to different yield criteria.

Table 1 Experimental data for the parameter evaluation

Barlat89	Barlat91	Barlat97	Barlat2000 &BBC2000
σ_0, R_0, R_{45}, R_{90}	σ_0,σ_{45},σ_{90}, σ_b	σ_0,σ_{45},σ_{90}, σ_b, R_0, R_{45}, R_{90}	σ_0, σ_{45}, σ_{90}, σ_b, R_0, R_{45}, R_{90}, R_b

2.3 Error Minimization

To compute the anisotropic parameters using the Downhill Simplex method, an error function was established as the sum of squares of the differences between

Table 2 Yield stresses and R-values of five materials [MPa]

Material	σ_0	σ_{45}	σ_{90}	σ_b	R_0	R_{45}	R_{90}	R_b
AA5182-O	115.8	111.6	114.3	125.0	0.957	0.934	1.058	0.948
AA6022-T4E32	133.9	133.1	127.3	140.7	0.823	0.411	0.678	1.244
AA6022-T43	136.6	136.1	128.5	128.8	1.029	0.532	0.728	1.149
718AT	211.9	219.4	216.5	227.8	1.830	2.294	2.517	0.803
719B	210.9	222.6	211.6	259.6	2.165	1.591	2.930	0.860

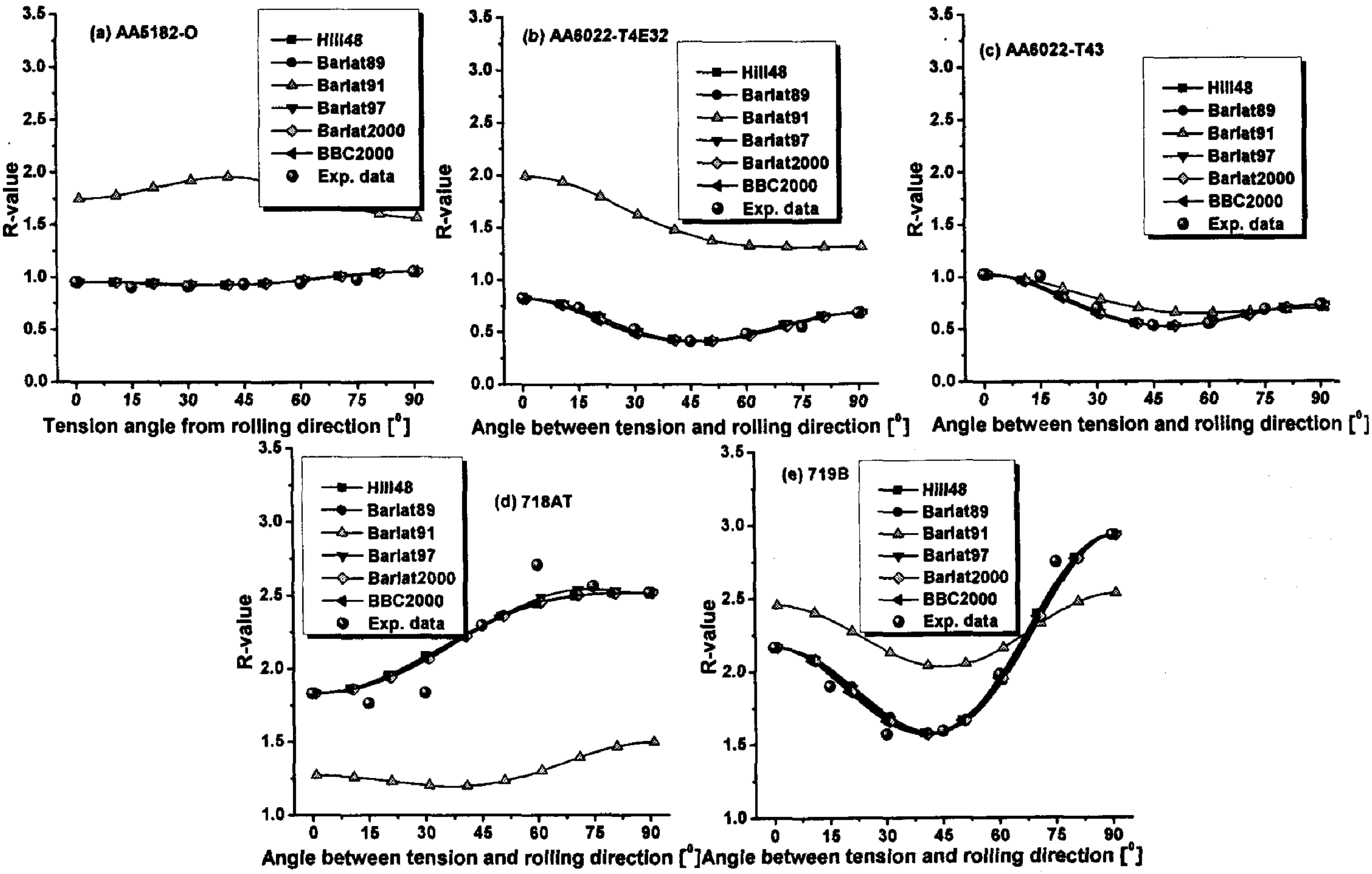

Fig. 3 Directionality comparison of the R-values with respect to different yield criteria.

experimental and predicted yield stresses and R-values in different loading conditions:

$$e(x_i)=\sum_j\left(\frac{\sigma_j^{pre}}{\sigma_j^{\exp}}-1\right)^2+\sum_k\left(\frac{R_k^{pre}}{R_k^{\exp}}-1\right)^2 \qquad (1)$$

where x_i represent the anisotropic parameters of yield criteria, σ_j^{pre} and $\sigma_j^{\exp}$ are the predicted yield stress and the yield stress measured from experiments and R_k^{pre} and $R_k^{\exp}$ are the predicted R-value and the R-value measured from experiments, respectively. The suffix j and k denote the loading conditions. The number of experimental data used in the parameter evaluation is the same as the number of anisotropic parameters to be determined in this work. Therefore the Downhill Simplex method finds the true solution of the anisotropic parameters x_i when the error function $e(x_i)$ infinitely approaches its true minimum (equal to zero). The experimental data used for the anisotropic parameter evaluation are different for different yield criteria because of the different number of anisotropic parameters for different yield criteria. Table 1 lists the experimental data used for the parameter evaluation of different yield criteria.

2.4 Experimental Data

The yield stresses and R-values in the rolling, diagonal and transverse directions as well as the equibiaxial tension condition were used for the parameters evaluation. Five kinds of materials, AA5182-O, AA6022-T4E32, A6022-T43, 718AT and 719B, were chosen in this study. The material data was from Stoughton's work [16] and listed in Table 2.

3. RESULTS AND DISCUSSION

3.1 The Yield Surfaces

The yield surfaces of Barlat's and BBC2000 yield criteria were shown in Fig. 1 with the yield surface of Hill48 for comparison. Barlat91, Barlat97, Barlat2000 and BBC2000 yield criteria can predict the equibiaxial yield stress accurately while Hill48 and Barlat89 yield criteria cannot.

3.2 Directionality of the yield stresses

The predicted yield stress directional variations were compared in Fig. 2. Barlat91, Barlat97, Barlat2000 and BBC2000 yield criteria can predict the yield stresses accurately in rolling, diagonal and transverse directions and describe the yield stress directionality tendency much better than that of Hill48 and Barlat89 yield criteria.

3.3 Directionality of the R-values

The predicted R-value directional variations were compared in Fig. 3. All the yield criteria can describe the R-value directionalities of 5 kinds of materials except Barlat91 yield criterion.

CONCLUSIONS

Barlat's and BBC2000 yield criteria were evaluated by their performance on the directional variation prediction of the yield stresses and the R-values. Barlat97, Barlat2000 and BBC2000 yield criteria were most qualified for the description of the yield surface and the directionalities of the yield stresses and R-values.

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