Table 3 Springback comparisons using the 9 point stress-strain equation

R_t (in.)	Theory[2] (1)	Springback (1/in.) Experimental	Theory[2] (2)	Percent Difference Between (1)-Exp.	(2)-Exp.	(1)-(2)
0.500	0.759	0.737[1]	0.666	2.9	9.6	12.2
	0.759	0.749[1]	0.666	1.4	11.0	
0.375	0.818	0.778	0.737	5.8	5.3	9.9
	0.818	0.790	0.737	3.6	6.7	
0.281	0.882	0.850	0.810	3.7	4.7	8.1
	0.882	0.844	0.810	4.5	4.0	
0.250	0.908	0.865	0.841	5.0	2.9	7.5
	0.908	0.889	0.841	2.2	5.4	
0.188	0.976	0.863	0.916	13.1	6.2	6.1
	0.976	0.954	0.916	2.2	4.0	
0.156	1.022	0.878	0.967	16.5	10.2	5.4
	1.022	1.036	0.967	1.3	6.6	
0.125	1.079	0.966	1.029	11.8	6.6	4.6
	1.079	1.051	1.029	2.7	2.1	
0.094	1.155	1.219	1.110	5.3	9.0	3.9
	1.155	1.219	1.110	5.3	9.0	
0.063	1.264	1.484	1.226	14.8	17.4	3.0
	1.264	1.489	1.226	15.1	17.7	
0.031	1.457	1.758	1.427	17.1	18.8	2.0
	1.457	2.032	1.427	28.3	29.8	

Note:

[1] Upper figures are for 135 deg angle of bend while lower figures are for 120 deg angle of bend.

[2] Theory (1) uses $e = ks^n$, theory (2) uses $e = \dfrac{s}{E} + ks^n$.

6 Assumption of a non-deviating neutral axis is true for wire products if the ratio of $R_t/h \geq 2$ is adhered to. This is not as optimistic as the previously stated 1.5 ratio [10].

7 Springback is not overly sensitive to variations in material properties present in Ramberg-Osgood's stress-strain equation.

Acknowledgment

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DISCUSSION

C. T. Yang[2]

The authors are to be commended for their fine work shown in this paper. The problem of springback was clearly defined and the approach to the solution was properly chosen. The writing was clear and easy to read.

The discusser, however, wishes to make some comments on the following points:

1 In assumption 5 the neutral axis in plastic bending does not deviate from its undeformed position. This could cause error in the final equation. But it can be solved by using the writer's approach mentioned in his paper. (reference [10])

2 Page 2, equation (1) is based on the similarity between two triangles in Fig. 1. However, these two triangles are not similar, even if the curve is linear up to the point C. Therefore, there is some question about the legitimacy of the equation.

3 The authors used the stress-strain equation (11) instead of (10), that is, the elastic portion was neglected. This would cause error in the final results. The writer wonders why the authors did not use equation (10). The mathematics involved might be a little messy but would not be too bad, because in the first term of equation (10) only s is a variable, and E is a constant. Integration would be easy.

4 In bending of metal in the plastic region, temperature and strain rate are always two factors affecting the results. It is wondered whether or not the authors have done some work on wire bending with these two factors considered.

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In conclusion, the discusser wishes to extend his congratulations to the authors for the nice work and also hopes that they will carry on with this type of study in the future. This country has been lagging in the study of metal deformation.

Authors' Closure

The authors thank Mr. Yang for his comments. Our comments on the points he made are as follows:

1 Our experimental results were close enough to predicted results permitting neglect of consideration of the error caused by an incorrect assumption of the neutral axis position. Mr. Yang's approach for determination of the neutral axis would provide more rigor to this equation.

2 Although the triangles *as drawn* in Fig. 1 do not appear similar, the derivation is based upon a *construction* wherein the hypotenuse CD is purposely drawn parallel to the slope AB of the moment curvature curve.

3 Theory 2 used equation (10); Theory 1 used equation (11). This was not made clear in our paper. The results of using Theories 1 and 2 are shown in Table 2.

4 The equations developed are only considered applicable at room temperature and normal metal working strain rates. No work has been done by the authors for high temperature-high strain rate conditions.