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Effect of Brinell Hardness Test on Cold Working Process

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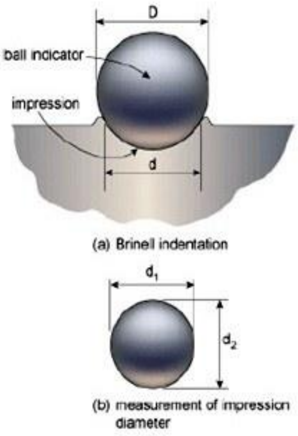
Abstract:
The main aim of this study is to find out the brinell hardness distribution in formed parts by relating plastic strains included in the finite element analysis. Based on the plastic flow curve of the material, an analytical relation was established between the plastic strains involved in the metal during cold working and brinell hardness test so that its hardness can be determined from numerically obtained plastic strains without producing the part and taking measurements. To get prior results the model developed in the study, cold extrusion experiments were performed on samples made of two different metals at five different extrusion ratios. These samples were cut at the centres and brinell hardness measurements were taken which were then compared to the analytical predictions. The results showed that within the applicable range of brinell hardness test, which covers a great percentage of hardness levels resulting from cold forming operations, the analytical model can reliably be used

Keywords: Brinell Hardness test, Flow Curve, Effective Strain, Spherical Indentation, ColdForming, Extrusion, Plastic Deformation.

INTRODUCTION

If a volume of metal is cold worked, the resulting plastic distribution may not be uniform. Knowing that inducing plastic deformation alters material’s strength, different regions of a cold formed part will have different strength. For part reliability, we need to characterize and determine its strength. A practical way of characterizing strength is hardness.



$$BHN = \frac{P}{\frac{\pi D}{2}\left[D - \sqrt{D^2 - d^2}\right]}$$

Where:

P is the test load [kg]

D is the diameter of the ball [mm]

d is the average impression diameter of indentation [mm]

LITERATURE REVIEW

Hardness as a measure of material’s resistance to permanent is an important quality parameter for the finished product. It is also a measure of forge ability of a material undergoing a cold forming process. Generally, cold-formed parts are forged in a number of stages and in each stage the material undergoes additional permanent deformation.

The material, during the process, sometimes becomes so hard that further forming becomes impossible without fracturing the part. In order to continue the process, the part should be heat treated, and thus its hardness should be reduced. Therefore, it is important to know whether all stages can be achieved consecutively without any interruption of forming process or a heat treatment is necessary at some intermediate stage. Because of being an important quality criterion, a measure of strength, and a means of determining formability of the material, we need to determine the hardness of a part. Trial and error, by producing prototypes, taking measurements and repeating the process, is not a feasible approach. It is difficult, time consuming, and costly. Estimating the hardness distribution without actually making the part is a more desirable approach.

In order to establish a correlation between effective strain and hardness, Kim, Lee, and Altan @1# performed an upsetting experiment, and then measured the hardness at various locations in the part. They also calculated effective strain distribution in the upset part through a FE analysis of the upsetting process. By correlating the measured hardness and the numerical results, they found a relation between Vickers hardness and effective strain. They also checked the validity of this relation by comparing numerically determined effective strain distribution in a backward extruded can to the measured hardness distribution. Gouveia*et al.* @2,3#performed a similar study for cold forward extrusion. They obtained a relation between Vickers hardness and effective strain by measuring the hardness at the center of cylindrical specimens compressed at specific ratios. According to the compression ratio, the compressed specimens had known values of effective strain.

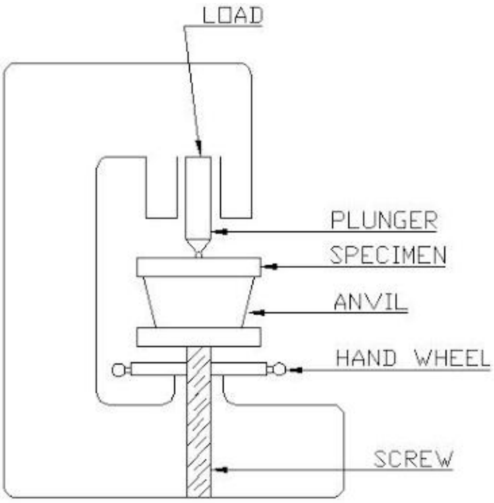


Fig 1: BRINELL HARDNESS TESTER

They used their relation to verify the numerically calculated effective strain distribution in an extruded part by comparing with the measured hardness distribution. Ruminski*et al.* @4# obtained an empirical relation between Vickers hardness and effective strain to determine the mechanical property distribution in cold drawn tubes. However, these were empirical relations specific to certain materials with a certain flow curve. If one seeks a relation between hardness and strain for another material, an upsetting test, hardness measurements, and FE simulations are required followed by correlation with results. Choi *et al*. @5# avoided this burdensome procedure by performing a FE simulation of the Brinell hardness test for a cold formed material. Thus, they obtained Brinell hardness of a material that has undergone a certain extent of plastic strain. Based on the calculated hardness they found a relation between hardness and strain, and then verified this relation by comparing the predicted hardness distribution with the measured values. Although they avoided the cumbersome experimental work that the previous methods required, their approach still poses difficulties concerning accurate FE modelling of the Brinell test indentation, and computational expense of such a nonlinear contact problem with moving contact boundaries. Similarly, Tekkaya @6# carried out a FE analysis of conical indentation on a cold worked part to find the equivalent pyramidal Vickers hardness and obtained a relation between Vickers hardness and flow stress.

RESULTS AND DISCUSSIONS

Table 1- Measured and calculated hardness values of materials with no initial strain

Material ~Steel!	k ~MPa!	*n*	Measured HB	Predicted HB	%Error
AISI1010 @1#	665	0.255	98*	99	1.7
WNr. 1.0303 @2,3#	685.2	0.185	110*	119	8.4
XC18 @28#	664	0.10	142*	140	1.1
SCM415 @5#	768	0.139	143	149	4.0
Z2CN18-10 @28#	862	0.21	148*	142	4.3
Mild steel @11#	1000	0.249	149*	150	0.7
XC80 @28#	921	0.17	159*	166	4.1
35CD4 @28#	819	0.09	185*	178	3.7
XC48 @28#	1133	0.16	195*	208	6.5
16NC6 @28#	1026	0.17	196*	184	6.1
100C6 @28#	1023	0.14	196*	197	0.6
42CD4 @28#	939	0.10	204*	200	2.2
Z38CDV5 @28#	1136	0.17	213*	203	4.6
XC38 @28#	1102	0.11	221*	228	3.5
XC65 @28#	1607	0.24	221*	239	8.3
0.3C, 0.4Mo, 1.4Mo,1.6Ni temp. at 725°C @12#	1137	0.120	247*	230	7.0
ASTM A514, T1 @30#	1103	0.088	256	242	5.6
A508B @29#	1133	0.105	258*	238	7.9
35NC15 @28#	1235	0.08	272*	276	1.5
Z15CN17-03 @28#	1403	0.10	288*	297	3.3
AISI 4130 tempered at 670°C @27#	1300	0.096	297*	279	6.3
AISI 4130 tempered at 550°C @27#	1375	0.070	338*	316	6.6
0.3C, 0.4Mo, 1.4Mo, 1.6Ni temp. at 425°C @12#	1534	0.061	402*	361	10.2
AISI 4130 tempered at 400°C @27#	1860	0.049	458*	452	1.3
AISI 4130 tempered at 300°C @27#	2213	0.056	535*	527	1.6
0.3C, 0.4Mo, 1.4Mo, 1.6Ni temp. at 200°C @12#	2163	0.050	537*	524	2.4

CONCLUSION

In this study, we propose an analytical relation between the Brinell hardness of a cold formed material and the effective strain based on the flow curve constants of the unformed material. Accordingly, we avoid formidable experimental and numerical procedures.

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