Mathematical & Computational Applications, Vol. 2, No. 2, pp. 71-77, 1997.

APPLICATION OF THE HALL-PETCH RELATION TO MICROHARDNESS MEASUREMENT ON AA 1030, Cu, CuSn7, CuZn30 and 6114 ALLOYS

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Abstract: In this experimental study, the strip formed specimens made from aluminum alloy 1030, pure Cu, CuSn7, CuZn30 and low carbon steel 6114 were cold worked to different ratios. To be able to determine the microhardness values of the materials, the microhardness tests were applied. Grain sizes of the materials were determined by the Heyn method using metal microscope.

The hardness of materials, H, is dependent on the grain diameter, d, in a similar way as in the flow stress in the Hall-Petch relation: $H=H_0+K_Hd^{-1/2}$ where H_0 and K_H are constants. The microhardness of the materials is found to vary with the grain size according to the Hall-Petch equation with reasonable accuracy.

1. INTRODUCTION

It is known that mechanical properties are affected by grain size for metallic materials. A general relationship between yield stress (and other mechanical properties) and grain size was proposed by Hall [1] and greatly extended by Petch [2, 3].

$$\sigma_0 = \sigma_i + K_H d^{-1/2} \tag{1}$$

where σ_0 : the yield stress

σ_i : "friction stress", representing the overall resistance of the crystal lattice to dislocation movement

K_H: "locking parameter", which measures the relative hardening contribution of the grain boundaries

d : grain diameter

The Hall-Petch equation was originally based on yield-point measurements in low-carbon steels. It has been found to express the grain size dependence on the flow stress at any plastic strain out to ductile fracture and also to express the variation of brittle fracture stress with grain size and the dependence of fatigue strength on grain size [4]. The Hall-Petch equation also has been applied not only to grain boundaries but to other kinds of boundaries such as ferrite-cementite in pearlite, mechanical twins, and martensite plates [5]. The Hall-Petch relation is not always satisfied, especially in the case of subgrain strengthening [6] and at large strains [7].

Attempts have been made to correlate the hardness of a material with its flow stress [8, 9]. Hall [10] proposed that the hardness dependence on grain size might follow directly the Hall-Petch [1, 11] relation (1), thus the hardness-grain size relation was described by

$$H=H_0+K_H d^{-1/2} \qquad (2)$$

where H_0 and K_H are constants. This was shown to be valid for cartridge brass [12, 13] and Al [14, 15], Cu alloys [16].

Jindal and Armstrong [12] related H_0 and K_H for polycrystalline cartridge brass and leaded brass to σ_0 and K previously reported by Armstrong et al. [11]. However, a problem that has been encountered in the interpretation of the relation between hardness and $d^{-1/2}$ is that the hardness intercepts of H_0 of subgrain size samples are appreciably lower than for coarse-grained or single-crystal samples. It has been suggested [14] that a more suitable fitting is obtained by replacing the negative power -0,5 of the grain diameter by the higher negative value -1,5. Dollar and Goreczyca [17] examined the Hall-Petch's exponent for the values of -0,5 and -1.

Taha and Hammad [18] investigated the Hall-Petch relation for Al, Cu, Al-Cu alloy and Al-MD105 which represent pure metals, solid solution and dispersion hardened materials. The grain boundary hardening K_H of Al-MD105 is found to be the highest although this material recrystalizes to larger grain size than those for the other materials; this is attributed to the resistance of boundaries to deformation arising mainly from the presence of hard, second phase alumina particles. However, the contribution of solution, precipitation, and dispersion hardening may be added to grain boundary hardening.

The purpose of this work is to investigate the Hall-Petch relation derived from the relation between the microhardness and the grain size for Aluminum AA 1030, pure Cu, CuSn7 bronze, CuZn30 brass and low carbon steel 6114.

2. EXPERIMENTAL

Table 1-3 gives the chemical composition of the materials used. The materials were in the form of sheets which were annealed (isothermal or isochronally) after being rolled to various amounts of cold work to produce materials of various grain sizes. Before being cold rolled, the materials AA 1030, Cu, CuSn7, CuZn30 and 6114 were annealed at 593 K, 673 K, 673 K, 773 K and 1103 K for 1 h, respectively. Cold rolled samples were polished and etched to measure the grain size. The microhardness values and the grain diameters of the samples were measured under metal microscope. The grain size of the specimens were determined by using the Heyn method according to ASTM-E 117

Table 1. Chemical composition of the AA 1030

Cu	Fe	Si	Zn	Mn	Al
0,05	0,60	0,35	0,06	0,05	balance

Table 2. Chemical composition of the 6114 low carbon steel

C	Si	Mn	P	S	Fe
0,024	0,019	0,22	0,010	0,010	balance

Table 3. Chemical composition of the Cu alloys

Materials	Sn	Pb	Zn	P	Mn	Fe	Ni	Si	Cu
Cu	0,007	0,017	0,001	0,021	0,008	0,018	0,11	0,11	99,76
CuSn7	7,41	0,012	0,026	0,14	0,005	0,012	0,002	0,002	92,39
CuZn30	0,021	0,066	31,35	-	-	0,05	0,017	0,017	67,85

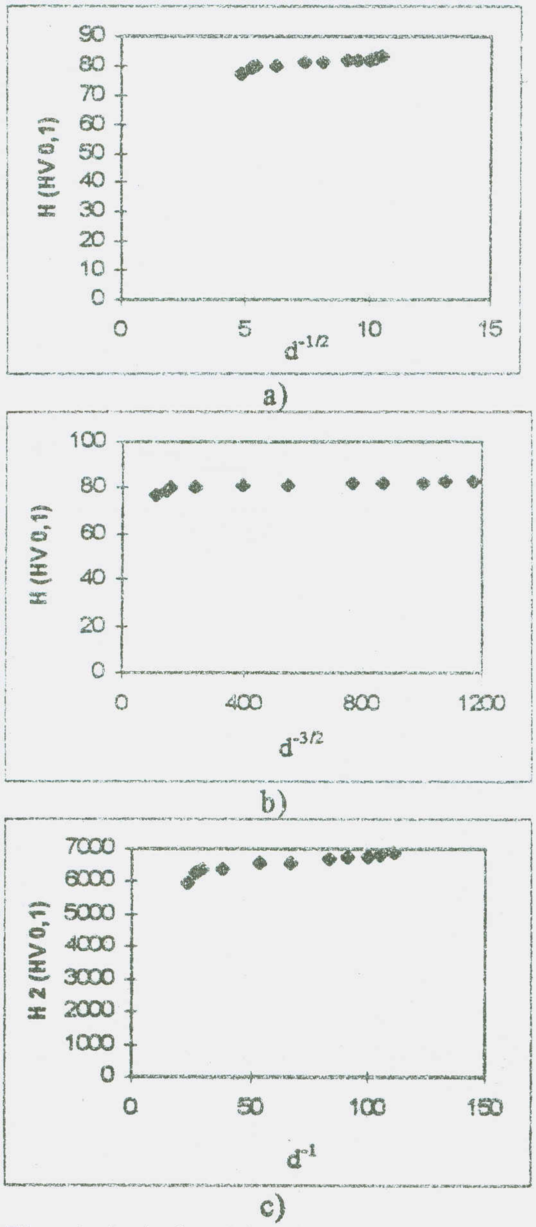


Fig.1. Relationship between hardness and grain size for AA 1030 according to: a)Hall-Petch Relation $H=H_0+K_H d^{-1/2}$; b) $H=H_0+K_H d^{-3/2}$; c) $H=\sqrt{(H_0)^2+(K_H d^{-1/2})^2}$.

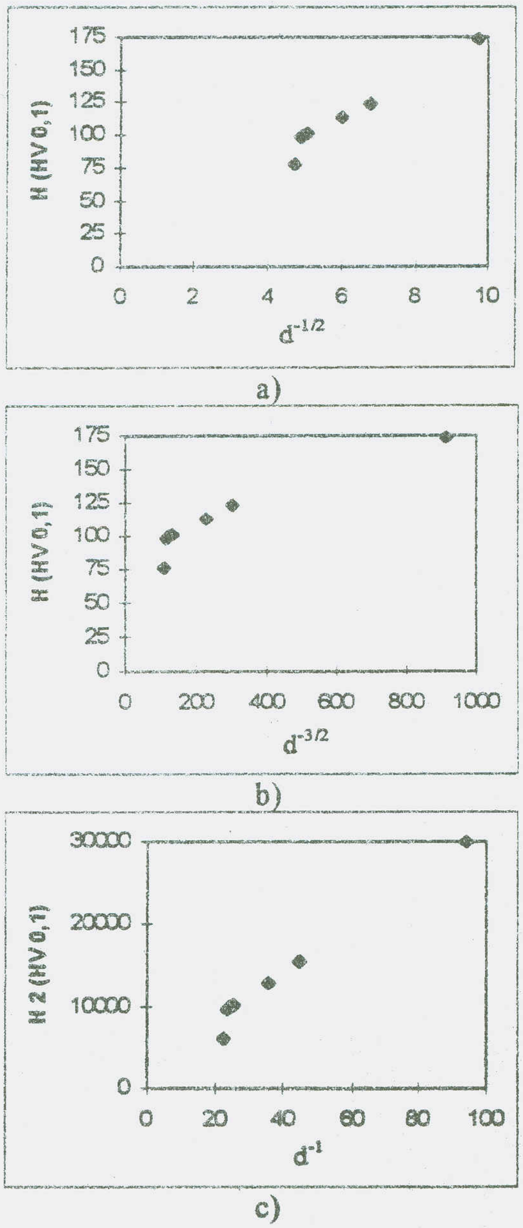
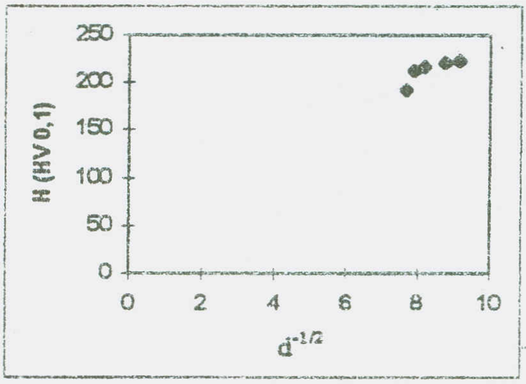


Fig.2. Relationship between hardness and grain size for Cu according to: a)Hall-Petch Relation $H=H_0+K_H d^{-1/2}$; b) $H=H_0+K_H d^{-3/2}$; c) $H=\sqrt{(H_0)^2+(K_H d^{-1/2})^2}$



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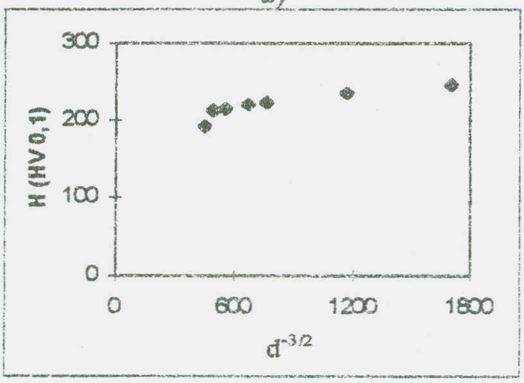

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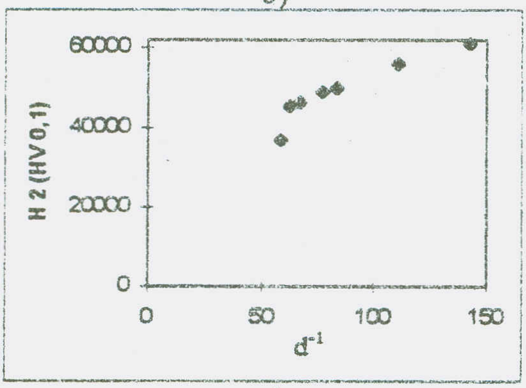

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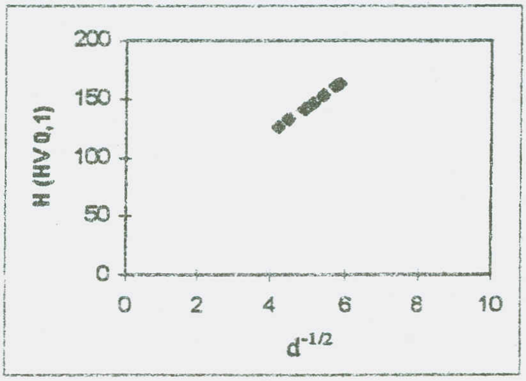
Fig.3. Relationship between hardness and grain size for CuSn7 according to: a)Hall-Petch Relation $H=H_0+K_Hd^{-1/2}$; b) $H=H_0+K_Hd^{-3/2}$; c) $H=\sqrt{(H_0)^2+(K_Hd^{-1/2})^2}$.



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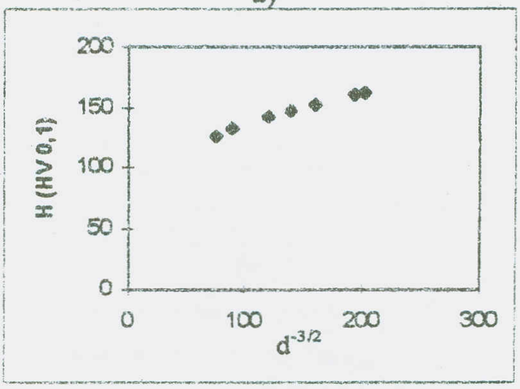

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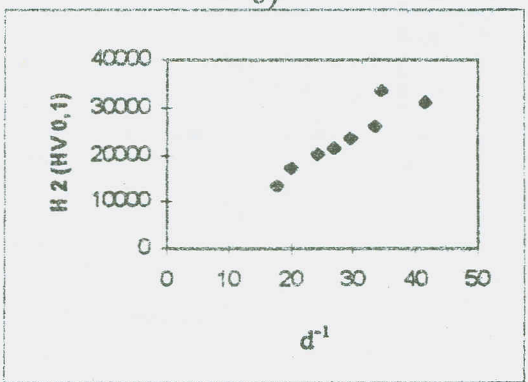


c)

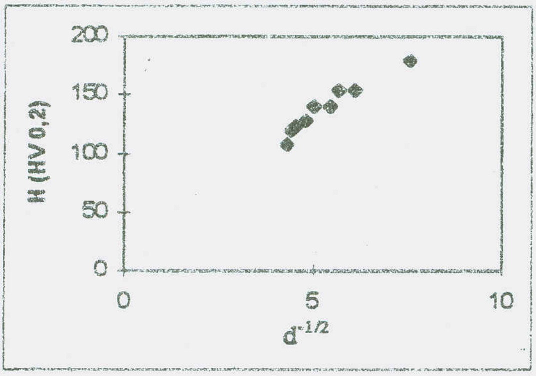
Fig.4. Relationship between hardness and grain size for CuZn30 according to: a)Hall-Petch Relation $H=H_0+K_Hd^{-1/2}$; b) $H=H_0+K_Hd^{-3/2}$; c) $H=\sqrt{(H_0)^2+(K_Hd^{-1/2})^2}$.

3. RESULT AND DISCUSSIONS

Fig.1 to 5 show the relationship between hardness and grain size according to (2), (3) and (4), for AA 1030, pure copper, bronze, brass and 6114.

$$H=H_0+K_Hd^{-3/2} \quad (3)$$

$$H=\sqrt{(H_0+K_Hd^{-1/2})^2} \quad (4)$$



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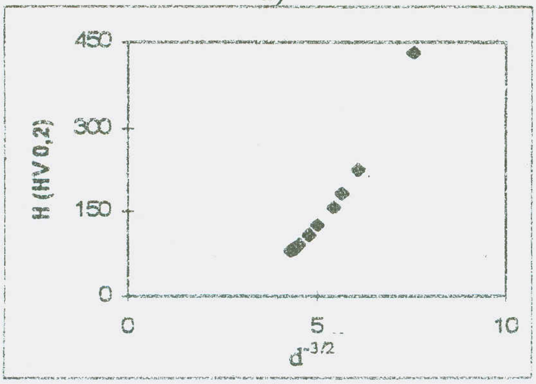

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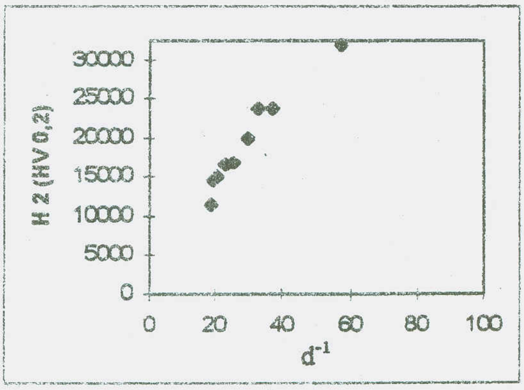

c)

Fig.5. Relationship between hardness and grain size for 6114 low carbon steel according to: a)Hall-Petch Relation $H=H_0+K_H d^{-1/2}$; b) $H=H_0+K_H d^{-3/2}$; c) $H=\sqrt{(H_0)^2+(K_H d^{-1/2})^2}$.

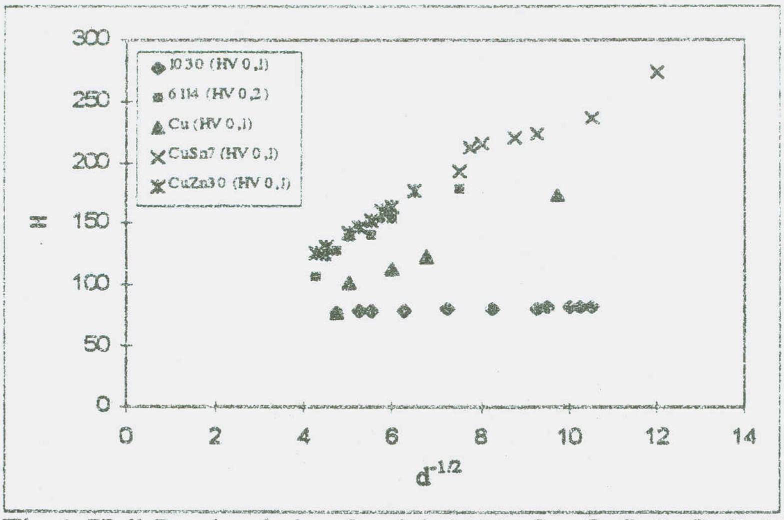

Fig.6. Hall-Petch relation for AA 1030, Cu, CuSn7, CuZn30 and, 6114.

Table 4. The Hall constants and correlation coefficients according to various equations.

Material	(2) H_0	(2) K_H	(2) Correlation coefficient	(3) H_0	(3) K_H	(3) Correlation coefficient	(4) H_0	(4) K_H	(4) Correlation coefficient
1030	74.8	0.77	0.99	78.5	$4*10^{-3}$	0.92	77.84	2.74	0.91
6114	31.7	20.1	0.96	108.7	$180*10^{-3}$	0.91	72.6	22.18	0.96
Cu	13.4	16.5	0.97	85.5	$98*10^{-3}$	0.95	41.53	17.35	0.98
CuSn7	127	10.3	0.93	193.12	$34*10^{-3}$	0.90	171.3	15.23	0.93
CuZn30	32.05	22.3	0.99	109.6	$260*10^{-3}$	0.93	27.82	28.12	0.93

The Hall-Petch relationship between the microhardness value and the grain size for the being tested materials is shown in Fig 6. The relationship between H and d is linear. H_0 and K_H constants in equation (2,3,4) were calculated by the least square method. The results obtained were given in table 4. When the correlation coefficients are taken into account, it is seen that equation (2) has the highest values. This means that, equation (2) is the most suitable one.

The values of H_0 according to (3) and (4) show great fluctuations, which means that the correlation between harduess and grain size is more fitted to the Hall-Petch equation (2). However, the slopes (table 4) are found to be significantly different for the various materials and highest for CuSn7 according to (2) to (4).

Tabor [9] related the hardness H of a material to flow stress at 8% tensile strain as

$$H=3\sigma_{\varepsilon=0.08} \tag{5}$$

On the basis, Hall [10] proposed that the hardness of polycrystalline material depends on grain size just as does the yield stress according to (2).

The variation of Hall-Petch constants for different materials may be due to the fact that in the Hall-Petch relation, grain boundaries were considered as the only obstacles for mobile dislocations. In metals, however, there are many kinds of obstacles, such as point defects, precipitates, cell boundaries, sub-boundaries, pre-existing dislocations, and so on. Since these obstacles have various potential barriers, the mean free path of mobile dislocations, d in (1) to (4), strongly depends on the existence and formation of these obstacles.

It is known that 6114, which is low carbon steel has bbc crystal structure, and the remainings have fcc crystal structure. However, these different structures did not affect on hardness. From our results and others, it appears that the structure and strength contributions to the grains may be greatly affected by the presence of impurities, solute elements, and particles.

Such effects as well as the influence of texture should be further investigated to improve the fundamental understanding of strengthening processes and to advance the development of engineering materials.

4. CONCLUSIONS

According to the microhardness and grain size values of AA 1030, Cu, CuSn7, CuZn30 and 6114 alloys specimens which were cold rolled to different ratios, the following conclusion can be drawn.

The hardness (H) of these materials may be related to the grain size (d) by a similar relation as stress according to Hall-Petch

$$H=H_0+K_H d^{-1/2}$$

where H_0 and K_H are experimental constants.

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