The Iraqi Journal For Mechanical And Material Engineering, Vol.12, No.2, 2012

Comparison of Applied Pressure Effect on Improving Density, Hardness, and Microstructure by Both Squeeze Casting Process and Pressure Die Casting Process for 380-Al Alloy

Dr. Najeeb S. Abtan
Lecturer
College of engineering
University of Tikrit

Dr. Kadhim H. Ghlaim
Assist. Proff.
Dijla University College

الخلاصة:

يتضمن هذا البحث دراسة تأثير الضغط المسلط أثناء عمليتي السباكة بالعصر والسباكة بالضغط على تقليل المسامات المتولدة أثناء عملية السباكة بكلا الطريقتين. تم تسليط الضغط في السباكة بالضغط والمنصهر في حالته السائلة أي عند درجة حرارة (750) درجة مئوية. أما في حالة السباكة بالعصر فيتم تسليط الضغط لحظة وصول درجة الحرارة إلى (650) درجة مئوية أي إن السبيكة نصفها سائل والنصف الآخر صلب ويمكن تسميتها بالحالة العجينية.

تم قياس كل من الكثافة والصلادة والتركيب ألمجهري للمسبوكات المنتجة بكلا الطريقتين وتبين تحسن واضح في الكثافة والصلادة بكلا النوعين ولكن النتائج كانت أفضل بالنسبة لسباكة العصر حيث أن تأثير الضغط كان أفضل في الزيادة المتلاحقة في قيم الكثافة مع زيادة الضغط المسلط ونفس القاعدة انطبقت على زيادة قيم الصلادة، وأيضا تبين من خلال الفحص ألمجهري التناقص في حجم البلورات في السباكة بالعصر أكثر من التناقص في حالة السباكة بالضغط وهذا يعود إلى حالة السائل في كلا الحالتين لحظة تسليط الضغط حيث تبين أن الحالة العجينية للمسبوكة تمثل الحالة المثلى للضغط المسلط لتحسين الخواص الميكانيكية والمجهرية للمسبوكات.

المفاتيح : سباكة العصر، سباكة الضغط، الكثافة، الصلادة.

Abstract:

The present study includes the effect of applied pressure on elimination the porosities that formed during both squeeze casting process and pressure die casting.
For pressure die casting the pressure was applied on the full liquid molten alloy (750^{o}C) where the pressure was applied on molten alloy at (650^{o}C) i.e. the molten was fifty liquid fifty solid (mushy zone).

The tests and measurements of density, hardness, and microstructure show the improvement in density and hardness for the samples of both techniques but the increasing in hardness and density values in squeeze casting were higher than the values of pressure die casting samples also the test of microstructure shows the decreasing in (DAS) for the squeeze sample more than the (DAS) of pressure casting samples.
The above improvement in microstructure, hardness, density belongs to the behavior of applied pressure in both cases which means that the mushy zone of molten alloy represents the optimum region to improve the mechanical properties by applied pressure

Keywords: squeeze casting, pressure die casting, density, hardness.

Sample	Mean
DAS	Dendrite Arm Spacing
L	Length of line
N	Number of intersection
H_V	Vickers hardness
P	Applied pressure
d_{av}	The average diameter of two diagonal length of rhombus indentation
ρ_s	Actual density of sample (g/cm^3)
ρ_w	Water density at (38 ^{o}C) = 0.998 (g/cm^3)
W_s	Sample weight in air (gm)
W_{sb}	Sample and basket weight in water (gm)
W_b	basket weight (gm)
N_w	No. of wires used to hung the basket to the balance arms =2
D_w	Basket wire diameter = 5 mm
D_b	Basket diameter (mm)
V_f	Volume fraction
S_q	Squeeze sample
P_d	Pressure die cast sample
P^*	Applied load (5kgf)

Introduction:

Squeeze casting is one of the modern casting process, which has been invented to address these shortcomings and has a high potential to produce sound castings [1]. It is a generic term to specify a fabrication technique where solidification is promoted under high pressure within a re-useable die [2]. The high pressure applied pressure, which is several orders of magnitude greater than the melt pressure developed in normal casting processes, keeps entrapped gases in solution and squeezes molten metal from hot spots to incipient shrinkage pores [3]. The applied pressure forces the molten metal to have an intimate contact with the mold metal which in turn leads to rapid heat transfer that yields a pore free, fine grain sizes, close dendrite arm spacing components with mechanical properties approaching these of a wrought products [4].

Uram et al. [5], who may be the earliest Americans to study the effect of pressure on the solidification of metals, reported in the 1950s that, by applying a gas pressure of 1.7 Mpa to an aluminum alloy during its solidification the amount of micro-porosity was reduced. However, their results indicated that the reduction in porosity was not accompanied by any improvement in the mechanical properties. Hartley [6], reported a technique developed by GKN Technology in UK for the pressurized solidification of Al-alloy in re-usable dies. S. Rajagopal [7], reviews recent progress in developing and applying squeeze casting in these countries. Process parameters and details for ferrous and non-ferrous applications are also covered, along with the highlights of recently concluded experimental program for squeeze casting mortar shells from ductile iron.

In this investigation the effects of applied pressure on the density, hardness and micro-structure of squeeze cast A380 alloy and pressure die cast A380 alloy to comparison between both of these methods were investigated, and find the optimum values of applied pressure that will giving optimum densities.

Squeeze casting process:

Squeeze casting is process combines the advantages of pressure die casting, gravity die casting and forging processes but the amount of squeeze pressure is less than that used in forging [8]. The process has number of names such as extrusion casting, pressurized crystallization, liquid forging and solidification under pressure. Two types of squeeze casting technology have been given the name (direct and indirect) squeeze casting. In the direct squeeze casting, the metal is poured direct ally into the melt in direct squeeze casting the pressure is more difficult to apply compared to direct squeeze casting, the melt is injected into the bottom of the die with hydraulic ram [9].

The experimental procedure:

1. The material and melting process:

   The used alloy is 380 Al-alloy (ASTM) which has the chemical composition as shown in table (1), pieces of dimensions (20*20*15) mm have been cut from row billet. The pieces were melted in a graphic crucible in an electrical resistance furnace. The melted temperature of alloy was (750^{o}C) and was measured by calibrated thermocouple type (K).

2. The squeeze die and casting sample:
   The casting sample was a shaft of dimensions (Φ20*100 Lg) mm. The die which was used for casting the squeeze Sample is shown in fig. (1) and designed according to the shape and size of the sample with the requirement of squeeze casting process.

3. Casting procedure.
   A. Squeeze casting procedure:
      The procedure of the process as following:
      a. The molten alloy (100 gm) of (750^{o}C) was poured in the die cavity of preheating temperature (300^{o}C) by using a dish with dimensions enough for pouring the required quantity of the molten.
      b. The dwell time (time between pouring and the starting of squeeze action was approximately 4 sec) in order to reach the molten 650^{o}C (middle temperature of musty zone). i.e. the molten has approximate (50%) solid and (50%) liquid.
      c. Pressure of (100 MPa) was applied by punch of press as shown in fig. (2).

d. The punch was kept over the pressed sample 15 sec (the alloy was reached full solidification under pressure).
e. The punch was released and the sample was shaking out.
f. The steps (A-E) were repeated for applied pressure (110,120,130, 140) MPa.

B. pressure die casting procedure:

The casting procedure of pressure die casting was the same procedure of squeeze casting process but the only difference was the pressure was applied on molten metal when it was full liquid (i.e. before the mushy zone). The used die was the same squeeze die, the pressure values were the same of squeeze casting.

4. Tests and measurements:

A. Microstructure examination:

Every cast sample was cut with rotary saw machine to three parts and were machined to dimensions (Φ15*15 Lg) mm. Each part was then ground, polished and the sample for microstructure examination were etched using solution (concentrate HCL 2.5 ml, concentrate HNO3, 2 ml, 40% Hf 0.75 ml, and water 40 ml) for 20 sec [10] optical microscopy photographic has been taken using microscope connected to computer the microstructure test was used for:

i. Calculate the volume fraction of α-Al (white area) in the digital image and measured by calculation the percentage of black area and then the white area (α-Al) equal unity subtracted black percentage.
ii. Calculate the dendrites area spacing (DAS) and the measurements of DAS were calculate by using following equation:

$$DAS = \frac{L}{MN} \tag{1}$$

B. Hardness test:

Vickers hardness number was measured by using equation

$$\mathrm{HV} = 1.8544\,\frac{P^*}{(d_{av})^2} \tag{2}$$

A series of indentation (3) were done on the face of samples.

C. Actual density examination:

Actual density was determined by comparing the weight of the sample in air with the weight of the sample in water. This technique is known as pykonometry method depends on the fact that, the buoyant force applied on an object submerged in fluid is equal to the weight of displaced fluid [11]. The density of the sample is determined as follow:

$$\rho_s = \frac{\rho_w W_s}{W_s (W_{sb} - W_b)} \left(\frac{1 + N_w D_w^2}{D_b^2 - N_w D_w^2} \right) \tag{3}$$

D. Theoretical density:

Theoretical density of the casting samples can be calculated according to the chemical composition of the alloy (table 1) as follow:

Theoretical density of used alloy equal the summation of (fraction of each element times its density) so the Theoretical density of used alloy equal to 2.987 gm/cm^3.

Results and Discussion:

1. Density:

The relationship between the density of both the squeeze castings and pressure die casting sample VS applied pressure for various values (100,110,120,130,140) MPa is depicted in Fig (3).

The density of squeeze casting samples and pressure die casting samples varied from (2.78-2.98) for squeeze castings and from (2.78-2.9) for pressure die castings. The difference between theoretical density and each of squeeze castings and pressure castings (ΔP) was varied from (0.207-0.007) for squeeze castings, (0.207-0.087) for pressure castings as shown in Fig (4).

At applied pressure (100-140) MPa, the balance between the two effects of applied pressure (cooling rate, compaction) leads to increase the density values.

The difference between the density values for squeeze and pressure casting sample was due to effect mechanism of applied pressure for both cases, for pressure die casting the applied pressure increases the cooling rate of liquid phase by compaction action which decrease the formation of shrinkage porosity but for squeeze casting, the applied pressure presses the liquid phase between the dendrites arms solid phase plus the increasing of cooling rate so the pressure in squeeze casting lead to increase the density value more than pressure casting.

2. Metallographic study:

The results of metallographic study of both types of casting procedures (pressure die casting and squeeze casting) were showed that in two cases, the microstructure of prepared samples were of hypoeutectic structure consisting of primary (α) Al (solid solution of (Si) in (Al)) in a matrix of eutectic (α-Si).

The results of micro-examination were showed that the dendrites of Al in samples of pressure castings are finer with increasing of the applied pressure due to increasing the cooling rate as shown in figs. (5,6) for the samples of squeeze casting being more fine than that of pressure casting at same applied pressure values due to the two effects of applied pressure(increasing cooling rate plus increasing compaction action).

The (DAS) of squeeze samples were (6.7, 6.6, 6.4, 6.5, 6.4) µm and for applied pressure (7.5, 7.1, 7.06, 7, 7) respectively.

3. Hardness test:
   The values of hardness for both samples were increased as the applied pressure was increased Fig(7) due to the increasing of cooling rate as the applied pressure was increased but the values of squeeze sample were higher than the values of pressure die casting samples due to the balance of effects of applied pressure (cooling rate effect and compaction effect).

Conclusions:

The following conclusions were made based on the study:

1. The density of casting samples increases with increases in applied pressure for both types of process but the increasing of density in squeeze casting is more than the increasing of density for pressure casting.
2. The squeeze casting and pressure casting help to refine the microstructure of casting.
3. The applied pressure for both casting types increases the hardness at the same behavior of density increasing.
4. The applied pressure decreases the difference value between the actual density and calculated density ($\Delta\rho$).

References:

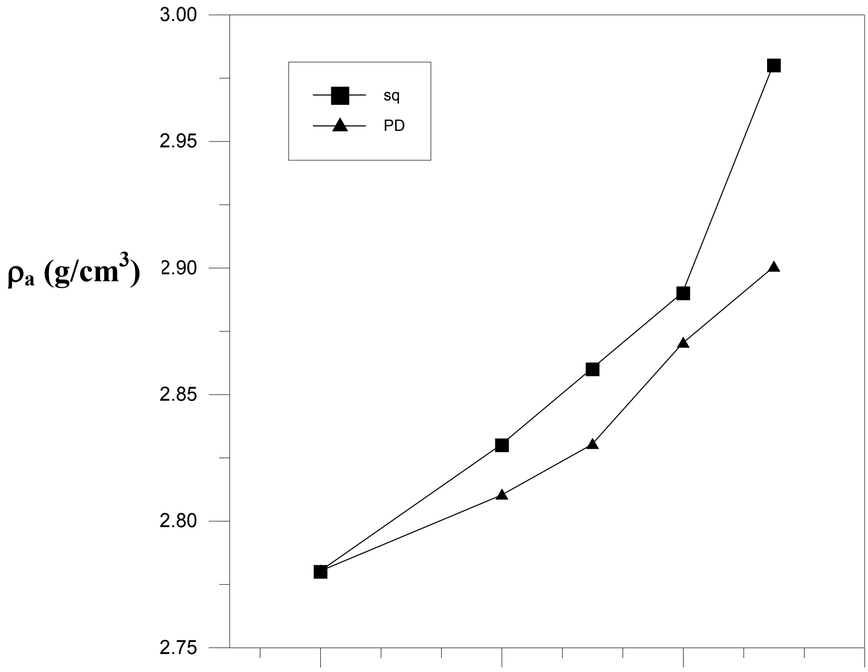
1. A. Maleki, B. Niroumand, A. Shafyei, "Effect of squeeze casting parameters on desity, Macrostructure and hardness of LM13 alloy", Material Science and Engineering A 429 (2006) 135-140.
2. M.R. Ghomashchi, A. Vikhrov, " Squeeze casting: an overview", Journal of Materials Processing Technology 101 (2000) 1-9.
3. H. HU, "squeeze casting of magnesium alloys and their composites", Journal of Materials Science 33 (1998) 1579-1589.
4. P. Vijian, V. P. Arunachalam, "Modeling and multi objective optimization of LM24 aluminum alloy squeeze cast process parameters using genetic algorithm", Journal of Materials Processing Technology 186 (2007) 82-86.
5. S. Z. Uram, M. C. Flemings and H. F. Taylor, Trans. AFS 66 (1958) 129.
6. P. Hartley, "Die-casting of aluminum parts- a new technique", S. Afr. Mech. Eng. 35 (50) (1985) 180-181.
7. S. Rajagopal, "Squeeze casting: A review and update", J. Applied Metal Working, Vol. 1, No. 4-3.
8. J. R. Davis, "Casting metals handbook", 2^{nd} ed., part 3, pp. 727-781, 1998.
9. G. Williams, "Squeeze form combines casting with forging", Foundry Trade Journal, pp. 66, 1984.
10. John L. Jorstad and J. L. J, "High integrity die casting process variations", International Conference on structural Aluminum Casting, Nov. 2-4, 2003.
11. S.T.Meclain, "A study of Porosity Quantification Techniques and Pore Morphology in Al-alloy castings", M.sc. Thesis, Department of Mechanical Engineering, Mississippi state university, Mississippi State, USA, 1997.

Table (1) the chemical composition analysis in mass% of 380 Al-alloy

Element / Alloy	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Ni	Sn	Al
380	9.5	1.23	3	0.11	0.19	1.31	0.01	0.03	0.12	0.04	REM

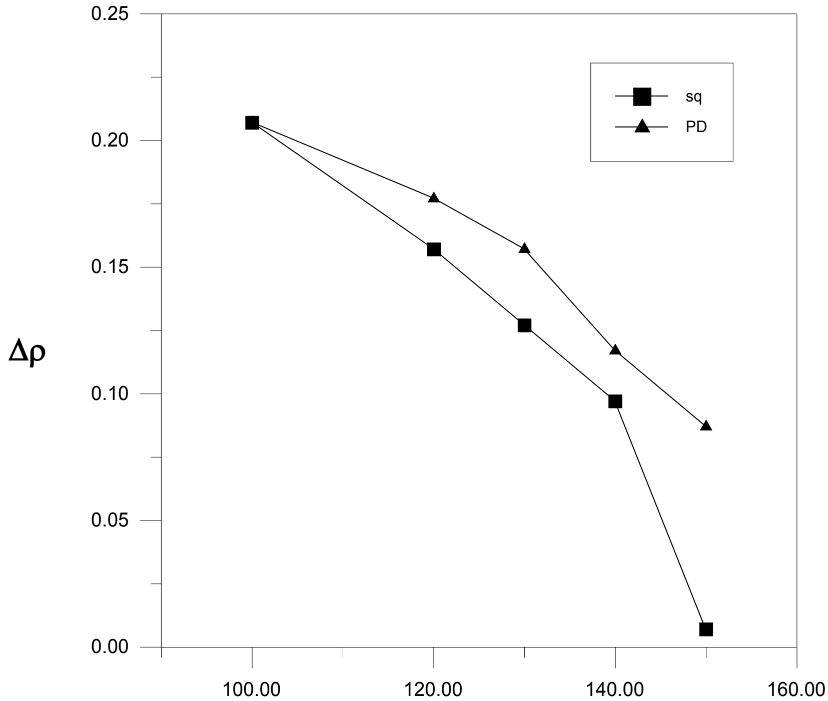
Fig. (1) squeeze die and heating system.

Fig. (2) The used press with capacity of (3) tons



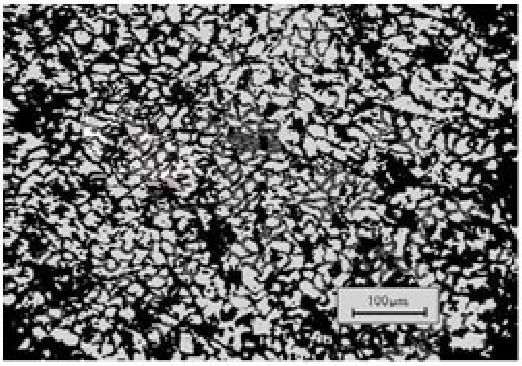
Applied pressure (MPa)

Fig. (3) The relationship between applied pressure (P_a) and actual density (ρ_s)

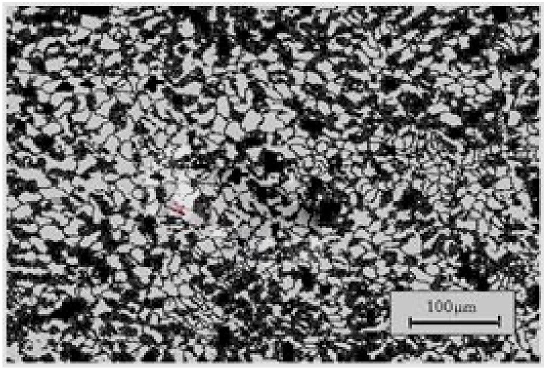


Applied pressure (MPa)

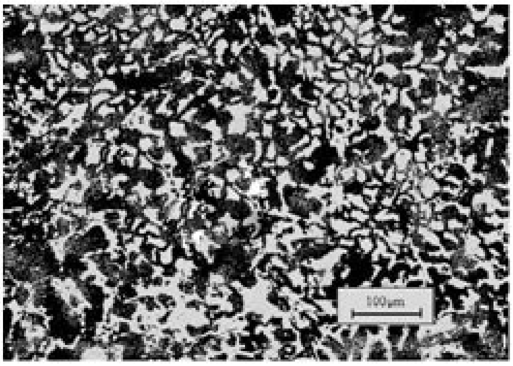
Fig. (4) The relationship between applied pressure (P_a) and density difference ($\Delta\rho$).



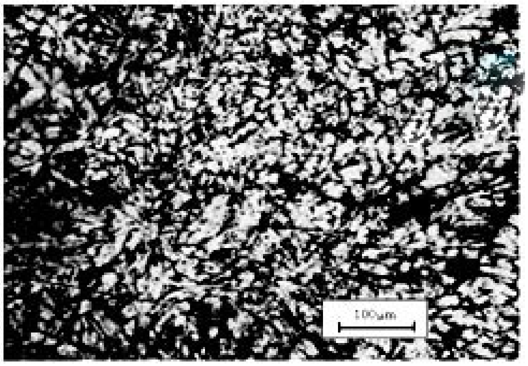
(A) Vf of α-Al =0.5548 ,DAS=6.7μm



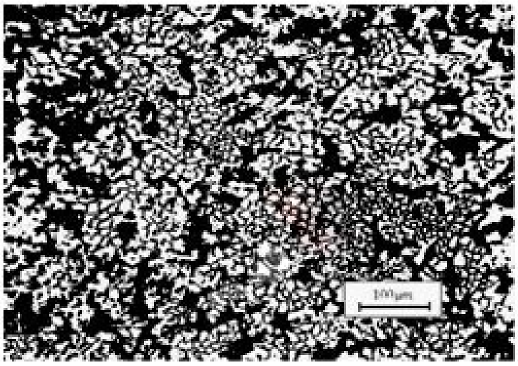
(B) Vf of α-Al =0.55 ,DAS=6.6 μm



(C) Vf of α-Al =0.55 ,DAS=6.4 μm

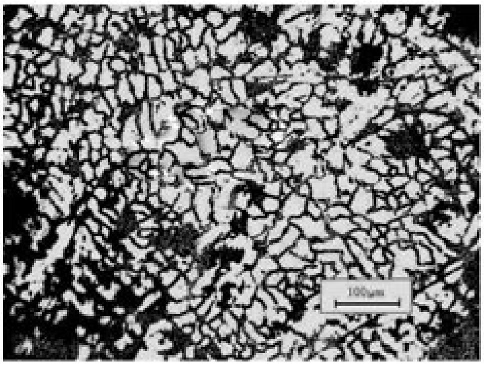


(D) Vf of α-Al =0.54 ,DAS=6.5 μm

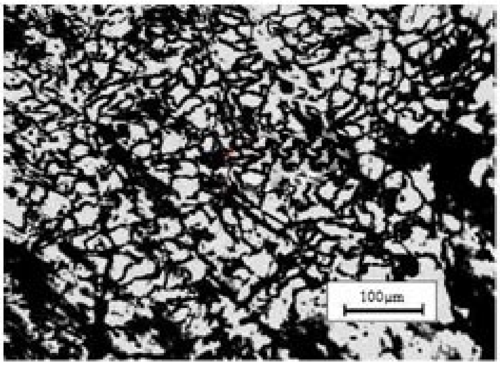


(E) Vf of α-Al =0.51,DAS=6.4 μm

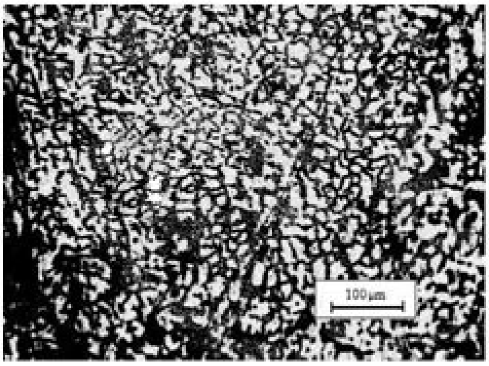
Fig (5) the microstructure of squeeze sample
(A) at (100 MPa), (B) at 110 MPa, (C) at 120 Mpa, (D) at 130 MPa, (E) at 140 MPa



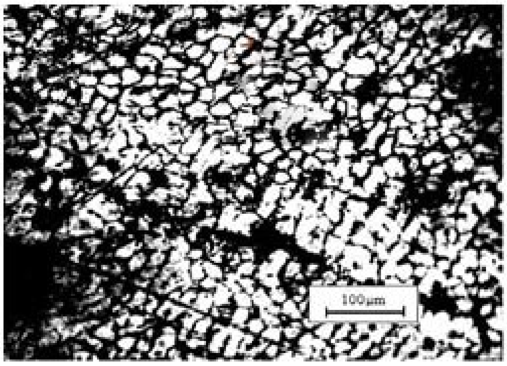
(A) Vf of α-Al =0.73 ,DAS=7.5 µm



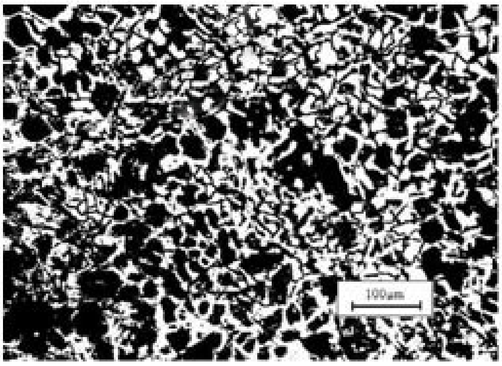
(B) Vf of α-Al =0.70,DAS=7.1 µm



(C) Vf of α-Al =0.68, DAS=7.06 µm



(D) Vf of α-Al =0.67, DAS=7 µm



(E) Vf of α-Al =0.67 ,DAS=7µm

Fig (6) the microstructure of pressure sample
(A) at 100 MPa, (B) at 110 MPa, (C) at (120 MPa), (D) at 130 MPa, (E) at 140 MPa

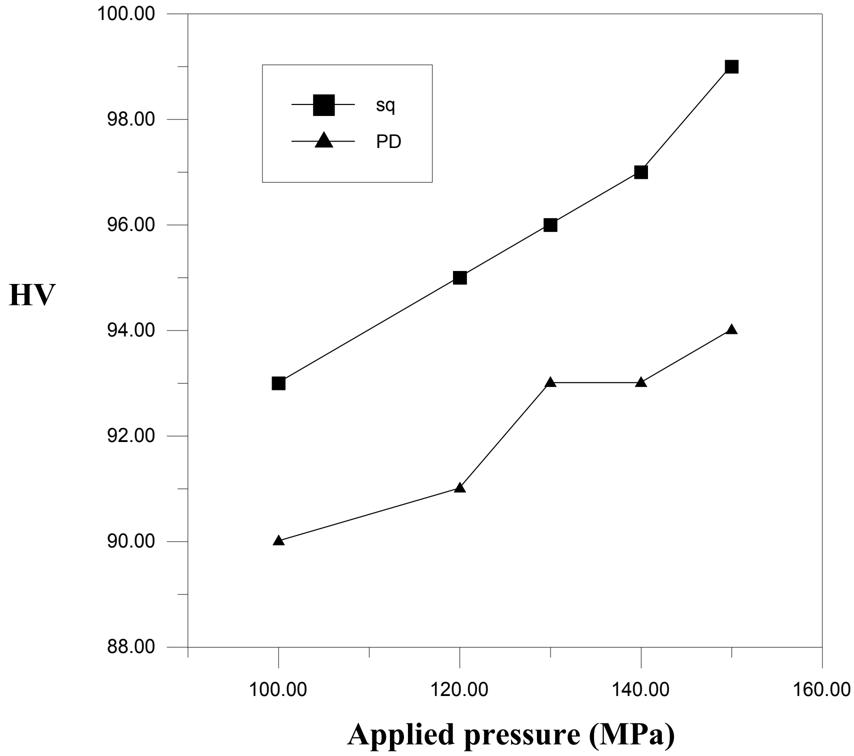


Fig. (7) The relationship between applied pressure (P_a) and Vickers hardness (HV)