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EFFECT OF Mg CONTENT ON PENETRATION RESISTANCE OF Al- Mg ARMOUR PLATES

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ABSTRACT

A series of Al-Mg armour plates were cast in a metallic mold with Mg content varying from 1% to 5% Mg. The effect of Mg content on the mechanical properties and microstructure was investigated. Tensile, Impact toughness, and Hardness tests were carried out on specimens machined from the 35 mm thickness cast armour plates. Penetration resistance tests were carried out on 200 x 200 x 32 mm plates using 7.62 x 39 mm projectiles. Energy consumed during penetration was evaluated and taken as a measure of penetration resistance.
The following relationship between penetration resistance and Mg content was deduced using the obtained results :

P.R. = 1366 + 58 (Mg %) .

where P.R. = Penetration Resistance (Joules).

INTRODUCTION

High strength light weight aluminium alloys have become of great importance as engineering materials for many military applications. Recently Al-Mg alloys have been utilized successfuly in the production of hulls for armoured vehicles like the American armoured vehicles M113 and the Spanish armoured vehicle (1,2) .
The utilization of Al-Mg alloys for production of armoured plates means reduction of vehicles weight allowing better chances of carrying greater amounts of amunitions. This also

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leads to lower fuel consumption and longer combat ranges for vehicles. Moreover,light weight vehicles are considered the backbone of'airborn rapid combat forces and there are many technological advantages attained by using Al-Mg alloys instead of classicaly used steels for production of armour plates. Forming of Al-Mg alloys is less expensive and its weldability can be compared to the armour steels. The penetration resistance of armour plates material is one of the main properties that judge its suitability for military applications. Generally, penetration resistance of armour plate material depends upon its mechanical properties such as ultimate strength,hardness,ductility, and impact toughness(3). However ,within the available published literature, the effect of Mg content on penetration restsance of Al-Mg armoured plates has not been studied and determined. This work aimes at investigating the effect of Mg content on penetration resistance of Al-Mg armour plates.

MATERIAL AND EXPERIMENTAL PROCEDURE

The used material in this work was prepared by melting commercially pure aluminium 99.7% and Al-Mg master alloy of 10% Mg in a fuel crusible furnace of 50 Kg capacity. The melting technique and additives like flux and grain refiner were kept constant in all melts. Pouring was carried out in metallic mold with dimensions of 35 x 300 x 900 mm preheated to 80 C .
Inner walls of the metallic mold were coated with a graphite layer for easy removal of the cast plates. Pouring temperature was 720 C. Chemical composition of prepared melts were determined and are given in table 1 .
The cast plates from the four melts were machined to samples for tensile, impact toughness,and penetration resistance tests Fig 1 from locations shown in Fig 2. The microstructure of the as cast plates were observed by optical microscope using Keller solution for etching (HF 1 ml , HCl 1.5 ml , HNO_3 2.5 ml and H_2O 95 ml).
Penetration resistance tests were carried out by direct shooting using 7.62 x 39 mm armour piercing projectiles at a firing distanceof 16 m on plates having dimensions of 200 x 200 x 32 mm and at an impact angle of 90° .
Penetration resistance was determined by measuring the kinetic energy of projectile before impact and after perforation of the target using the following equation (4-8):

$$PR = \tfrac{1}{2} (m v_1^2 - m v_f^2)$$

where : PR ... Penetration Resistance (Joules) .
m Projectile mass (Kg) .
v_1 Impact velocity (m/s).
v_f Perforation velocity (m/s) .

The arrangement of the apparatus used for velocity measurements is shown in Fig (3) .

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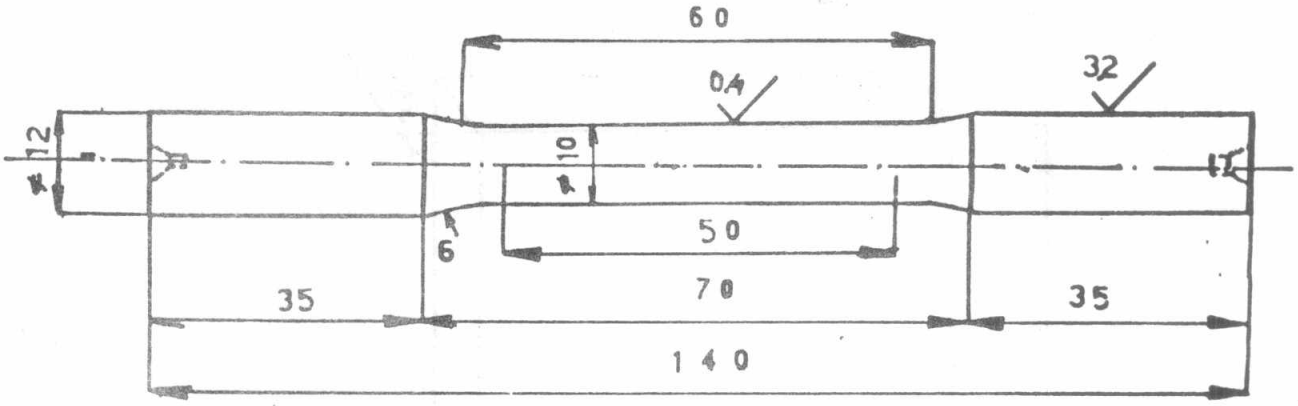
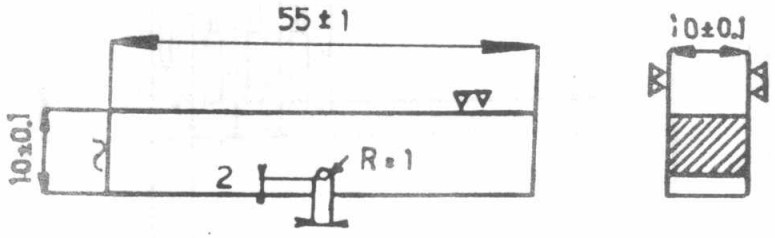
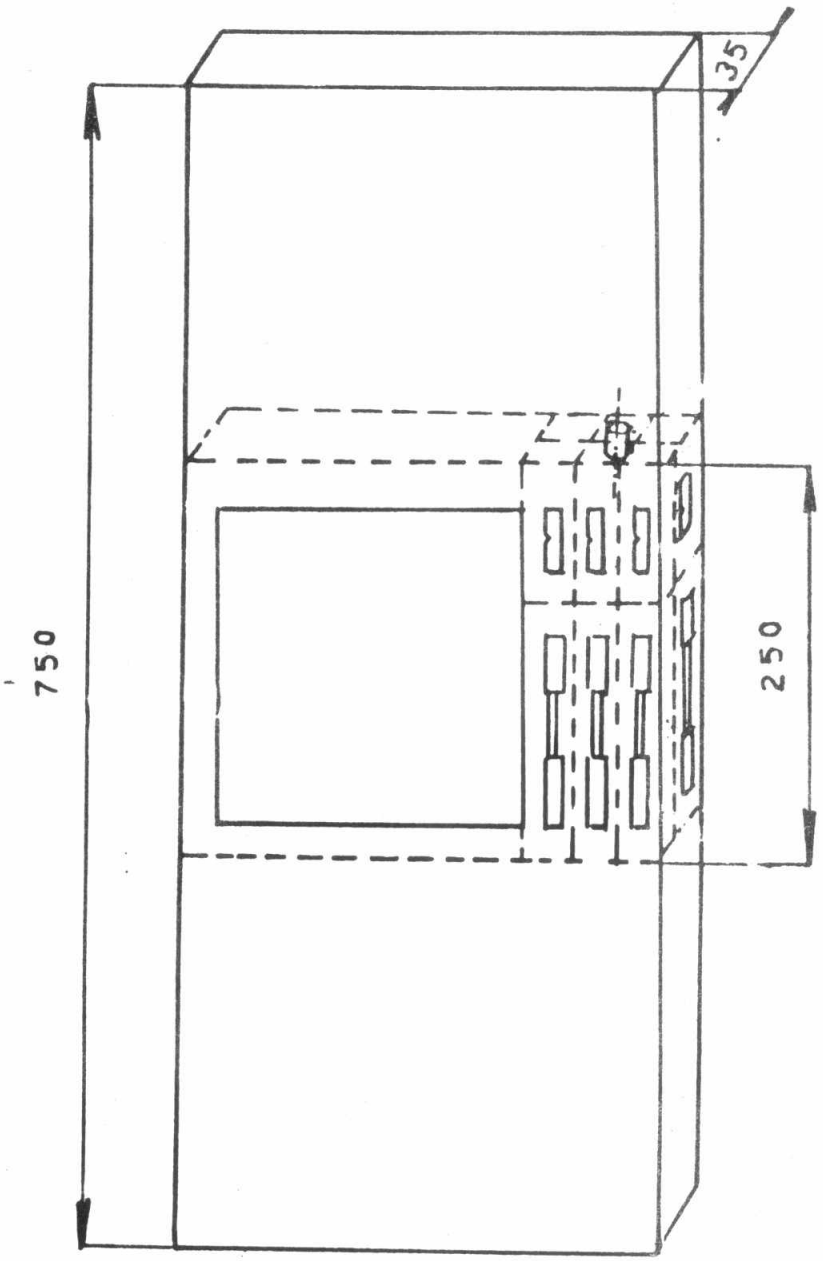


(a) Tensile test specimen (A 10x50 DIN 50125).



(b) Impact test specimen (DVM test piece).

Fig(1) : The used standard tensile and Impact test specimens.



Fig(2) : The location of Tensile, Impact, Microstructure and Penetration resistance test specimens.

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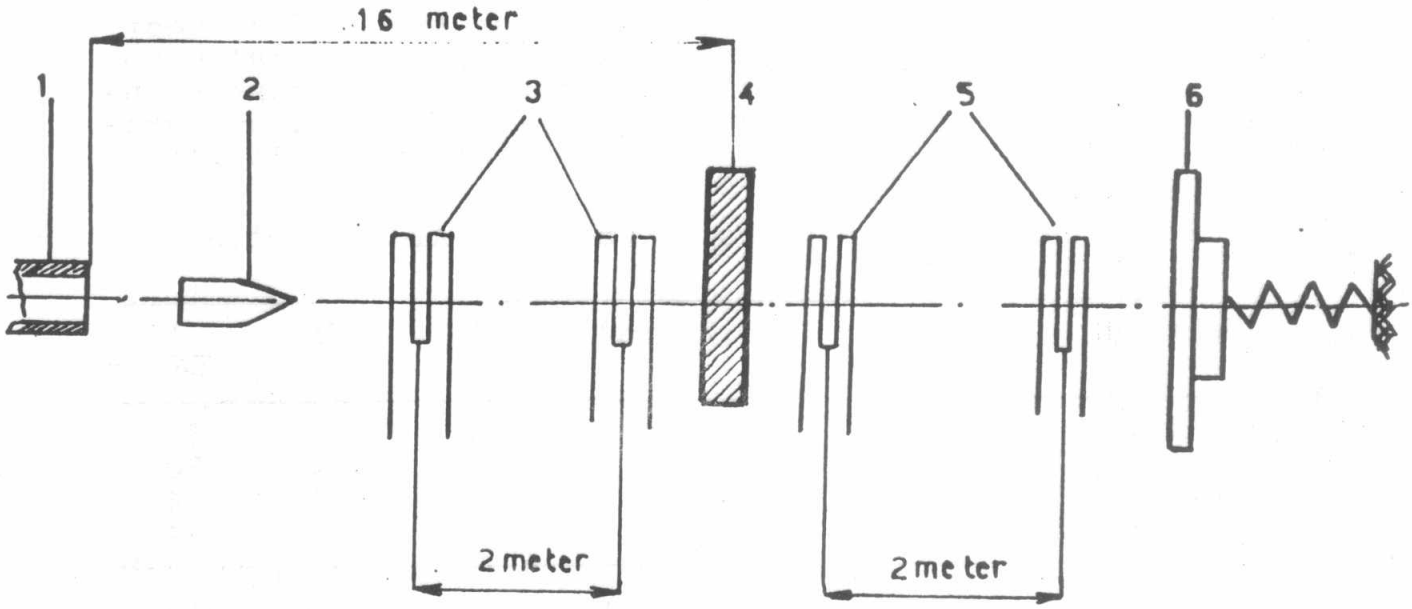

Fig (3) The used apparatus for velocity measurment

1- Ballistic rifle
2- Projectile
3- Impact velocity frames
4- Target plate
5- Post- Parforation velocity frames
6- Projectile Stopping arrangment.

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Table 1. Chemical composition of used melts.

Melt No	Alloy	weight %			
		Mg	Si	Fe	Al
01	Al -1 Mg	0.99	0.081	0.12	Rem
02	Al -2,5 Mg	2.44	0.07	0.1	Rem
03	Al -4 Mg	4.30	0.11	0.13	Rem
04	Al- 5 Mg	5.12	0.13	0.14	Rem

RESULTS AND DISCUSSION:

Results of mechanical properties tests for the used as cast Al-Mg alloy plates are given in table 2. and illustrated in Fig 4 . As the figure explains , there is a remarkable increase in ultimate tensile strength , yield stress,and hardness and a decrease in the Impact toughness and ductility with the increase of Mg content.

Table 2. Mechanical Properties of Cast he Al-Mg Plates of 35 mm Thickness .

Melt No	σ_u (MPa)	$\sigma_{0.2}$(MPa)	δ %	HB	IT KJ / m^2
01 (Al-1 Mg)	118	54.5	22.0	37	31
02 (Al-2,5 Mg)	159	68.8	17.8	44	28
03 (Al-4 Mg)	189	102.8	14.2	60	24
04 (Al-5 Mg)	216	120.0	14.5	61	24

Representative microstructures of the as cast Al-Mg plates are shown in Fig.5. , where the black phase of Mg_2 Si and the grey phase of Mg_5 Al_8 are both existing on the grain boundaries .
The microstructure observation of samples taken from the four melts showed that the existing phases at high Mg content of Mg_2 Si and Mg_5 Al_8 are responsible for the observed higher mechanical properties with the increase of Mg content in the melts .

Therefore,the increase in the tensile strength and hardness with the increase of Mg content can be attributed to solid solution hardening and the appearence of the precipitates of Mg_2 Si , Mg_5 Al_8 on the grain boundries.
Results of Penetration Resistance of the tested as cast Al-Mg alloy plates are summarized in Table 3., and the effect of the variation in Mg content on the penetration resistance is illustrated graphically in Fig 6. As this figure explains, Penetration Resistance increases with the increase of Mg content . More over the increase in penetration resistance has a similar trend to that of the increase in hardness and strength with the increase of magnesium content .

Using the obtained experimental results, the dependence of penetration resistance on Mg content could be represented by the following formula :

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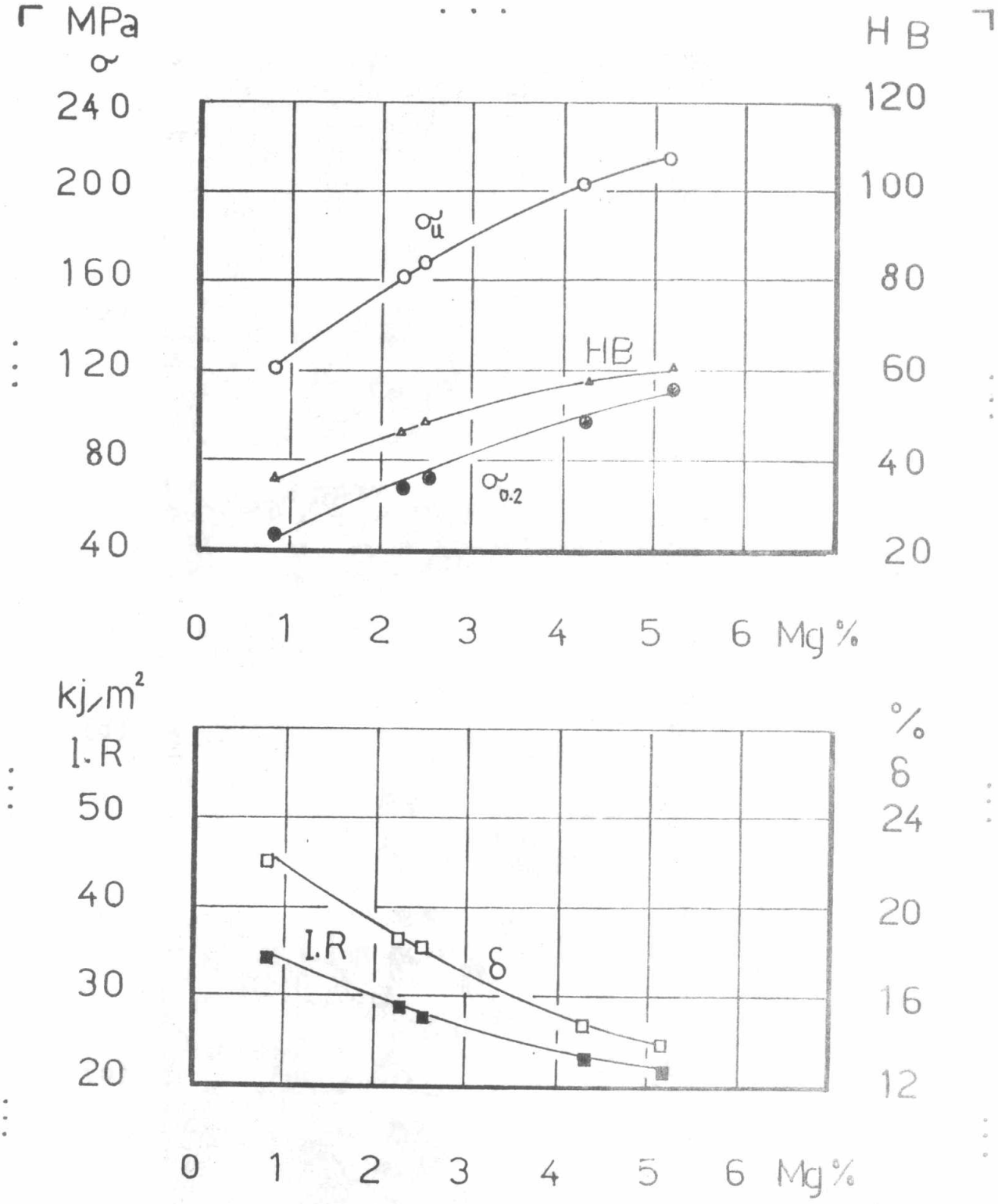

Fig (4) The variation of mechanical properties with Magmesium content for Al-Mg alloys.

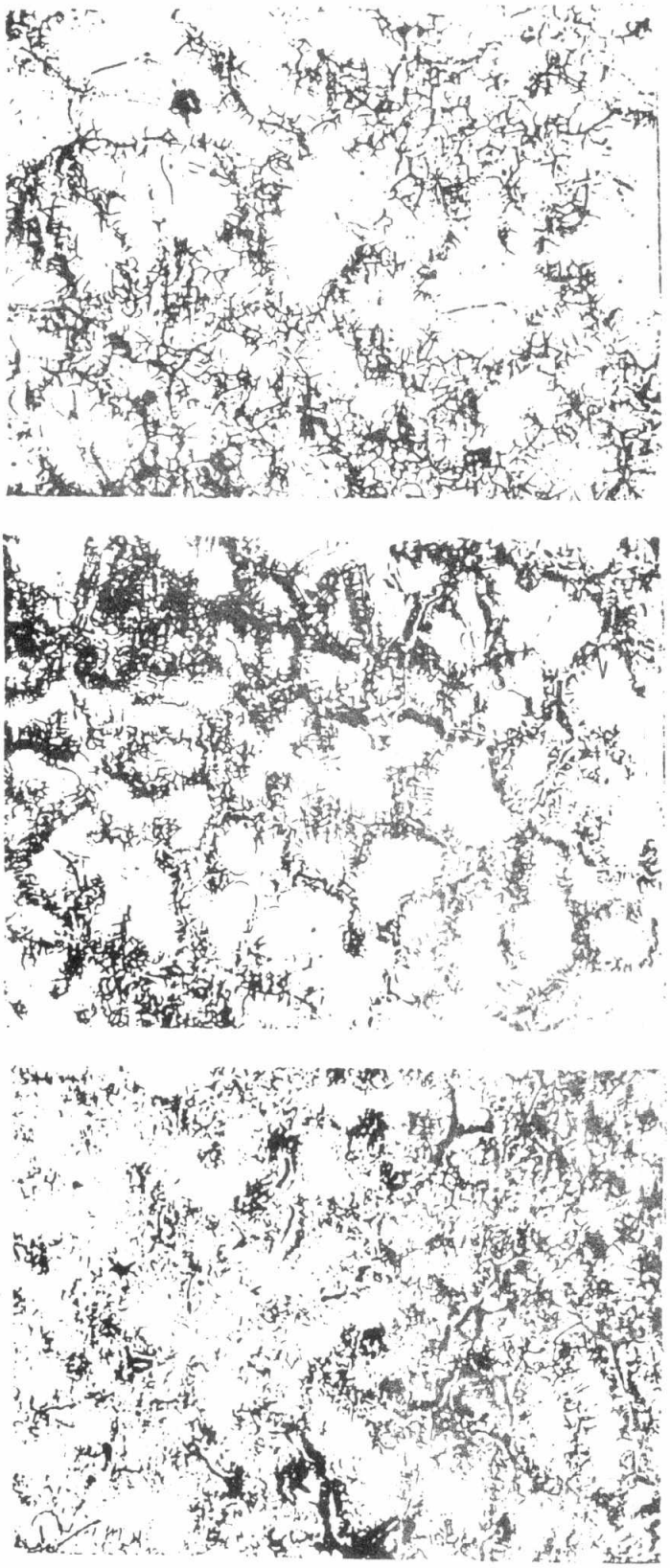

Fig (5) Photomicrographs of the specimens of Al-Mg alloys.
(a) Al-0.99% Mg. (b) Al-2.44% Mg
(c) Al-5.12% Mg Magnification :100x

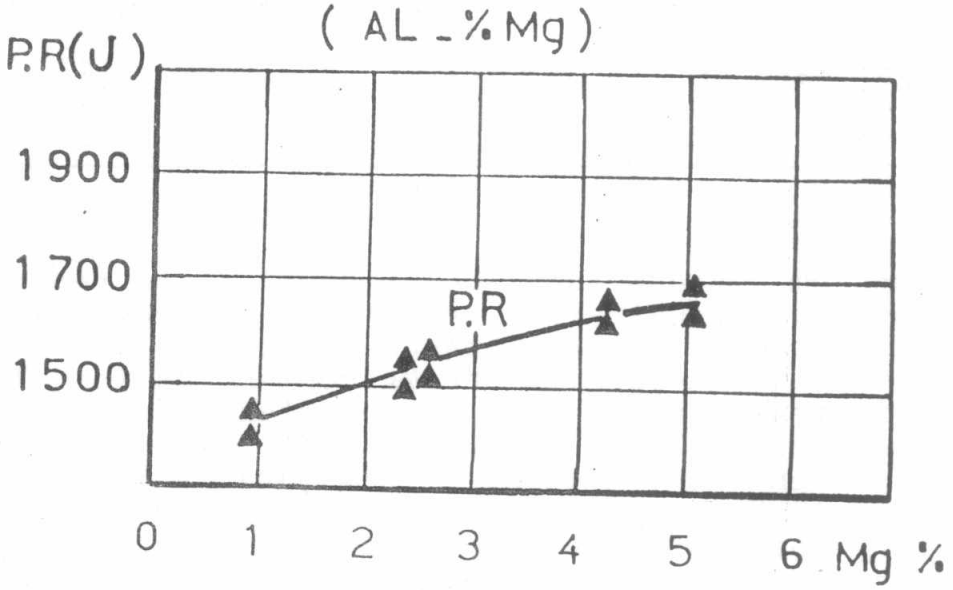

Fig (6) The variation of Penetration resistance with Magnesium content for Al-Mg alloys .

$$PR = 1366 + 58 \times (Mg\%)$$

where PR = Penetration Resistance in (J)

Mg% = weight percentage of Mg .

Table .3. Variation of Penetration Resistance Of Al-Mg armour plates with increase of Mg% content.

Melt . No	Magnesium %	Penetration Resistance (Joules)
01 Al-1 Mg	0.99	1429
02 Al-2,5 Mg	0.44	1547
03 Al-4 Mg	4.30	1649
04 Al-5 Mg	5.12	1652

CONCLUSION :

Magnesium content in Al-Mg armoured plate remarkably affects its penetration resistance . A remarkable increase in the penetration resistance of Al-base alloys plates was observed by increasing the Mg content up to 5.12% . The increase in penetration resistance in the range of Mg content up to 2% is believed to be due to the solid solution strengthening in Al phase,and in the range from 2 to 5.12 % Mg due to combined effects of solid solution strengthning and the existance of the second phase particles of $Mg_2 Si$, and $Mg_5 Al_8$.

The following relation ship was found to explain the dependence of penetration resistance on Mg content in Al-Mg alloy armour plates .

$$P.R = 1366 + 58 \ (Mg\%) .$$

Where P.R. is Penetration Resistance (J) .

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