The modification of some properties of Al-2%Mg alloy by Ti &Li alloying elements

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Abstract:

Aluminium-Magnisium alloys are light, high strength with resistance to corrosion and good weldability. When the content of magnesium exceeds 3% there is a tendency to stress corrosion .

This work is an attempt is to prepare low density alloy with up to approximately 2.54 g / cm^3 by adding different contents of Ti, and lithium to aluminum-2%Magnisium alloy. The lithium is added in two aspects, lithium chloride and pure metal. The casting performed using conventional casting method. Moreover, solution heat treatment (SHT) at 520 ºC for 4 hrs, quenching in cold water, and aging at 50ºC for 4 days were done to get better mechanical properties of all samples. Microstructure was inspected by light optical microscope before and after SHT. Alloy3 which contains 1.5%Ti was tested by SEM and EDS spectrometer to exhibit the shape and micro chemical analysis of Al_3Ti phase. Hardness, ultimate tensile strength, and modulus of elasticity were tested for all alloys. The results indicated that Al_3Ti phase precipitates in alloys contain 0.5%T, 1%Ti, And 1.5%Ti. The phases Al_3Li as well as Al_3Ti were precipitated in alloy4 which contains 2%Ti, and 2.24%Li. Mechanical properties test results also showed that the alloy4 has achieved good results, the modulus of elasticity chanced from 310.65GPa before SHT to 521.672GPa, after SHT and aging, the ultimate tensile strength was changed from 365MPa before SHT to 469MPa, after SHT and aging, and hardness was increased from 128 to 220HV.

Key words: AL-Mg, Al-Mg-Ti and Al-Mg-Li-Ti alloys,

الخلاصه

تعتبر سبائك الالمنيوم–مغنيسيوم من السبائك الخفيفة. تجمع هذه السبائك بين المتانة العالية ، مقاومة التاكل الكيمياوى، والقابلية للحام. عندما تتعدى نسبة المغنيسيوم في هذه السبائك عن 3% فاها تصبح عرضة للتاكل الاجهادي.

يتم في هذا البحث تحضير سبيكة ذات كثافة قليلة تصل الى (2.54غم\سم2) باضافة الليثيوم ونسب مختلفة من التيتانيوم الى سبيكة (Al-2%Mg) . تم اضافة الليثيوم على شكل معدن نقي وعلى شكل مركب كلوريد الليثيوم. اجريت السباكة بالطريقة التقليدية واجريت لها عملية المعاملة المحلولية بدرجة حرارة (520) درجة سليزية لمدة (5) ساعات ثم التقسية بالماء البارد بعدها اجريت لها عملية التعتيق بدرجة حرارة (50) دلرجة سليزية لمدة (4) ايام. تم اختبار البنية المجهرية بواسطة المجهر الضوئي قبل وبعد المعاملة المحلولية لمعرفة تاثير هذه المعاملة على البنية المجهرية والخواص الميكانيكية، تم فحص البنية الماكروية باستخدام المجهر الالكتروني الماسح(SEM) و (EDS) للعينة التي تحتوي 1.5%Ti. كذلك تم فحص خواص الصلادة، مقاومة الشد، ومعامل المرونة. اظهرت النتائج تكون طور (AL3Ti) في السبائك 1-3 التي تحتوي(0.5%Ti، 1%Ti، 1.5%Ti) على التوالي. اما في السبيكة 4 التي تحتوي على (2%Ti, 2.24%Li) فان كلا الطورين (Al3Ti و Al3Li) قد تكونا. وقد اظهرت نتائج فحص الخواص الميكانيكية ان السبيكة 4 ذات خواص عالية بعد المعاملة المحلولية افضل من السباك الاخرى، حيث ان معمل المرونة تغيرمن 310.65 قبل المعاملة المحلولية والتعتيق الى 521.672GPa بعد المعاملة المحلولية والتعتيق) ، كذلك مقاومة الشد القصوى من 365 الى 469Mpa بعد المعاملة المحلولية والتعتيق)، و الصلادة قد ازدادت من HV128 الى220HV).

الكلمات المفتاحية:- سبائك الالمنيوم – مغنيسيوم، المنيوم– مغنيسيوم– تيتانيومن وسبائك المنيوم– مغنيسيوم– ليثيوم– تيتانيوم.

Introduction:

Al-Mg alloys are very attractive for military, automotive and aerospace industries as a result of combination of light weight and high strength. Aluminum is the only popular metal that elevate the beta transfer temperature and is more dissolvable in both alpha and beta phases (Labisz,2006).

Al-Mg alloys exhibit the best combination of high strength and corrosion resistance. Also exhibits good weldability up to 3%Mg. When magnesium content exceeds 3% stress corrosion resistance is reduced (Ron,1994).

Magnesium is used as the alloying element, because its aspect ratio (length/width) of precipitates increases to higher values, reduces agglomeration of phases particles. Other researchers are studied the diffusivity and equilibrium solid solubility of titanium in Al. They found that the presence of Ti in Al alloys, refined the microstructure of alloy because of its low equilibrium solid solubility and diffusivity. Labisz, etal are studied the effect of Mg addition to Al-2%Ti up to 4%Mg on the microstructure and phases of these alloys. They found that, After SHT for 4 hrs, the grain size are bigger and no more regular as in the cast condition. Also, they deduced that most steady intermetallic in the Al-Ti alloys is the Al3Ti phase (Labisz,2011).

The addition of Li to aluminium alloys reduces the weight of alloys. The density of alloy decreases by a 3% with every 1% addition of lithium. The presence of lithium in Al alloys also improve the elastic modulus of aluminum. The addition of Li 1% , the elastic modulus of elasticity rises about 6% (Gupta,2006).

Wanwu Ding, etal, investigate the effect of Al–5Ti master alloy with contents of (0.6%, 1.0%, 1.6%, 2.0%, and 3.0% master alloy) on commercial Al alloy and holding time (10, 30, 60 and 120 min) on grain refinement of commercial Al alloy. They deduced that Al–5Ti master alloy which has blocky $TiAl_3$ particles has better refining effect than the master alloy with needle-like $TiAl_3$ particles (Wanwu,2014).

The aim of this work is to study the influence of 0.5, 1,1.5 and 2% Titanium and lithium as $LiCl.3H_2O$ and pure element on Tensile, modulus elasticity, hardness and microstructure of Al-2%Mg alloy before and after solution heat-treatment and aging.

Experimental work

The alloys were prepared and casted by using gas furnace as in table 1.

The sample contents were prepared for casting. Then, aluminium was melted in silicon carbide crucible by using gas furnace.

Titanium chips were immersed into molten aluminium. After 5 minutes Lithium chloride or lithium metals and magnesium were warped by aluminium foil before adding to molten metal then, immersed into molten and mixed after 5 minutes.

Aluminum chloride was added to melt to remove the slag

Table 1: composition of alloys before casting

Sample no.	Ti%	Li%	Mg%	Al%
1	0.6	5 as $LiCl.3H_2O$	2.3	Bal.
2	1.2	5 as $LiCl.3H_2O$	2.3	Bal.
3	1.7	5 as $LiCl.3H_2O$	2.3	Bal.
4	2.2	3 as pure metal	2.3	Bal.

The molten metal was mixed and the slag was removed. Thereafter, the melt was poured in cast iron mold after preheated to 200^{o}C. The samples were prepared for chemical examination, tensile strength, and hardness test. The chemical composition of alloys was tested using Optical Emission Spectrometer (OES) at General Company for Engineering Inspection and Rehabilitation – Baghdad- Iraq, as shown in table2.

Table 2 composition after casting

Sample	Si%	Fe%	Cu%	Mn%	Mg%	Cr%	Zn%	Ti%	Li%	Al%
1	0.0810	0.254	0.0740	0.0064	1.95	0.004	0.192	0.5	0.8	Bal
2	0.0970	0.303	0.123	0.0081	2.14	0.005	0.124	1.08	0.95	Bal
3	0.0825	0.343	0.0184	0.0084	2.05	0.005	0.032	1.44	0.9	Bal
4	0.072	0.251	0.0123	0.0062	2.16	0.008	0.002	1.19	2.24	Bal

Other samples were solution heat-treated at 520^{o}C for (5 hrs) and aged at room temperature for (4 days).

Table 3: mechanical properties before solution treatment and aging

Alloy	Ultimate tensile strength MPa	Modulus of elasticity Gpa	Vickers Hardness N/mm^2
1	254	132.76	90.79
2	287	175.9	113
3	322	230.82	118
4	392	310.65	128

The tensile stresses and modulus of elasticity were examined for samples before and after solution treatment by universal tensile testing machine type (WAW-200). The hardness of samples was tested by universal hardness tester type (Wilson UH-250) as in table 3 and table 4 respectively. Solution heat-treatment carried out by electric furnace type (SRJX-515). Microstructure of samples was examined by Light Optical Microscope type (UH-250) equipped with digital camera and SEM type (JSM-7200F).

The microstructure test of alloy 3 was accomplished by scanning electron microscope equipped EDS to show the microchemical analysis and the shape of Al_3Ti phase.

Table 4 mechanical properties after solution treatment and aging

Alloy no.	Ultimate tensile strength MPa	Modulus of elasticity Gpa	Vickers Hardness N/mm^2
1	302	177.76	130
2	347	289.9	155
3	384	369.82	168
4	469	521.672	220

Results and Discussion

The results were discussed as follow:

Microstructure:

The microstructure was carried out by light optical microscope before and after solution heat treatment. Alloy 3 was investigated by SEM and EDS spectrometer to show the shape and micro chemical analysis of Al_3Ti phase. The solution that has been used for the etchant was (Kealer solution)**.**

Fig.1a shows the microstructure of alloy 1 with content of 0.5%Ti before

solution treatment. Fig.1 indicates the presence of (Al_3Ti**)** in many features**;** bars, stars and other shapes in small quantity (Labisz,2011). The same feature appears in fig.5 after SEM and EDS spectrometer test.

Fig. 1b shows the microstructure of alloy 1 after SHT and aging. In fig.1b there is a noted changing in the shape of Al_3Ti; the stars, rods and others shapes were changed to a uniform, fine and circular more regular dispersed particles. These changes were as a result of aging of the alloy. Fig. 2a shows the microstructure of the alloy 2 after casting. In fig.2a the phase Al_3Ti was more intensity and needle shape. This increment in Al_3Ti was as a result of Ti content increasing

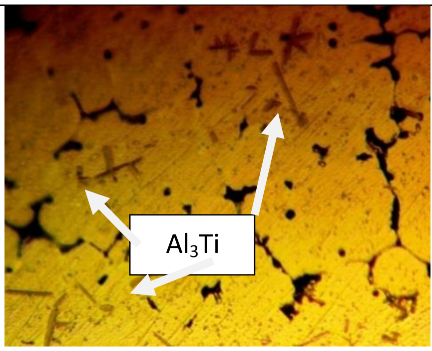


Figure 1a: microstructure of alloy 1 before solution treatment 200x.

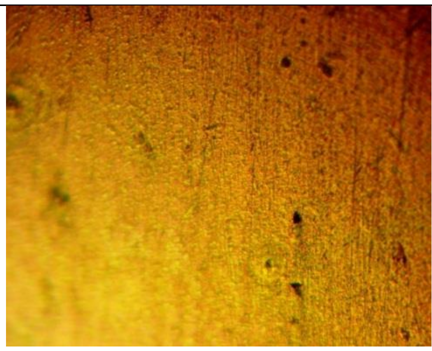


Figure 1b: the microstructure of alloy 1 after solution treatment 200x.

As shown in fig. 2b the phase Al_3Ti was irregular distributed. The particles were distributed as clusters. This changing in shape and distribution of Al_3Ti particles may be as a result of increment of Ti to Mg ratio.

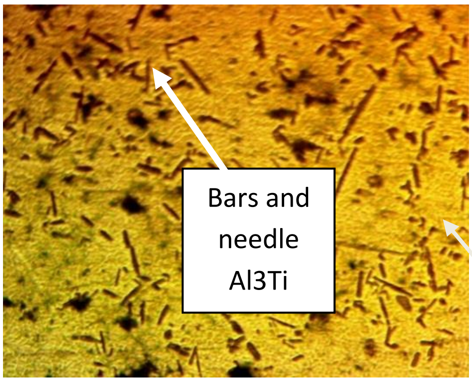


Figure 2a microstructure of alloy 2 after casting 200x

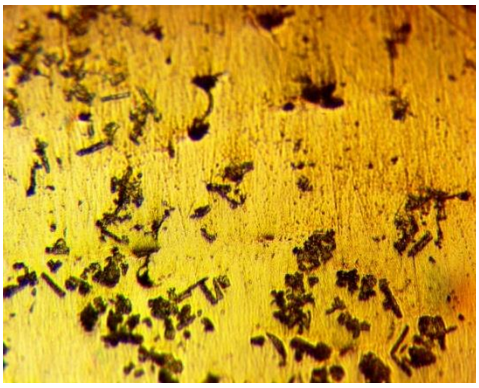


Figure 2b microstructure of alloy 2 after solution treatment 200x

It appearS from microstructure of alloy 3 after casting in fig.3a, the shape of Al_3Ti changed to thin and longitudinal needles.

The increasing of Ti content increases uniformity of the porosity in aluminium alloys.

The shape of pores was spherical because Al_3Ti and α-Al may be preventing the pores from growing directionally (**Labisz**, 2011)

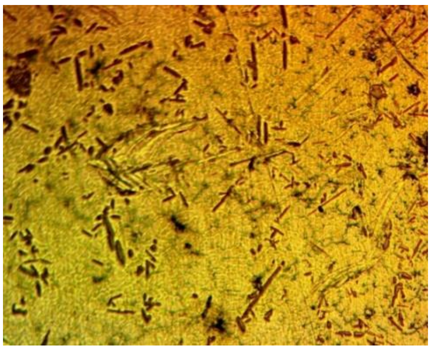


Figure 3a: microstructure of alloy 3 after casting 200x

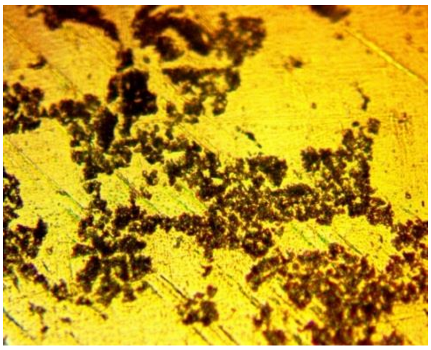


Figure 3b: microstructure of alloy 3 after solution treatment and aging 200x

From fig.3b it can be distinguished the agglomerations of Al_3Ti phase in primary α-Al.

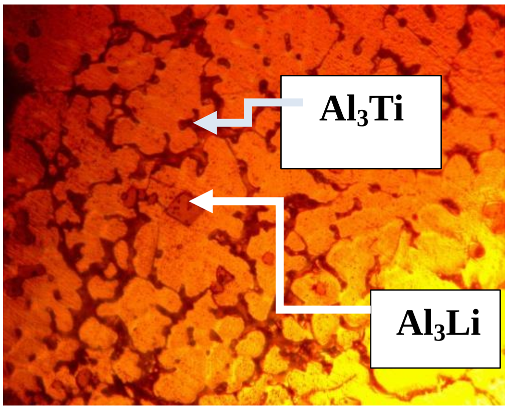


Figure 4a: microstructure of alloy 4 after casting 200x

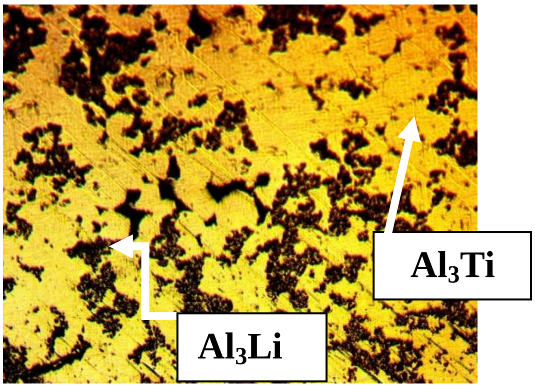


Figure 4b: microstructure of alloy 4 after SHT 200x

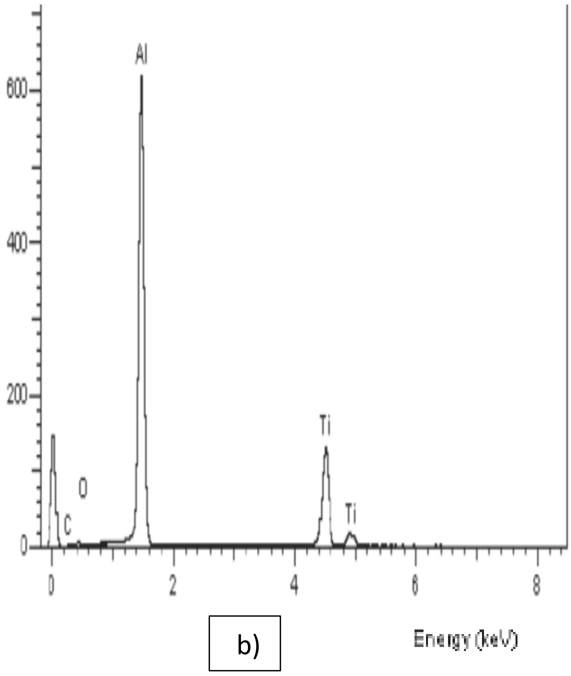
The agglomeration increases with increasing Ti content. From fig.4a there are three phases can be denoted, α-Al is the matrix, Al_3Li phase precipitated on grain boundaries of α-Al and Al_3Ti distributed in α-Al matrix (Rioja ,2012).

This distribution of phases was because Li addition to Al-Ti-Mg alloy.

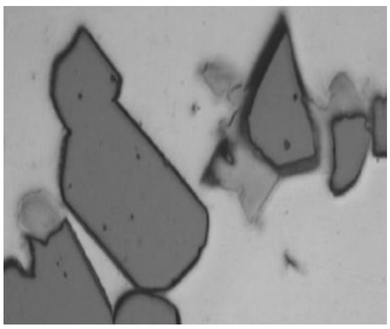
Fig. 4b appears the microstructure of alloy 4 after SHT and aging.

Fig. 5a demonstrate SEM microstructure and microanalysis of alloy 3. The (a) reveals the SEM microstructure of this alloy showing the shape of Al_3Ti distributed in Al-Mg matrix. Fig.5b shows the composition of Al_3Ti particles. Fig.5b exhibits the micro composition of Al-Mg Matrix.

AS shown in fig. 1, 3, 5 and 7, there is a small amount of the Al_3Ti phase in alloy 1 and increase with increasing of Ti content. This Al_3Ti phase's particles are composed in centralized areas of the matrix, and they do not restraint the development of directional pores in the other areas. As shown in fig.1 there are many of non-uniform pores.



b)



a)

Figure 5: SEM and EDX microanalysis at particle and matrix on microstructure of fig.a which shows SEM image for microstructure of alloy 3. b) graph shows composition of particle. b) reveals the composition of Matrix

AS Ti content increased a globular pores enclitic by equiaxed peritectic homogeneously distributed Al_3Ti phases are formed, as result of preventing the growth of directional pores by the primary α -Al and Al_3Ti phases. These Al_3Ti phase particles could be looked in the optical micrographs on Fig.1. The Al_3Ti phase shows aspect of bulk particles, also in shape of needles as in figs. 2a and 3a. After SHT this phase appears as small and semi spherical shapes.

Mechanical properties:

The mechanical properties were investigated before and after solution treatment. Four samples were examined after casting and other four samples after solution treatment and aging. The results of testing were as in tables 2 and 3 respectively.

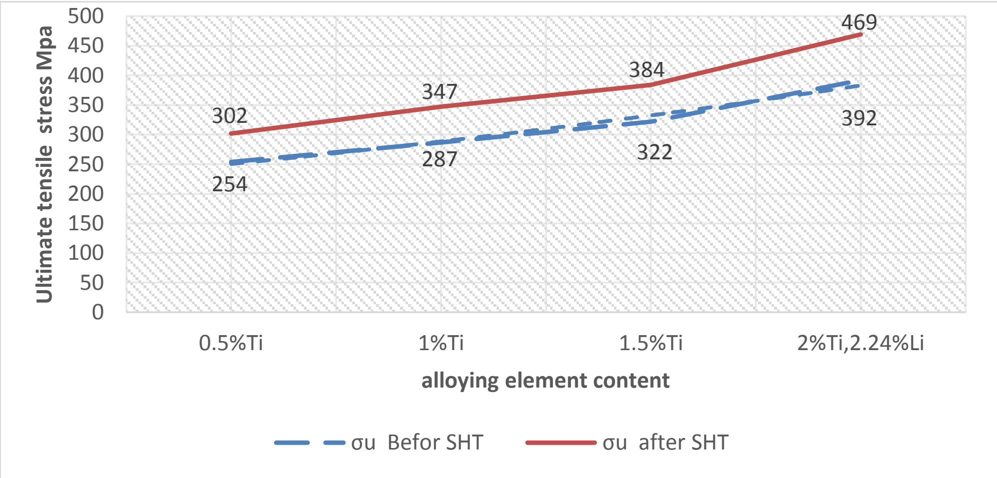


Figure 6: The variation of ultimate tensile stress with alloys content before and after SHT.

Fig.6 represents the variation of ultimate tensile strength with Ti and lithium contents in investigated alloys before and after solution heat treatment (SHT).

As shown in fig.6 the tensile stress was increased from 254 to 365MPa with increasing the Ti contents from 0.5 to 2%. This increment in tensile is because the content of Al_3Ti phase was increased with increasing of Ti content in the alloys. $TiAl_3$ has (HCP) structure in which the titanium atoms were associated with aluminum atoms by covalent bond (BATALU ,2006).

For alloy1the the tensile strength increased from 254 to 302 MPa before and after SHT respectively. This increment was as a result of precipitated particles that precipitated because of SHT. The value of tensile for the other samples also, was increased for the same reason. For alloy4 there was noted increase in tensile. This increment was as a result of increase of the Li content. The addition of Li in small amounts improves the precipitation strengthening ability of Al when spherical δ' (Al_3Li) precipitates during heat treatment (Rioja, 2012).

When comparing between the curves before and after SHT, clearly shows that the tensile stress proportionally increases with titanium content, but the tensile strength has increased at a higher rate after Li addition and aging as in alloy4.

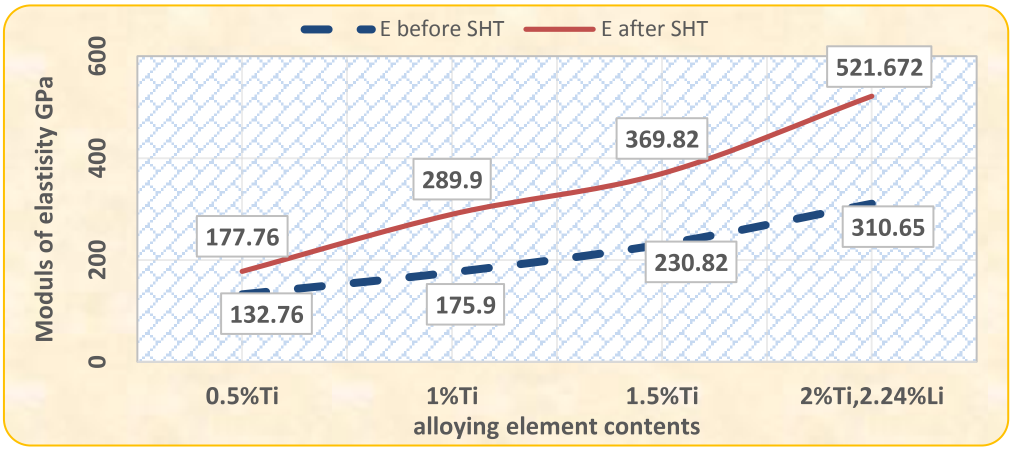


Figure 7: The variation of modulus of elasticity with alloys content before and after SHT.

When comparing between the curves before and after SHT, clearly shows increment in ultimate tensile strength is related to the precipitation of $TiAl_3$ in (alloys 1 to 3) and $TiAl_3$ and δ' (Al_3Li) in alloy 4.Fig.7 shows the modulus of elasticity behavior before and after SHT.

Fig. 7 reveals clearly that the modulus of elasticity increases as titanium ratio increased in the cast. But this increasing was not proportional, as is the case in the maximum tensile stress. The modulus of elasticity was obtained from tensile test curve from the computer of the testing machine.

This is due to the fact that increasing the amount of titanium leads smoothness crystalline size in the aluminum alloy. And as the microstructure is fine then the modulus of elasticity is high. The modulus of elasticity of alloy4 is higher than the other samples as results of increasing of Li content (Eswara ,2014 and 2017).

. The presence of Al_3Ti and Al_3Li phases in small particle shape also act as a refiner for grains because of their effect on increasing the recrystallization temperature. The refining of microstructure increases the mechanical properties like UTS, modulus of elasticity and hardness.

Fig. 8 reveals the effect of increasing the Ti content on hardness value of alloys 1 to 4. It clearly reveals that the hardness increases with increasing of Ti content in both curves but the rate of increasing in alloys after SHT was higher than in alloys before SHT.

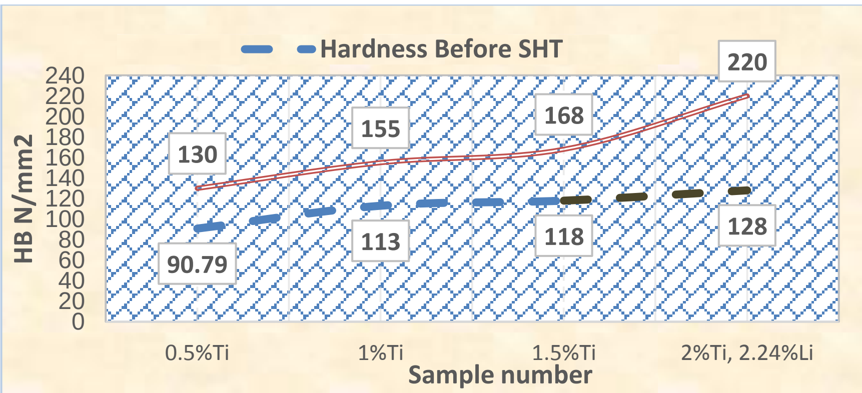


Figure 8: Hardness of alloys 1 to 4 before and after SHT

The reason is the precipitation of Al_3Ti phase. Also, fig.8 shows the hardness value of the fourth alloy has the highest hardness as a result of presence both of intermetallic compounds Al_3Ti and Al_3Li in the structure. Both of those intermetallic compound are hard and act as obstacle for dislocation movement moreover, they act as an inhibitor for growth of the propagation of grain boundary sliding in alloy.

Conclusion:

- Presence of (Al_3Ti**)** in many features**;** bars, stars and other shapes in small quantity.
- (Al_3Ti**)** phase content increases with increasing Ti in alloys and its shape changes to needle shape.
- After SHT the aspect of (Al_3Ti) phase is changed to fine and regular.
- The addition of Li produce another phase as Al_3Li.
- Tensile, modulus of elasticity, and hardness increase with increasing of Ti and presence of Li increases these properties.
- Tensile, modulus of elasticity, and hardness increase after SHT.
- There is a notable increase of mechanical properties with the presence of Li.

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