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Effect of Addition Of Copper and Copper–Nickel Elements on Structure and Properties of Low Carbon Steels.

Dr. Munthir Mohammed Radhy

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Abstract

The purpose of this study is to investigate the effect of adding different amounts (2, 4, 6% of Cu) on properties and microstructure of low carbon steel .Also study the effect of the same amounts of Cu with half amount of Ni(1,2,3%Ni) are added on properties of low carbon steels. All these alloys(Fe-Cu,Fe-Cu-Ni) appear an increase of hardness and strength with increase of the amount of Cu or Cu-Ni. The microstructure obtained after heat treated(quenched and aging) of Fe-Cu and Fe-Cu-Ni alloys has been studied by optical microscopy, investigated by X-ray diffraction and hardness measurement. The microstructures obtained after quenching depending on composition and cooling rate, the massive ferrite and massive martensite appears on most of structures in above alloys. The microstructure after aging of above alloys shown some of precipitates appear as dash plates, rod and spheres in ferrite or martensite structure and this precipitates appear as X-ray diffraction were identified the copper rich phase €.

Keywords: Fe-Cu alloys, Fe-Cu-Ni alloys, Heat treatment, Mechanical properties , Massive Ferrite, Massive Martensite.

تأثير إضافة عنصر النحاس وعنصري النحاس والنيكل على التركيب والخواص للفولاذ المنخفض الكربون

الخلاصة

الغرض من هذه الدراسة هو بحث تأثير إضافة كميات مختلفة من عنصر النحاس بنسبة (2,4,6%) على الخواص الميكانيكية والتركيب المجهري للفولاذ المنخفض الكاربون كذلك دراسة تأثير إضافة عنصر النحاس بنفس النسبة اعلاة مع نصف كمية النحاس من عنصر النيكل(3,2,1%) على الخواص الميكانيكية والتركيب المجهري للفولاذ المنخفض الكاربون.جميع السبائك تظهر زيادة في الصلادة ومقاومة الشد مع زيادة كمية النحاس او كمية النحاس والنيكل. التركيب المجهري الناتج بعد عملية المعاملة الحرارية(االاخماد والتعتيق) لسبائك الحديد-نحاس والحديد-نحاس-نيكل يدرس بواسطة المايكروسكوب الضوئي ويفحص بواسطة اشعة الحيود X وتقاس صلادتة. التركيب المجهري التي يظهر بعد عملية االاخماد فقط يعتمد على كمية النحاس والنيكل في السبيكة وعلى معدل التبريد, حيث يلاحظ ظهور فرايت كتلي اومارتنسايت كتلي في اغلب السبائك اعلاة . التركيب المجهري الناتج بعد عملية التعتيق يظهر رواسب بشكل الواح متقطعة وقضبان وكرات في قوام فيراتي او مارتنسايتي وهذه الرواسب هي على الاغلب تؤشر في فحص أشعة الحيود X ظهور النحاس بشكل طور.(€)

* Production and Metallurgical Engineering Department ,University of Technology\ Baghdad

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

Introduction

Alloys of the Fe-Ni system frequently additionally alloyed with cobalt or copper ,are used to seal metal conductors into glass apparatus. These alloys have a thermal expansion coefficient equal to that of glass and the dependence of this coefficient on temperature is very close to that of glass (1).Also the (Fe-Cu-Ni) alloys are used as the pressure vessel of a pressurized water reactor and line pipe steel for low temperature(2).

The Fe-Cu phase diagram reconstructured from references (3,4,5) is shown in Fig (1), if Fe-Cu alloy were quenched from austenite region to form martensite the ferrite would be super saturated and the material could then be aged to higher strength levels. The necessity to quench could probably be remedied by addition of nickel to increase the hardenability.

Fe-Cu alloys are well known as the steels which exhibit precipitation strengthening through precipitation of fine Cu particles within the ferrite matrix. Copper precipitation are a major contribution to the hardness increase ,and many investigations in Fe-Cu alloys and steels have been carried out under various conditions. it is believed that the structure sequence during the aging precipitation should be BCC and € - Cu (6,7,8).

The low carbon bainitic steels containing copper where developed in last sixty years ago (9). Copper additions to low carbon steels can give 150 MN/m2 increase in yield strength, which is appreciable, and can be made to occur in air-cooled condition without a separate ageing treatment if 3% Cu is added. Such an effect however requires that the transformation temperature is higher than that at which the copper precipitates. Some studies about Fe-cu alloys in following.

Yuuji et al(9). studied the Fe—0.5to4%Cu alloys when were cooled from (γ) field under various cooling conditions (water quenching, air cooling, furnace cooling) and phase transformation mechanisms examination and dilatometer. In all of the cooling conditions, hardness of Fe-Cu alloys becomes higher with increase Cu content. Effect of cooling conditions on hardness tends to the signification in alloys with Cu more than 1 mass%.

Deschamps (11)study the precipitation kinetics and strengthening have been investigated for a Fe-0.8%Cu alloy. Microstructure evolution during aging at 500 ^{o}C has been studied a combination of transmission electron microscopy and small- angle scattering to provide in formation on nature and location of precipitates as well as a quantitative estimate of their size and volume fraction. The precipitation kinetics measured in this study are fully compatible with results reported for alloys with higher Cu levels. Nucleation of Cu precipitation is promoted by the presence of dislocations whereas coarsening rates in the later stage of aging appear to be not affected by fast diffusion paths along dislocation. The strength of individual precipitates increases with precipitate size base on the analysis of the mechanical test results.

Ren et al (12) study the precipitation of copper during aging at 600°C in high-purity Fe-Cu alloy was examined by means of transmission electron microscopy, Nano-scale copper-rich clusters with B2-like structure were observed during either solution treatment or aging, which should play important role on precipitation strengthening.

Wang et al (13,14) studies the precipitation in aging Fe-Cu alloys and the stage of the formation of Cu-clusters nucleation, growth and coarsening of the coherent BCC –(€-Cu) phase in Fe during aging course .This study indicated that there were lots of Cu clusters in exist in solid solution, and subsequent phase transformation course involves a sequence of metastable phases, which compensate a higher cibbs energy by coherent or semi- coherent interfaces with the ferrite matrix.

Experimental work

1-Materials

In this research a series of (Fe.0.2C-Cu) alloy containing (2, 4, 6%.Cu) are prepare, also the same above alloy with addition of nickel as well as copper. The Ni added as half of Cu amount (1, 2, 3%Ni). The chemical compositions of these alloys were investigated in Nuser Company by used ARL. Spectrometer-Swiss device are shown in table 1.

2-Melting

The alloys were melted in induction furnace with argon protection and cast in sand casting as rods shape with (θ25× 300mm) are shown in Fig(2).A 4 Kgs charge which was the maximum capacity of melting furnace that supply as high as 60 KW at nominal frequency of 96 KHZ from 415 to 440 volts .

3-Heat treatment

The homogenization annealing was done for all specimens at (1150 ^{o}C) for two-hour and then the specimens were subject to the following heat treatment :

1- Soaking (solution annealing) at (1050 ^{o} C) for (1) hour and air cooled
2- Soaking at (1050 ^{o}C) for (1) hour and water cooled .
3- Soaking at (1050 ^{o}C) for (1) hour and air cooling and then aged at (485 ^{o} C) for (1) hour.

4-Tensile and hardness test

A standard tensile test specimen according DIN (50125)with dimension (A θ5×25 mm) by used SHIMAZA corporation machine. The Vickers hardness test used on universal device type Frank with Hv 2Kgf/15 s.

Result and discussion

To determine the mechanical properties which could be an achieved in the alloys in this study, specimens were austenitized at 1150 ^{o}C for two hour, air cooled to room temperature and then subsequent heat to 1050 ^{o} C for one hour that described earlier in heat treated, after that water cooled for some specimens and air cooled for others.

The results of hardness of alloys after water and air cooled and aging treated are shown in table 2. In all of the cooling condition (water quenching, air cooling), hardness of Fe-Cu alloys becomes higher with increasing of Cu content. The hardness tends to be signification in alloy with increased of Cu content from (2 to 6%) with water or air cooled. The results obtained for mechanical properties after air cooled and followed aging at 485 ^{o}C for 1h are shown in table 3. The table 3 shows increase of tensile value with increase of amount of copper, also the strength increase with the Ni amount in Fe-Cu alloys. This increase of tensile is a accompanying with increase of hardness and reduction of elongation.

In this study the massive ferrite and martensite have been reported in a number of quenching Fe-Cu and Fe-Cu-Ni alloy, especially in Cu and low Ni alloy. But massive martensite only reported in quenched Fe-Cu alloys has high Cu content and high Cu-Ni alloys. The microstructure with computed the hardness value of alloys shown massive ferrite as in Fig (3,4) of 2%Cu at most and 2%Cu-1%Ni alloys in both air cooled and water cooled .The alloys that contain 4% Cu at most ferritic structure, but these alloys at most are martensitic structure when water cooling as shown in Figs (5,6). The role of copper in these alloys is formed nuclei sites ,but it hardly solid –solution in Fe at room temperature. However some amount of Cu can be forcedly dissolved by means of a rapidly quenching cooling .It is to be expected that when annealing the all alloys, the Fe- rich regions will formed and Cu tendency to segregate from Fe and ultra fine grains structure can be achieved as reinforced phase in matrix. The X-rays diffraction in Fig(7) shown these phases are appear as (€–Cu) for all alloys. The Figs (3,4,5,6) with table 3 shows that strength of alloys depends not only on a difference of matrix, ferrite or martensite ,but also, on dispersion of(€–Cu) participates. In the case of air cooling for an Fe-2, 4%Cu alloys, the alloys undergoes preferentially (γ to α) massive transformation and then (€-Cu) precipitates finely within the massive ferrite matrix .This leads to a large strengthening with good hardness .As the copper increase or nickel the alloys have an increasing tendency to air hardness on slow cooling and have martensite structure after slow or fast cooling as shown in Figs (8,9,10). The nickel and copper are largely dissolve in ferrite. Any element dissolved in ferrite increases the hardness and strength in accordance with the general principles of solid solution hardening. The nickel and copper have unlimited solubility in gamma (γ) iron and are highly soluble in ferrite, contributing to strength increase of matrix after aging.

The microstructure change from massive ferrite to massive martensite after water cooling (quenched) in (4%Cu),and after air cooled of (6%Cu), (4%Cu- 2%Ni) and (6%Cu-3%Ni) due to-role of nickel favours the formation of massive martensite in preference to massive ferrite in the quenching alloy. The hardness value in massive martensite structure of (6%Cu) and (6%Cu.3%Ni) appear more than hardness of massive martensite structure of (4%Cu) and (4%Cu.2%Ni). The difference is due to the higher dislocation density and small size of the individual plates in matensite structure in two first alloys.

In the high-copper alloys the supersaturation are considerably greater than low copper alloys and copper will tend to precipitate during cooling resulting an increases of hardness on aging. Copper precipitation are a major contributions to the hardness increases on aging because the Cu formed with the supersaturated solid solution of (α-Fe) have bcc structure as a coherent bcc copper-rich clusters that are decomposed, which transformed to fcc- (€-Cu) precipitates upon reaching a critical size during aging and these precipitates have spherical shape at early stage of aging but their shape changes to rod due to the energy of aging treated. .The addition of nickel will contribute to accelerate the rate of precipitation that appear as sphere and rod and dash plate in the form copper – rich phase €. Also the nickel play the role of decreasing the ferrite solid solubility of copper and giving a greater degree of supersaturation with formation of a larger volume fraction of finely dispersed precipitate. and this causes appearing of martensite phase and increase the hardness and tensile properties, increases of hardness are shown in Fig (11,12) as Ni contents increased.

Conclusions

1. The mechanical properties(strength and hardness) are increased with increases of Cu and Cu-Ni alloy in low carbon steels.
2. Massive ferrite is obtained in Fe-2%Cu and Fe-2%Cu-1%Ni on air cooled and massive martensite is obtained on air and water cooling of alloys has Fe-4, 6%Cu, Fe-4%Cu-2%Ni andFe-6%Cu-3%Ni.
3. Massive martensite structure of alloys having 6%Cu and 6%Cu-3%Ni appear more hardness than massive martensite structure that having low content of 4%Cu,and 4%Cu-2%Ni due to higher dislocation density.
4. The structure having high content of Cu, Ni elements shown the precipitation of the copper- rich € precipitate .This phase precipitate in form sphere, rod, and dash plates.

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Table (1) chemical composition of alloys

Designation	Cu%	Ni%	C%	Fe%	Other alloying elements
A	1.8	-	0.18	balanced	traces
B	3.3	-	0.16		
C	6.2	-	0.18		
D	2.1	0.9	0.2		
E	3.5	2.2	0.22		
F	5.8	3.1	0.19		

Table (2) hardness value after water quenched and aging of carbon steel-Cu and carbon steel-Cu-Ni alloys

alloys	Hardness(HV) after water quenched	Hardness(HV) after aging*
A	125	260
B	195	345
C	260	422
D	160	285
E	220	278
F	270	438

***aging temperature at 480 ^{o} C**

Table (3) Mechanical properties of Fe-Cu and Fe-Cu-Ni alloys after air Cooling at 1050 oC for 3 h and aging at480o C

alloys	Heat treated type	Hardening HV	Yield strength MPa	Ultimate strength MPa	Elongation %
A	Air cooled (a)	155	334.4	412.8	25
	Aging (g)	239	588.8	684.8	12
B	a	268	675.2	764	14
	g	282	726.2	832	11
C	a	302	814	913.8	12
	g	315	846.4	948.6	11
D	a	170	392	473.6	19
	g	255	546	606.4	14
E	a	300	675.2	899.2	14
	g	320	811.2	907.2	12
F	a	380	880	950	11
	g	420	900	980	10

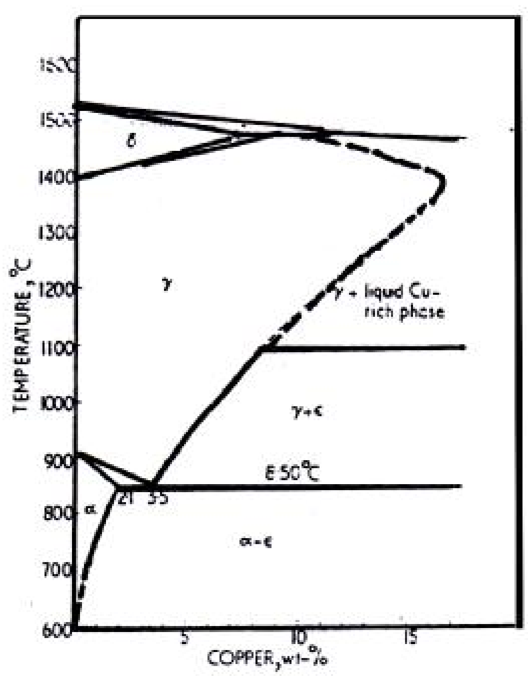
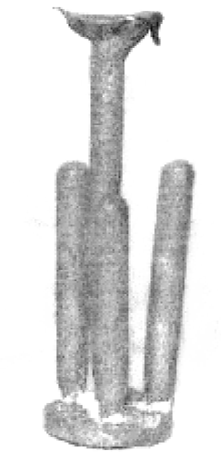


Figure (1) Iron rich end of the Fe-Cu diagram (1,2.3)



Figure(2) The Samples after Sand casting

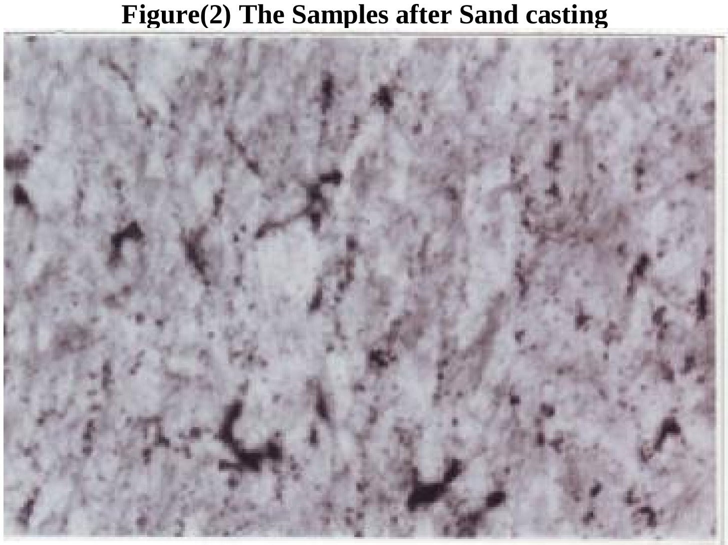


Figure (3) Microstructure of Fe-2% Cu alloys after air -cooled. ((Massive Ferrite with precipitates of Cu and some particles of Fe_2o_3 or Cu_2o)). (X200)

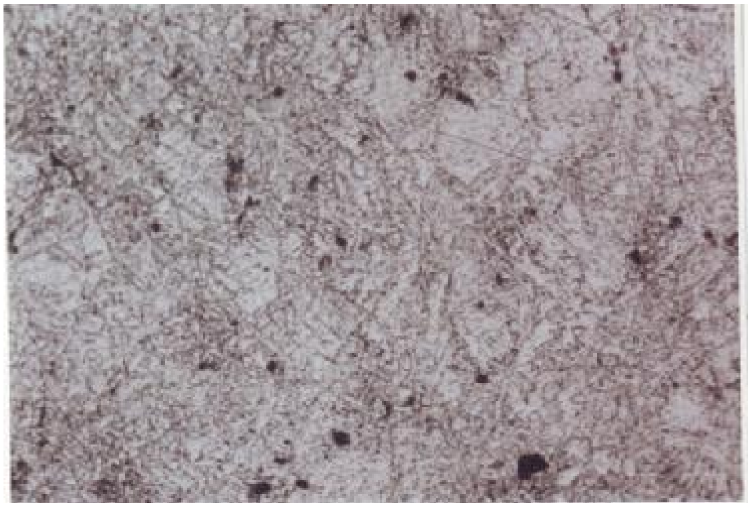


Figure (4) Microstructure of Fe-2% Cu-1%Ni alloys after air -cooled. ((Massive Ferrite with precipitates of Cu and some particles of Fe2o3 or Cu2o or Ni2o3)). (X200)

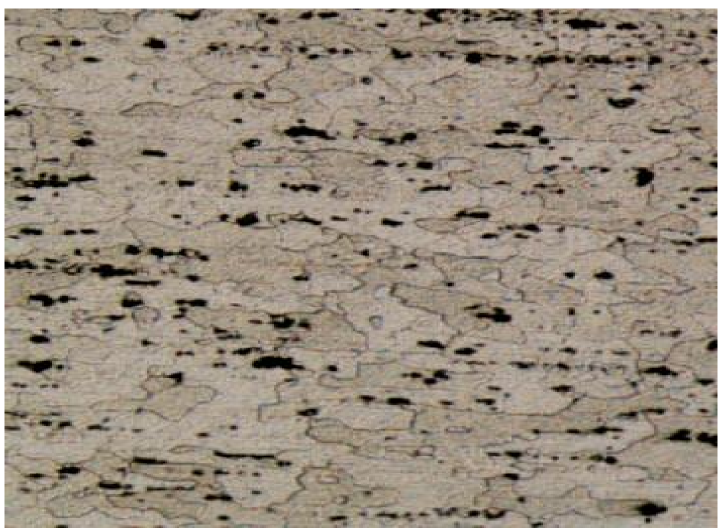


Figure (5) Microstructure of Fe-4% Cu alloys after air -cooled. (Massive Ferrite with precipitates of Cu and some Particles of Fe2o3 orCu2o)). (X200)

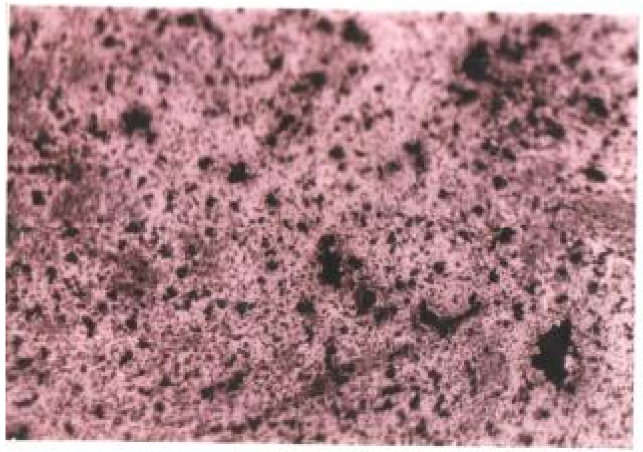


Figure (6) Microstructure of Fe-4% Cu alloys after water-quenched ((Massive Martensite with precipitates of Cu and some particles of Fe2o3 orCu2o)). (X200)

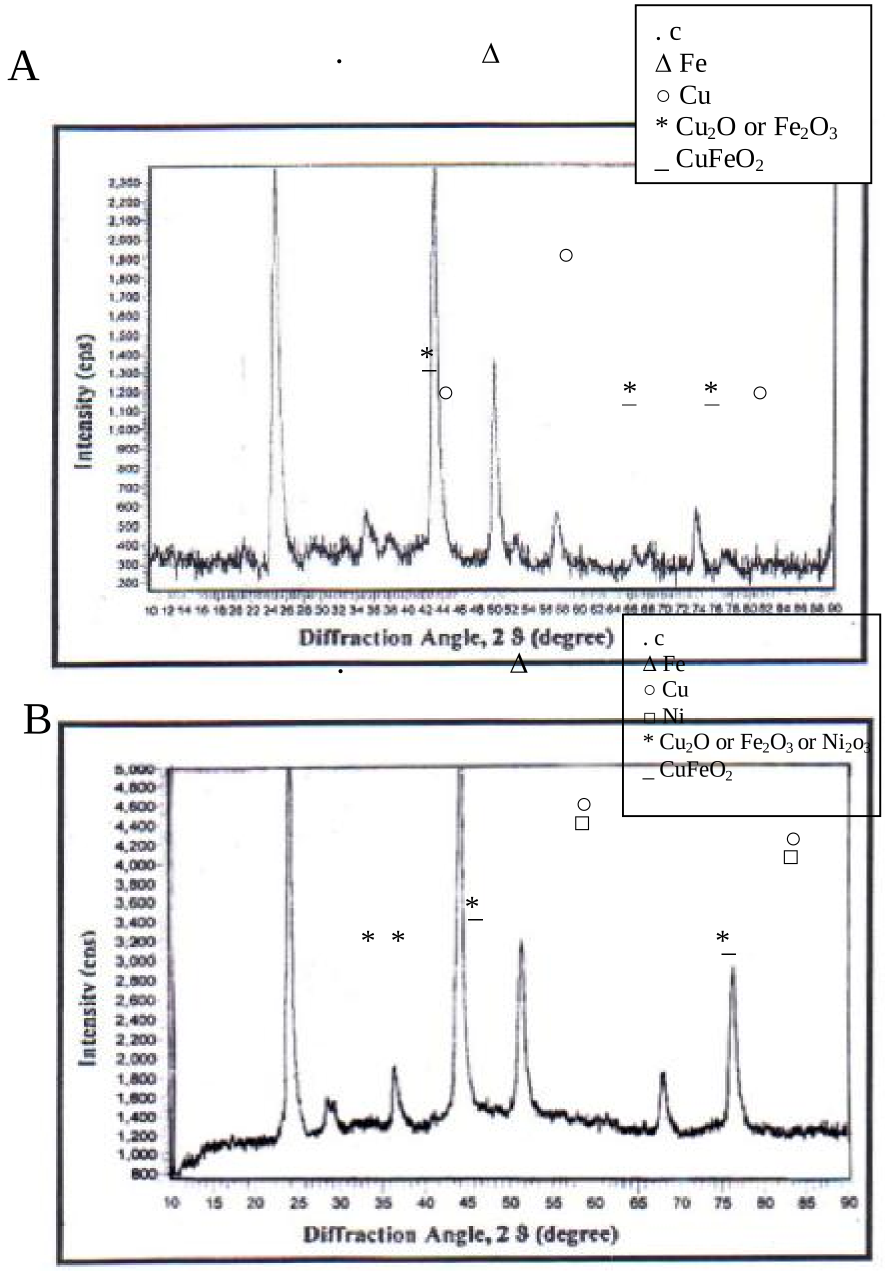


Figure (7) X- ray diffraction Analysis of alloys
A-Fe-0.2%C-6%Cu
B-Fe-0.2%C-6%Cu-3%Ni

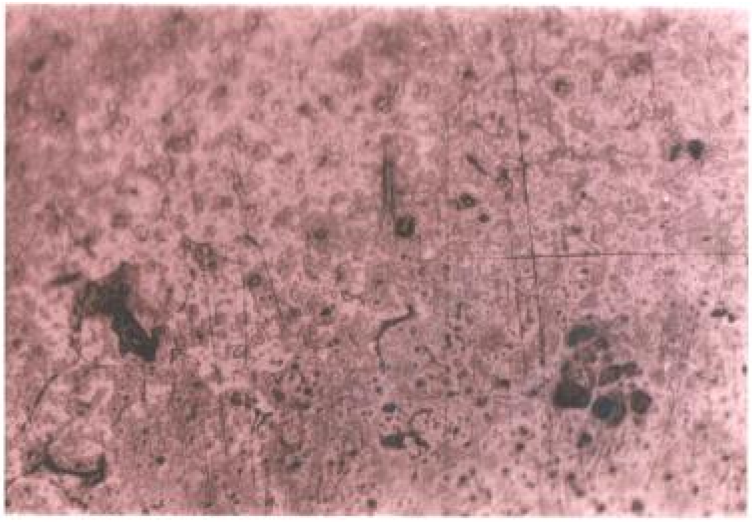


Figure (8) Microstructure of Fe-4% Cu-2%Ni alloys after air -cooled. ((Massive Martensite with precipitates of Cu and some Particles of Fe2o3 orCu2o orNi2o3)). (X200)

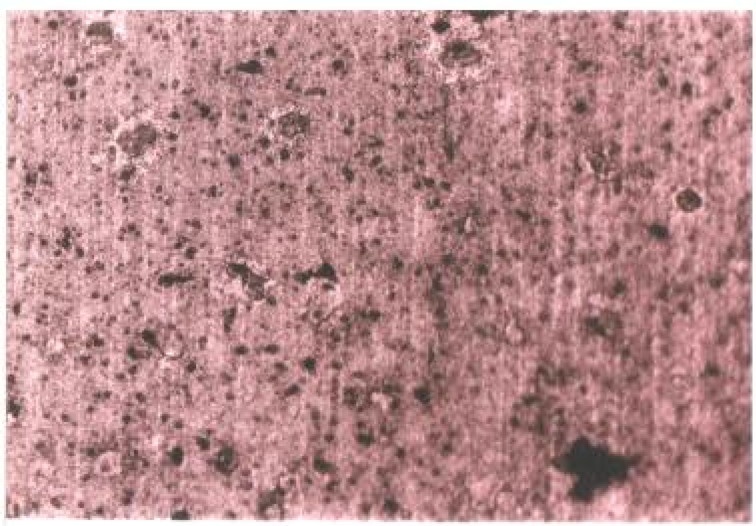


Figure (9) Microstructure of Fe-6% Cu alloys after air -cooled. ((Massive Martensite with precipitates of Cu and some particles of Fe2o3 orCu2o)). (X200)

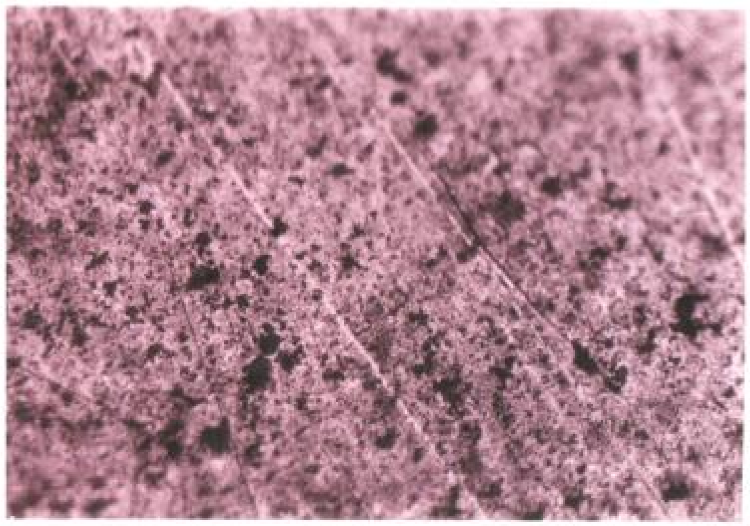


Figure (10) Microstructure of Fe-6% Cu-3%Ni alloys after air -cooled. ((Massive Martensite with precipitates of Cu and some particles of Fe2o3 orCu2o orNi2o3)). (X200)

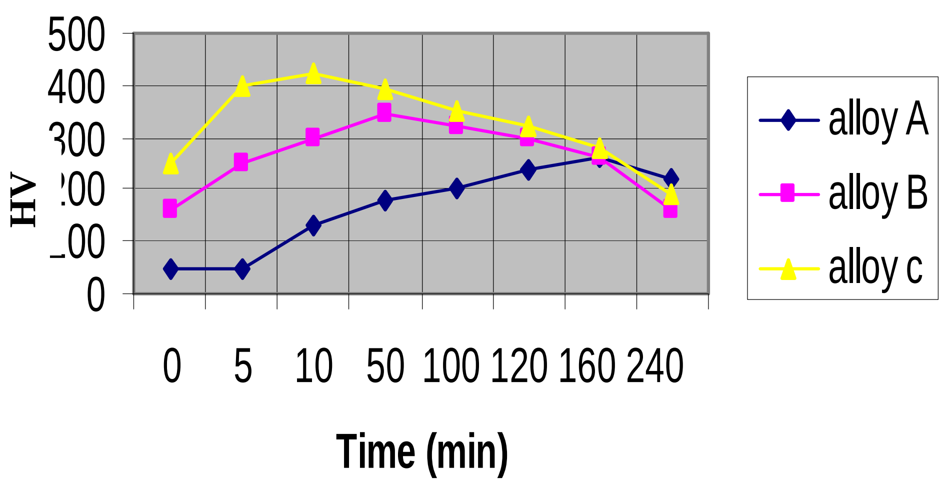


Figure (11 A) Precipitation hardening of Fe-Cu alloy after water quenching and aging at 480 o C

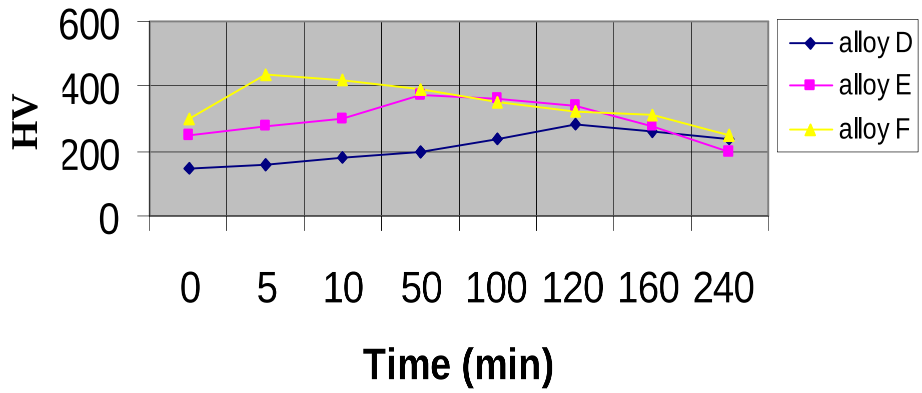


Figure (11 B) Precipitation hardening of Fe-Cu-Ni alloy after water quenching and aging at 480 o C

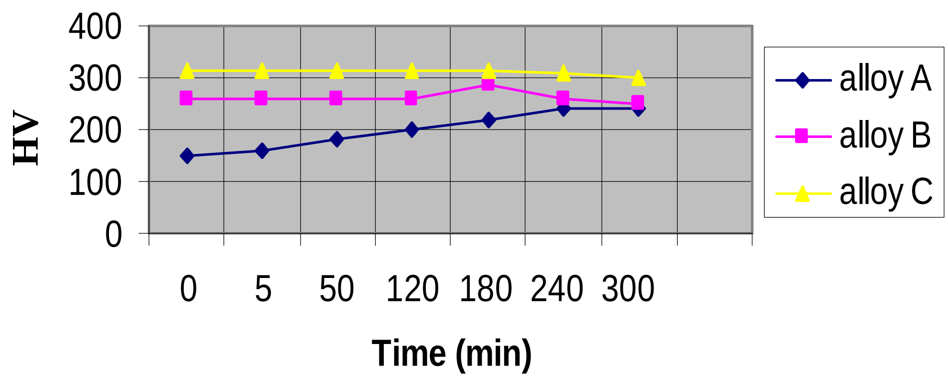


Figure (12 A) Precipitation hardening of Fe-Cu alloy after air cooling and aging at 480 o C

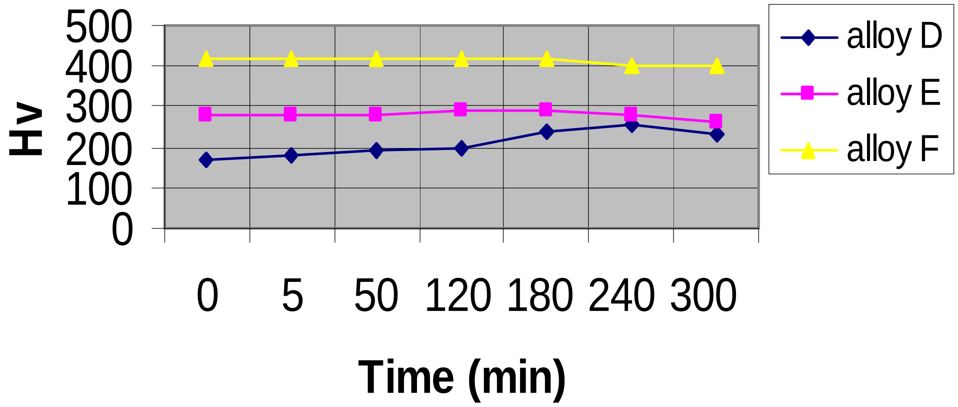


Figure (12 B) Precipitation hardening of Fe-Cu-Ni alloy after air cooling and aging at 480 o C