AGEING CHARACTERISTICS OF 7075 Al-ALLOY

A DISSERTATION
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requirements for the award of the Degree
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MASTER OF ENGINEERING
in
METALLURGICAL ENGINEERING
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The author is also thankful to all the laboratory staff of the concerned laboratories for extending their help to carry out the experiments.

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CERTIFICATE

Certified that the dissertation entitled, 'AGEING CHARACTERISTICS OF 7075 Al ALLOY', which is being submitted by Mr. C. Narayana Sastry in partial fulfilment for the award of the Degree of Master of Engineering in Metallurgical Engineering (Physical Metallurgy) of University of Roorkee, Roorkee is a record of his own work carried out by him under my supervision and guidance from 6·1·75 to 30·7·75.

The matter embodied in this dissertation has not been submitted for the award of any other degree.

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ABSTRACT

Ageing characteristics of Al 7075 alloy were studied by hardness measurements and tensile testing at ageing temperatures of 105°C, 120°C and 135°C. It is found that peak hardness on ageing at 105°C and 120°C is same but the time to reach peak hardness has drastically reduced from 58 to 20 hours. So optimum ageing temperature is 120°C. =

Effect of multiple ageing was studied by hardness measurements. Multiple ageing is found to decrease the time to reach peak hardness with little drop in peak hardness value.

Combined effect of multiple ageing and plastic deformation was also studied. The cycle consists of pre ageing and plastic deformation and re ageing. The variables used were percentage pre ageing, preageing temperature, percentage plastic deformation and re ageing temperature. Maximum hardness has been obtained by reageing 30 pct. deformed specimens at 120°C and 20 pct. deformed specimens at 135°C. irrespective of pre ageing temperature and percentage pre ageing.

CONTENTS

1. INTRODUCTION:

The Al - Zn - Mg alloys have the highest strength of any known Al alloys. The strength of these alloys depend upon Zn + Mg content and Zn to Mg ratio. The strength can be increased by increasing Zn + Mg content or decreasing Zn/Mg ratio. These alloys find wide application in air craft and space industries due to its high strength to weight ratio such as wind frittings and landing gear components.

The alloy 7075 is used for the parts like load carrying frames, fuel stage and wing strings, angle frittings etc. in air craft industry. In the T6 condition the mechanical properties of this alloys given below

U.T.S. = 58 Kgs/mm^2 ys = 51 Kgs/mm^2

Elongation = 11 Pct. Fatigue strength = 16 Kg/mm^2

The main problem with these alloys are their succeptability to stress corrosion cracking. This is thought to be associated with the type of distribution of solute atoms and morphology of the precipitates in the neighbour hood of grain boundary. Several methods were suggested to improve stress corrosion resistance and other mechanical properties. They can be summerised as follows:

1. Addition of trace elements to modify structure of precipitate. In Al - Zn - Mg alloy addition of Ag as trace element is highly benificial.

2. Multiple ageing. This improves resistance to stress corrosion with small decreases in strength.

3. Changing the quenching rate from solutionising temperature.

4. Plastic deformation prior to ageing.

Stress corrosion resistance of Al 7075 alloy can be improved by giving T 73 heat treatment at the cost of 15 pct. loss in tensile strength relative to the conventional heat treatment T 6.

The object of this work isto see the influence of multiple ageing and thermomechanical treatment on time to reach peak hardness and peak hardness value.

2. LITERATURE SURVEY:

2.1. Ageing Characteristics of Al - Zn - Mg Alloy:

The Al - Zn - Mg alloys are susceptable to stress corrosion cracking. This phenomenon is undoubtedly related to structural changes in the alloy and internal stresses during ageing. The essential alloying elements are Zn, Mg, Cu, Mn etc. The ageing behaviour is quite complex. Several workers have studied the ageing characteristics of Al - Zn - Mg alloys.

Al has large high temperature solubility for Zn which decreases to about 2 pct. at room temperature. This suggests the binary Al - Zn alloys may have marked response to age hardening treatment of course the extent of hardening is small. The mechanisim is thought to be that of decomposition of super saturated solid solution in two stages. The first stage is the formation of spherical GP zones Transmission electron micrographs of Al - 9.4 at Zn alloy show small spherical G P zones after ageing short times at room temperature and at 100°C. After further ageing at 100°C small precipitate plates parallel to (111) planes can be detected with associated strain fields. The structure of intermediate precipitate is elastically distorted F.C.C. with a lattice parameter 3.98 Å. X-ray results indicate that these precipitate losse coherency with the matrix while they are quite small in size, then equilibrium precipitate forms. The equilibrium phase forms by both continuous and discontinuous precipitation.

Polmear[2] published many ageing curves for a wide range of ternary Al - Zn - Mg alloys at temperatures from - 20°C to + 240°C. His results show that the small addition of Mg have pronounce effect on ageing response of Al - Zn alloys. The precipitation process in Al - Zn - Mg alloys has been studied by X-ray methods[3], Electron Microscopy[4], specific heat measurements[5] and hardness measurements 2,6,7,9. The ageing sequence is as follows:

Super saturated solid solution ⟶ Spherical G P zones ⟶
Intermediate plate like η' phase ⟶
Intermediate plate η phase ⟶
and Stable granular T phase

Gerold and his co workers investigated the structure of G P zones by an X ray small angle scattering technique and found ordered spherical G P zones in Mg rich (about 4 wt./Mg) alloy and side band structure in a poor Mg (about 1 wt./Mg) alloy. In Al - 4.5 pct zn - 1 pct Mg alloy the structure of ordered G P zones changes slightly so that it contains antiphase boundaries like Au Cu 11. In the boundary planes there are excess Zn atoms so that over all composition becomes $Mg_3 zn_5$ as opposed to Mg Zn in the alloy containing equal amounts of Zn and Mg. The atoms of Zn and Mg are arranged so that misfit due to the Mg atoms (+ 11 pct) and the Zn atoms (-2 pct) is approximately equal and opposite.

Thomas and Nutting[4] studied the precipitation of Al - 3.2 pct Zn - 2.5 pct. Mg. In ternary alloy the diameter of G P zones is ∼ 50Å after short ageing times at 160°C and the density of G P zones is $\sim 10^{15}/\mathrm{Cm}^3$. This suggests that most of solute atoms remain in the solution at this stage or are present as small clusters. Asano and Hirano[5] have shown that G P zones could be formed in Al - 5 pct Zn - 1 pct Mg on ageing considerably at high temperature. Thd stability of Zones depends upon Zn to Mg ratio and ageing temperature. Mond 01 fo 3 etal observed streaks along <111> direction in their X-ray studies. This suggests G P Zones forms on (111) planes.*

The η' phase has h. c. p. structure. This precipitates on (111) planes. The lattice parameters[4] of η' are $a = 4.96$ Å and $C = 8.68$ Å. The precipitate forms with orientation relationship.

$$(0001)_{\eta'} \parallel (111)_{Al} \; ; \; [11\bar{2}0]_{\eta'} \parallel [110]_{Al}$$

The misfit in C difection is $\sim$ 7 pct. There must be dislocations at the interface since the structure of the matrix and precipitate is different.* So the precipitate can never be completely coherent.* The structure at peak hardness is a mixture of G.P. Zones + η' phase and latter phase predominates.* During further ageing the G.P. Zones dissolves as η' precipitate coarsens.

At peak hardness the size of η' precipitate plates are $\sim$ 50 Å thick, $\sim$ 150 Å in diameter and density of precipitate is $\sim 2 \times 10^{16}/\mathrm{Cm}^3$. The η' phase usually precipitates at temperatures lower than 200°C.

As the η' precipitate becomes coarser and their structure reverts to the equilibrium low temperature phase η ($MgZn_2$).

The η phase has also h. c. p. structure.[7] This phase is stable and is of considerable importance in age hardening of Al - Zn - Mg alloys.

The T phase has composition $(Al\ Zn)_{49}\ Mg_{32}$.[7] and has cubic structure. This phase precipitates only at high temperatures.

2.2. Effect Of Trace Elements:

Trace elements can have two distinct effects on precipitation[1]. Firstly their presence can alter kenetics of zone formation so that apparent rate of solute diffusion is greatly reduced. Secondly they can assist the nucleation of intermediate precipitate. The second effect is more in Al - Zn - Mg alloys.

Addition of Cr to this alloy decreases the amount of heterogenous precipitation and promotes uniform structure within the grains.[7] It also inhibits the recrystallisation at solution treatment temperature probably by the action of insoluble particles at the grain boundaries Holl[9] studied the effect of Cr addition on ageing characteristics of Al - Zn - Mg alloy.[7] The Cr containing alloy exhibits low hardening response during ageing at elevated temperatures.[7] Cr favours the formation stable sub grain structure during annealing. The low hardening response of Cr containing alloy is due to anhilation of quenched in vacancies at the sub grain boundaries.

A minute Ti addition was found[10] to retard the rate of precipitation and prevent solute segregation at grain boundaries on air quenching.[7] Ti slows down diffusion of Zn and Mg atoms.

Au has no effect on ageing characteristics of Al - Zn - Mg alloy because of its low solubility[11].

The effect of Fe and Si on the precipitate structure was studied Thakery and Thomas[12]. They found that both Fe and Si raises G.P. Zone solves temperature. The presence of Fe or Si reduces the ductility of the alloy[13].

Polmear[7] had shown that trace additions of Ag or Cu to Al - Zn - Mg alloy increases the peak hardness of the alloy. Ag influence the second stage of hardening. Ag stimulates the nucleation of η' . Critical amount of Ag (0.1 to 0.3 pct.) is required to enhance the properties. Addition of Ag beyond 0.3 pct. has no further effect on ageing. Stress corrosion resistance of Al - Zn - Mg alloy can be improved by the addition of Ag. 7,8, 14. Tensile results reported, by polmear, suggest the effect of Ag on tensile properties is greater with reduced Mg content than in high strength alloys. Trace addition of Ag do not influence the diffusion of Mg in Al - Zn - Mg alloy[15] for the temperature range 200 - 300°C.

Cu addition effects early stages of ageing of Al - Zn - Mg alloys. The important effect is the rapid hardening as soon as the alloys were aged in the range 100 - 235°C. This effect increases with increasing Cu addition upto its solubility limit. The early hardening was most marked in Al - 4 pct. Zn - 3 pct. Mg 1.0 pct. Cu alloy. Since this alloy lies close to $(\alpha + s)$ phase field. This early rapid hardening is probably associated with the formation of S phase. Addition of Cu to Al - 8 pct. Zn - 3 pct. Mg did not change the form of ageing curves above 30°C. Early hardening described above is not observed since these alloys would probably lie in (α + T) phase field at low temperatures.

Cu does not effect the nucleation of intermediate precipitate. Once the early rapid hardening is over the quaternary alloy hardens in the same way as ternary alloy. The addition of Cu has little effect on time to reach peak hardness or the temperature at which the change from high to low level peak hardness values occurs. The effect of Cu can be varied with different Zn and Mg conten This is thought to be due to modifications in the ageing process. Baba[16] using electrical resistivity measurements, found that 0.23 pct. Cu addition to Al - 6 pct. Zn - 1.8 pct. Mg increased the maximum change in resistivity for this alloy aged at 90°C. He concluded that the number of G.P. Zones in this alloy was increased by Cu addition.

Smith and Grant[17] concluded that the addition of Cu to Al - Zn - Mg alloy increases the rate of homogeneous precipitation in these alloys at lower temperatures by increasing the number of G.P. Zones nucleated hence Cu accelerates low temperature nucleation and growth of G.P. Zones. Addition of Cu to Al - Zn - Mg alloy strengthens since Cu accelerates the formation and growth of G.P. Zones at low tempefature.

Addition of Agto high strength Al - Zn - Mg - Cu promotes uniform precipitation during ageing and [illegible] grain boundary precipitate free zone is greatly reduced. Polmear also suggested that Ag containing Al - Zn - Mg - Cu may be aged at temperatures above the normally used 135°C without sacrificing tensile properties. Elkington[18] showed that stress corrosion resistance of Al - Zn - Mg - Cu alloys can be improved by reducing Zn to Mg ratiom and reducing quench sensitivity. By these methods stress corrosion resistance can be improved at the expnse of tensile strength. But with the addition of Ag and by ageing at appropriate temperature stress corrosion resistance gets improved without loss of strength values.

2.3. Multiple Ageing:

Cereara and Giarda[19] investigated the influence of pre ageing at 0°C on ageing at 40°C of Al - 10 pct. Zn alloy by X- ray small angle scattering and resistivity measurements. They found that pre ageing effects size of G.P. Zones. The size of G.P. Zones on final ageing depends upon the pre ageing time. Size of G.P. Zones increases with increasing pre ageing time.

In Al - Zn - Mg alloys pre ageing at room temperature after solution treatment leads to formation finer precipitate structure during artificial ageing 9, 20.

Lorimer and Nichlson studied the influence quenching to below G.P. Zone solves temperature and holding at that temperature on final ageing of Al - Zn - Mg alloy. They concluded that long pre ageing times gives a very fine precipitate and narrow P.F.Z. during final ageing. The rate of refinement and narrowing of PFZ is much less at lower ageing temperatures. No effect has been observed by pre ageing at or below - 50°C.

Asano and Hirano[21] studied the influence of pre ageing on Al - 5 pct. Zn 1 Pct. Mg by calorimetric method. They explained effect of pre ageing interms of number of G.P. Zones at pre and final ageing by applying Beckers nucleation theory. They observed considerable increase in quantity of G.P. Zones during final ageing of pre aged alloy. No influence of pre ageing on intermediate precipitate has been observed. In contrast to Lorimer and Nicholson's[20] observations, Asano[21] et al say that refinement of G.P. Zones by pre ageing is responsible for the improved properties of Al - Zn - Mg alloy. They argued that G.P. Zones are spherical in shape where as the shape of η' precipitates are plate like. So it will be geometrically unfavourable for the G.P. Zones to act as nucleus of η' phase.

Holl[9] studied the influence of pre ageing at room temperature of Al - 5.3 pct. Zn - 1.8 pct. Mg - 0.09 Pct. Cr on artificial ageing by hardness measurements. In this alloy pre ageing helps in the formation of η' precipitate even in the presence of stable sub grain boundaries. The amount of η' precipitate formed during artificial ageing depends upon the pre ageing time.

Stress corrosion resistance of Al 7079 can be improved[24] by giving suitable multiple ageing treatments[22]. The resulting sacrifice in strength can be kept at low values either by raising final ageing temperature or accelerating quenching rate. Variations in quench rate and primary ageing temp. have effect on width of PFZ and precipitate distribution.

2.4. Thermo mechanical Treatment:

No. of workers have reported the influence of prior plastic deformation on ageing characteristics of Al-alloys. The aim for these studies are[25]

1. To obtain information on basic mechanisim where by super saturated solid solution decompose.

2. To investigate conditions which occur in industrial practice.

3. To produce different structure which is having properties different from convertionally aged materials.

and 4. To decrease the time of heat treating cycle.

The influence of plastic deformation on ageing can be considered in different situations. Plastic deformation prior to ageing after solution treatment or plastic deformation after solution treatment and preliminary ageing prior to final ageing. Plastic strain prior to ageing delays the zone formation due to decrease in vacancy concentration. In the as quenched condition the vacancy concentration is of order 10^{-4}. Whereas plastic deformation produces a vacancy concentration is of order 10^{-6}. Dislocations produced due to deformation acts as sinks for quenched in vacancies. So the removed of vacancies by plastic deformation delays the Zone formation[1].

During ageing of super saturated solid solution, Intermediate precipitate forms by transformation from previously formed Zones at Zone matrix interface. The transformation of Zones to intermediate precipitates is associated with change in volume. Since dislocations provide sites which will accomodate volume changes the stable nucleus size at a dislocation is lower than at zone - matrix interface. So rapid nucleation and growth of intermediate precipitate can takes place at dislocation Equilibrium precipitate formation also involves volume change they form preferentially at Grain boundaries. But dislocations are not as favourable as grain boundaries.

In alloy which is hardened by zone formation and softened by the formation of intermediate eg Al - Zn, cold work prior to ageing will cause rapid softening. On the alloy which is hardned by the precipitation of fine dispersion of intermediate phase eg Al - Cu will show rapid increase in hardening when deformed before aging.

Prior plastic deformation before ageing in Al - Zn alloy causes a decrease in resistivity maximum. Small angle X- ray studies suggested that the deformation decreases the solute concentration in the zones and increases the solute concentration in the matrix and reduces number of zones[22].

Sharma and Anantha Raman[23] studied the influence of plastic strain on ageing of Al - Zn - Mg alloy. Prior to ageing they did not observe considerable improvement in the strength, conserva[26] et al found that the combination preliminary two step ageing at low temperature and plastic deformation and final artificial ageing at higher temperatures marked by (TA_1 A_2 HA_3) improves the strength of Al - Zn - Mg. It is noted that the use of $TA.A_2$ HA_3 cycles on

Al - Zn - Mg with low Mg content, strength values can be reached to the level of high strength Al - Zn - Mg alloys.

Grain boundary regions in conventionally aged Al - Zn - Mg alloys are soft with respect to matrix which adversely affect the fatigue resistance and stress corrosion cracking. Deformation prior to ageing has a small beneficial effect on fatigue resistance but major beneficial effect on resistance to stress corrosion cracking[27].

In Al-Zn-Mg, the effect of cold work after quenching on ageing is either negligible or negative. The prior deformation after quenching from hinders the artificial ageing at 120°. The final tensile properties of the worked material are not much different from those of material directly aged after quenching[6]. The lack of nucleant action of the cold work has been explained by the fact that hardening is essentially due to G.P. Zones formation in the normal treatment.

It is well known that increase in strength is always accompanied by decrease in ductility and this is more apparent for the treatments involving combination of deformation and ageing conserva[28] etal suggested a sophisticated TMT cycle to modify plastic deformation and precipitation phenomena to get improvements in strength without drastic loss of ductility. It was found that the inhibiting effect that dislocations exert on ageing reaction can be substantially decreased by initial ageing at low temperature, for a given plastic deformation and final ageing temperature TAHA; (T = Solution treatment A = ageing H = Plastic deformation). The treatment (TAHA) involving solutionising, quenching, ageing, working and ageing on Al - Zn - Mg (Cu) alloys markedly increased the UTS and yield strength of these alloys compared to conventional treatments while maintaining adequate ductility.

The TMT treatment consisting preageing at 100°C for 1 hour after solution treatment and hot swaging at 120°C for 16 hours markedly increased the fatigue strength of 7075 alloy. The uniform and stable dislocation - precipitate structure formed by TMT is responsible for the improvement of fatigue properties[29].

3. EXPERIMENTAL PROCEDURE:

3.1. Alloy Preparation:

The alloy was prepared from E.C. grade aluminium (Minimum 99.7 pct. pure), zinc (99.9 pct. pure), magnesium (99.9 pct. pure), electrolytic copper (99.9 pct. pure) and chromium (99.9 pct. pure).

Aluminium was melted in graphite crucible in a muffle furnace. Weighed quantity of cu was added, the melt was stirred with graphite rod to prepare master alloy.

Aluminium and master alloy was melted in graphite crucible in a pit furnace. Weighed quantityof zinc, magnesium and chromium were added to the melt and stirred the melt properly with graphite rod. The alloy was cast in mild steel mould. 20 Kgs. of alloy was made.

The casting was drilled at eight places on the periphery which are at equal distance and diametically opposite to get sample for the analysis.

The alloy was chemically analysed for Zn, Mg, Cu and Cw, Si and Fe by volumetric method. Zn was analysed by dissolving the sample in acid mixture (Hcl and HNO_3). Cu is removed from the solution by passing H_2S. Zn content was estimated from ZnO by igniting ZnS at 800°C.

Mg is precipitated as magenesium quinotate from alkaline tartate solution. Mg content was determined from the weight of magnesium quinolate.

Cu was analysed by dissolving the sample in aqua regia. The copper sulphide is precipitated by passing H_2S in the solution. The precipitate was ignited to oxide at 600-700°C and Cu content was estimated from its oxide.

Cr is determined by dissolving the alloy in aquia regia. The dichromate is titrated with ferrous ammonium sulphate and potasium permanganate solution. The Cr content is determined from the amount of ferrous ammonium used.

Si is determined by using NaOH solution. The precipitate, SiO_2, ignited and volatatised as silicon tetra fluoride. The loss of weight is measure of SiO_2. For the determination of Fe the alloy is dissolved in mixed acids. No precipitate has been formed. The composition of the alloy is as follows

Zn = 5.3 wt pct., Mg = 2.3 wt. pct. Cu = 1.33 wt. pct.
Cr = 0.23 wt pct. Si = 0.22 wt. pct. Al=balance.

For final casting in batches of 2 Kgs. of alloy was melted in graphite crucibles in muffle furnace. Cryolyte was used as flux to minimise oxidation. Just before casting the alloy was degased by using hexachloroethane. The alloy was casted in mild steel moulds 4 cm x 4 cm x 16 cm. Casting temperature was fixed 740 ± 10°C.

3.2. Specimen Preparation:

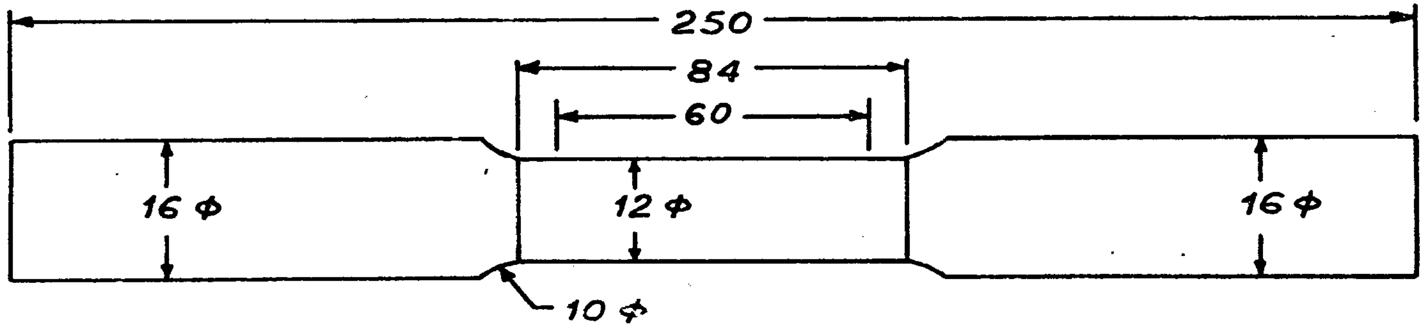
Castings were homoginised for 8 hours at 460°C and hot rolled to 20 mm x 20 mm at 460°C and machined to 18 mm x 18 mm. Hardness specimens and bars for tensile testing of size 18 mm x 18 mm x 25 mm and 18 mm x 18 mm x 250 mm were cut from bars. The hardness specimens ground and polished. Hardness pieces and bars for tensile testing were homoginised for 48 hours at 460°C ± 10°C The microstructure of hardness specimens revealed grain boundaries with single phase structure. The as quenched hardness was found to be 70 VPN. The average grain size measured was 0.1584 mm.

3.3. Heat Treatment:

The solutionising treatment was given at 460°C ± 10°C for 1 hour and then quenched in water at room temperature. Solution heated specimens were immediately subjected to further treatment. All heat treatment were carried out in silicon oil bath furnace. Mechanical treatment was given by cold rolling. Table 1 and 2 show the scheme of experiments carried out. After heat treatment the tensile specimens were turned from 18 mm x 18 mm x 250 mm bar. The dimensions of tensile specimen conforming IS : 1816 - 1961 is shown in fig. 1.

3.4. Hardness Measurements:

Vickers diamond pyramid hardness tester was used to take the hardness values. All hardness tests were made at a load of



ALL DIMENSIONS IN MM

FIG. 1 TENSILE SPECIMEN.

Table: 1 Scheme of Experiments (Hardness)

Experiment	Pre ageing temp. 0_c	Percentage preageing	Percentage Deformation	Ageing Temp. 0_c
1. Effect of Temp.	-	-	-	105°
	-	-	-	120
	-	-	-	135
2. Effect of Pot.pre age	105	25	-	120
		50	-	120
		65	-	120
		25	-	135
		50	-	135
		65	-	135
	120	25	-	135
		50	-	135
		75	-	135
		25	-	105
		50	-	105
		75	-	105
	135	25	-	105
		50	-	105
		75	-	105
		25	-	120
		50	-	120
		75	-	120
Effect of 3. Pot. Deformation.	135	75	10	120
		75.	20	120
		75	30	120
		75	40	120

5 Kg. For each reading duplicate specimens were used and the result reported is an average of 6 in dentations.

3.5. Tensile Testing:

Universal tensile testing machine was used. All specimens were tested at a load of 10 tonnes.

Table: 1 Scheme of Experiments (Hardness)

Experiment	Pre ageing temp. 0_c	Percentage preageing	Percentage Deformation	Ageing Temp. 0_c
1. Effect of Temp.	-	-	-	105°
	-	-	-	120
	-	-	-	135
2. Effect of Pot.pre age	105	25	-	120
		50	-	120
		65	-	120
		25	-	135
		50	-	135
		65	-	135
	120	25	-	135
		50	-	135
		75	-	135
		25	-	105
		50	-	105
		75	-	105
	135	25	-	105
		50	-	105
		75	-	105
		25	-	120
		50	-	120
		75	-	120
3. Effect of Pot. Deformation.	135	75	10	120
		75	20	120
		75	30	120
		75	40	120

Experiment	Pre Ageing Temp O$_c$	Percentage Pre ageing	Percentage Deformation	Ageing Temp. O$_c$
	105	50	10	120
		50	20	
		50	30	
		50	40	
	105	50	10	135
		50	20	
		50	30	
		50	40	
	120	75	10	135
			20	
			30	
			40	

Table: 2 Scheme of Experiments (Tensile Testing)

Pre ageing temp. in O$_c$	Percentage of pre ageing	Percentage of ageing	Ageing temp. in O$_c$
	–	80	120^{0}C
		90	120
		100	120
		110*	120
		120*	120
105	50	100	120
135	75	100	120

* 110 pct. and 120 pct. ageing corresponds to 10 pct. and 20 pct. over ageing respectively.

4. RESULTS AND DISENSSION:

4.1. Results:

Basic hardness curves have been plotted at ageing temperatures (TA) : 105°C, 120°C and 135°C as shown in fig. 2. Table 3 shows effect of ageing temperatures on peak hardness and time to reach peak hardness. Tables 4 to 9 (figs. 3 to 8) show the effect of percentage of percentage of pre ageing at one temperature on final ageing at some other temperature on corresponding peak hardness.

Figures 9 and 10 (tables 10 and 11) show the effect of percentage plastic deformation of samples preaged 50 pct. at 105°C on final ageing at 120°C and 135°C respectively. Figs. 11 and 12 (tables 12 and 13) show the effect of percentage plastic deformation of samples preaged 75 at 135°C and 120°C on final ageing at 120°C and 135°C respectively.

Table 13 shows the tensile properties of specimens aged at 120°C, preaged 50 pct. at 105°C and final aged at 120°C and preaged 75 pct. at 135°C and final aged 120°C.

4.2. Discussion:

Table 3 shows the increment in hardness of various ageing temperatures obtained from fig. 2. It can be seen that increment in hardness is almost constant at ageing temperatures 105°C and 120°C. But the time required to reach peak hardness reduces drastically from 58 hours to 20 hours. Ageing at 120°C reduces

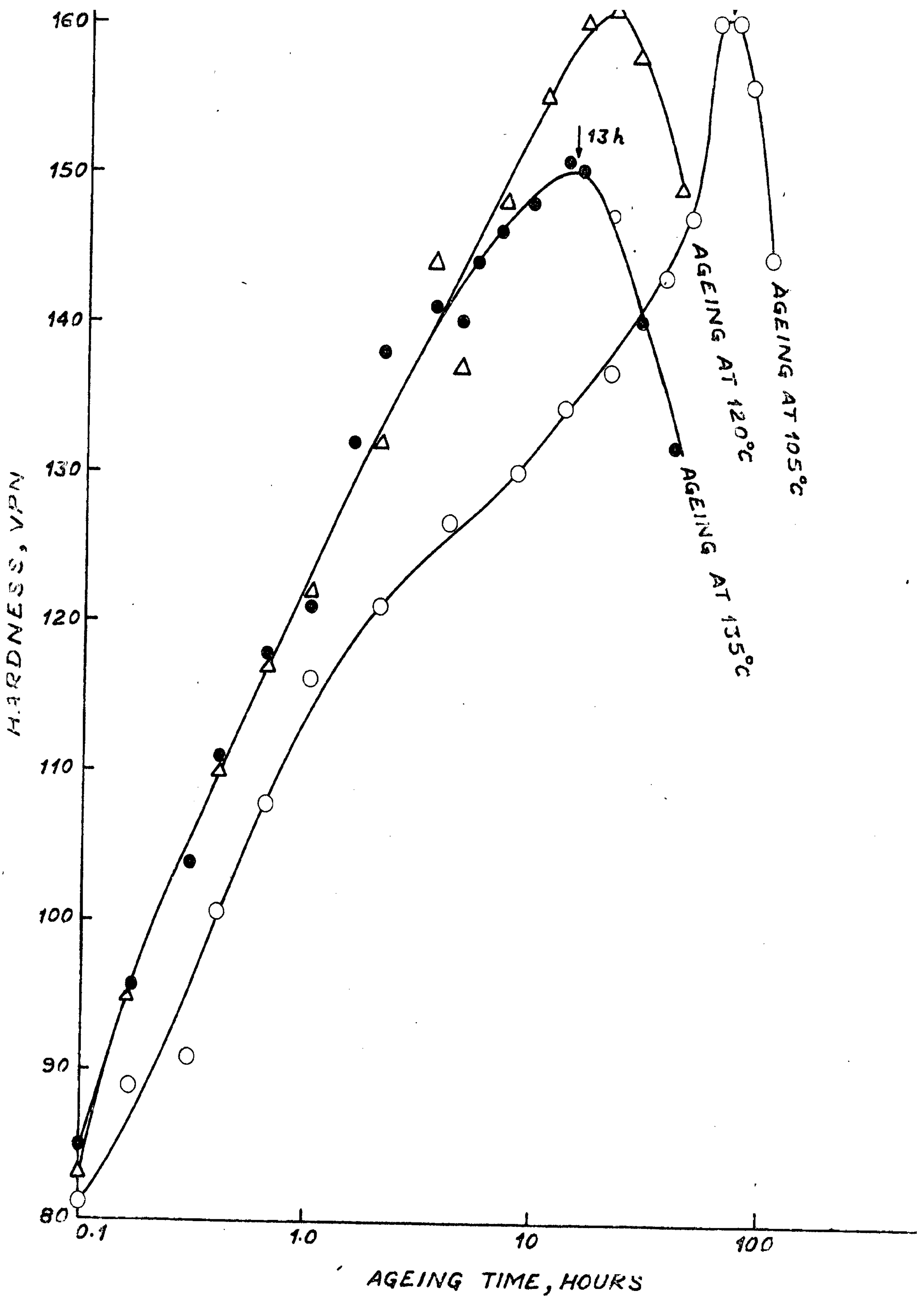


FIG 2 SET OF AGEING CURVES FOR

time about 66 pct. when compared to ageing at 105°C. There is considerable drop of 10 VPN in peak hardness on ageing at 135°C when compared to ageing at 105°C or 120°C and time to reach peak hardness reduced to 13 hours. Ageing at 135°C reduced about 35 pct. time to reach peak hardness with the percentage drop in increment in hardness is about 11 pct.

Ageing curve at 105°C shows two stages of hardening where as ageing curves for 120°C and 135°C show only one stage of hardening. This suggests that hardening at 105°C is due to zones and intermediate precipitate and at other temperatures the hardening is predominently due to intermediate precipitate. The volume fraction of precipitate decreases as the ageing temperature increases. The hardening by zone formation is due to elastic strains where as coherency strains are responsible for hardening by intermediate precipitate. The hardening effect due to coherency strain is higher than that of due to elastic strain.

The peak hardness for ageing at 105°C and 120°C is same. This suggests that loss in hardening effect due to decrease in total volume fraction of precipitate and coarsening of precipitate during. Ageing at 120°C is compansated by increase volume fraction of intermediate precipitate.

It is concluded from this that optimum ageing condition for this alloy is ageing at 120°C for 20 hours.

Table 4 shows the effect of percentage of pre ageing at 120°C on final ageing at 105°C obtained from fig. 3. It is

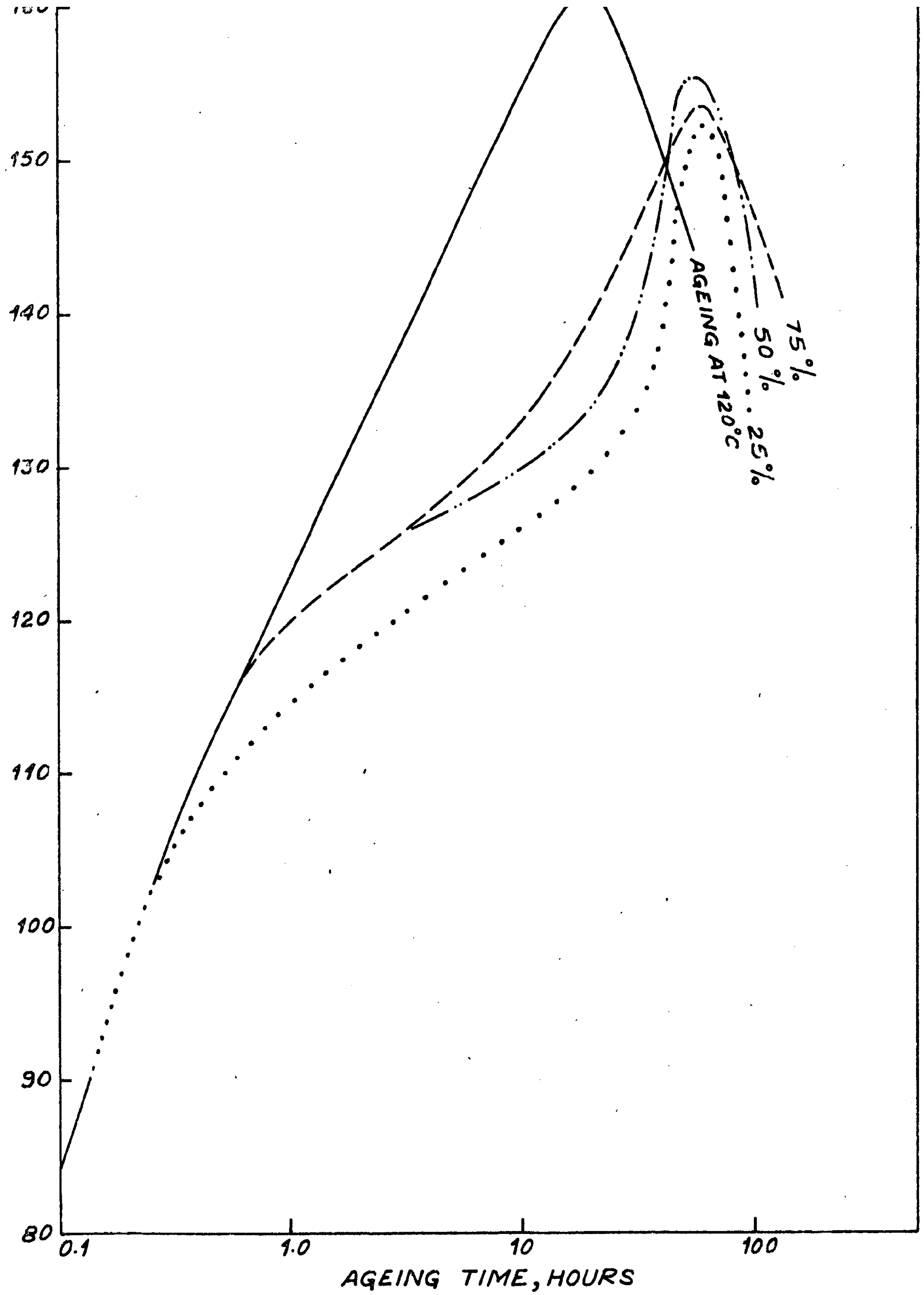


FIG.3 EFFECT OF PERCENTAGE PRE-AGEING AT 120°C ON AGEING AT 10

observed that percentage pre ageing does not have considerable effect on peak hardness values on ageing at 105°C. The peak hardness values are marginally reduced due to pre ageing. Reduction of peak hardness is about 4 pct. from 161 to 153 VPN. Time to reach peak hardness is reduced from 58 to 55 hours which is also marginal. Reduction in time is about 5 pct.

Fig. 4 shows the effect of percentage pre ageing at 135°C on final ageing at 105°C. In contrast to pre ageing at 120°C, the effect of pre ageing at 135°C has decreased the peak hardness value by 10 pct. (Table 5) from 161 to 143 VPN. 25 pct. pre ageing at 135°C has hardly any effect on time to reach peak hardness where as 50 pct. and 75 pct. pre ageing reduced time from 58 to 45 hours. Reduction in time is about 22 pct. The peak hardness values of 50 pct. and 75 pct. pre aged samples are almost same on final ageing. So from hardness point of view 50 pct. pre ageing is economical. pre ageing at 135°C forms comparatively coarser precipitate. Pre ageing at 120°C produces comparatively finer precipitate. When the pre aged samples are aged at 105°C the existing precipitated particles act as nuclie during further precipitation. Consequenoly the distribution of precipitates produced by double ageing treatment at 120°C followed by 105°C is finer as compared with a double ageing treatment of 135°C and 105°C. This explains the lower peak hardness value of 135° - 105°C combination as compared with 120°C - 105°C combination.

The proportion of intermediate precipitate in samples preaged at 135°C is more as compared with samples pre aged at

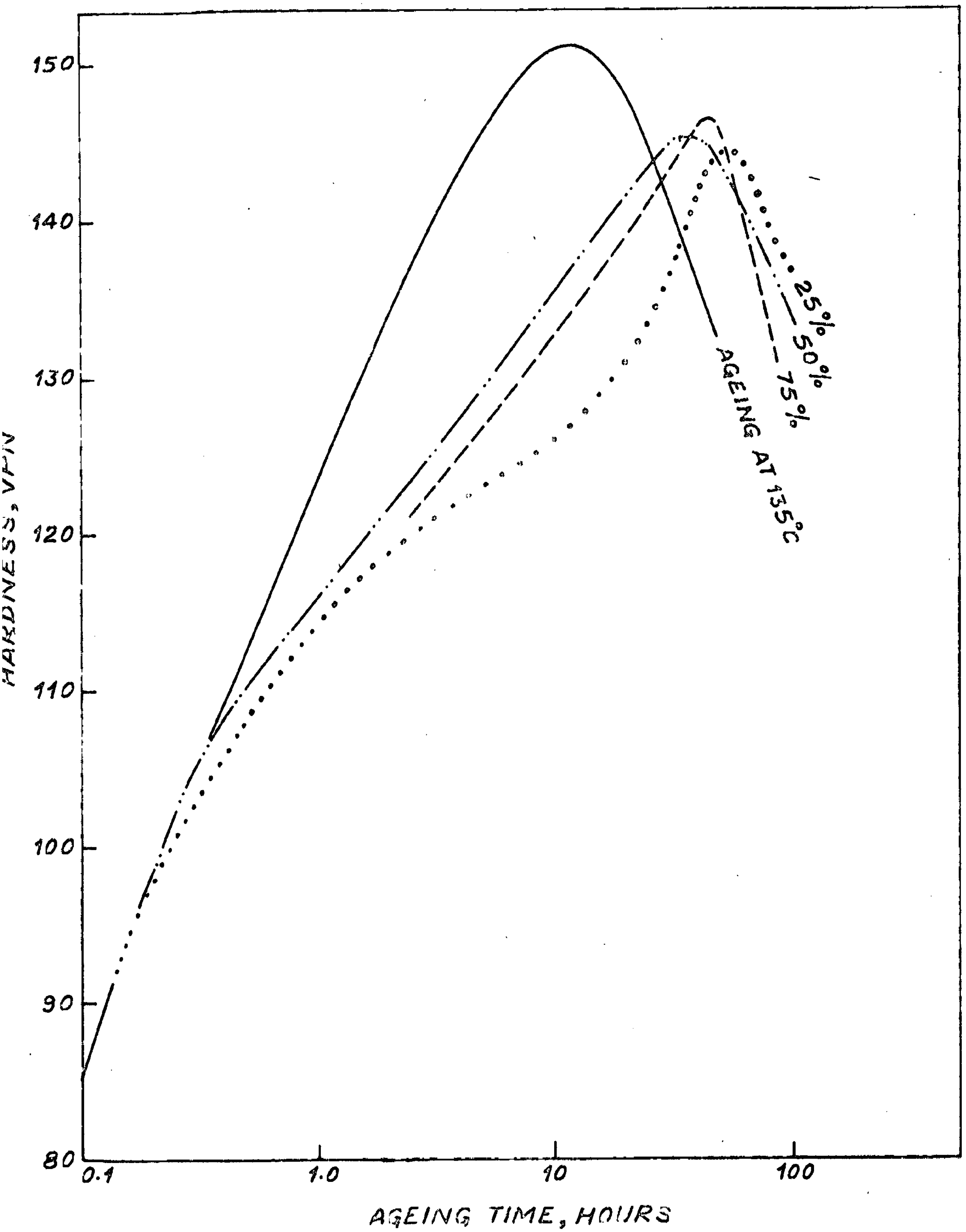


FIG.4 EFFECT OF PERCENTAGE PRE-AGEING AT 135°C ON AGEING AT 105°

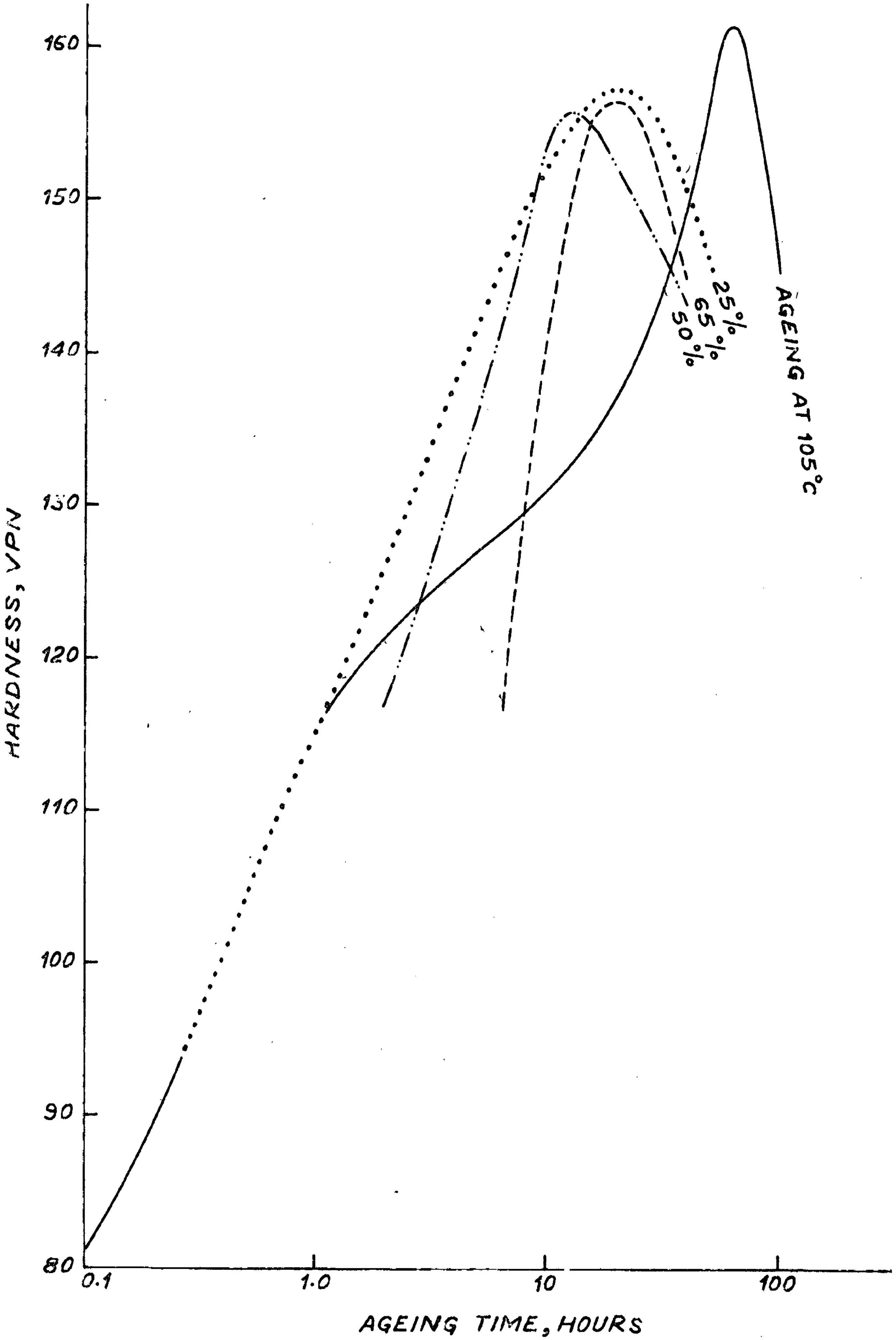
120°C Higher the amount of intermediate precipitate lower will be the time required to complete precipitation on reageing because of better stability. This explains the greater reduction achieved in time to reach peak hardness in 135°C - 105°C combination in contrast to 120°C - 105°C combination.

Figures 5 and 6 show the effect of pre ageing at 105°C and 135°C on final ageing at 120°C.

For 75 Pct. preageing at 105°C requires 20 hours which is time required to reach peak hardness at 120°C. So in this case the samples were pre aged to 65 pct.

It can be seen from the tables 6 and 7 obtained from figures 5 and 6 that percentage of pre ageing either at 105°C or 135°C has little effect on peak hardness value during final ageing. Table 6 shows the total time to reach peak hardness has decreased from 20 hours to 13 hours (reduction of time 35 pct.) during final ageing of 50 pct. pre aged samples at 105°C. Similarly 75 pct. pre ageing at 135°C has decreased time to reach peak hardness (Table 7). The drop in peak hardness is about 3 pct. from 160 VPN 156. VPN

Figures 7 and 8 show the effect of percentage pre ageing at 105°C and 120°C respectively on final ageing at 135°C. Pre ageing at either temperature has little effect onpeak hardness value (tables 8 and 9). The drop in peak hardness value is about 2 pct. and percentage decrease in time is about 30 pct. in samples preaged 50 pct. at 105°C. Where as reduction in time is about 24 pct. in


HARDNESS, VPN
160
150
140
130
120
110
100
90
80
0.1
1.0
10
100
AGEING TIME, HOURS
25%
65%
50%
AGEING AT 105°C

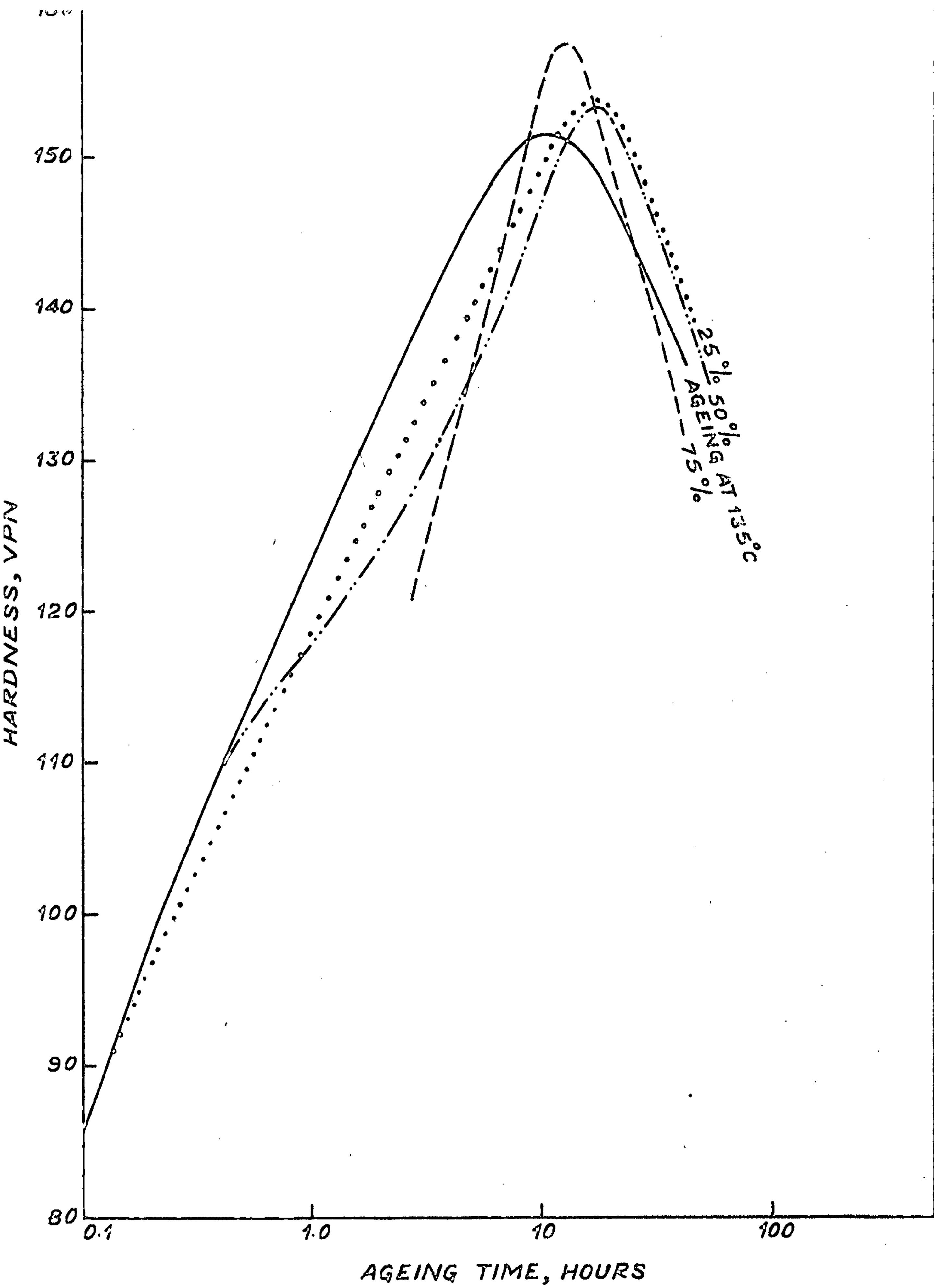
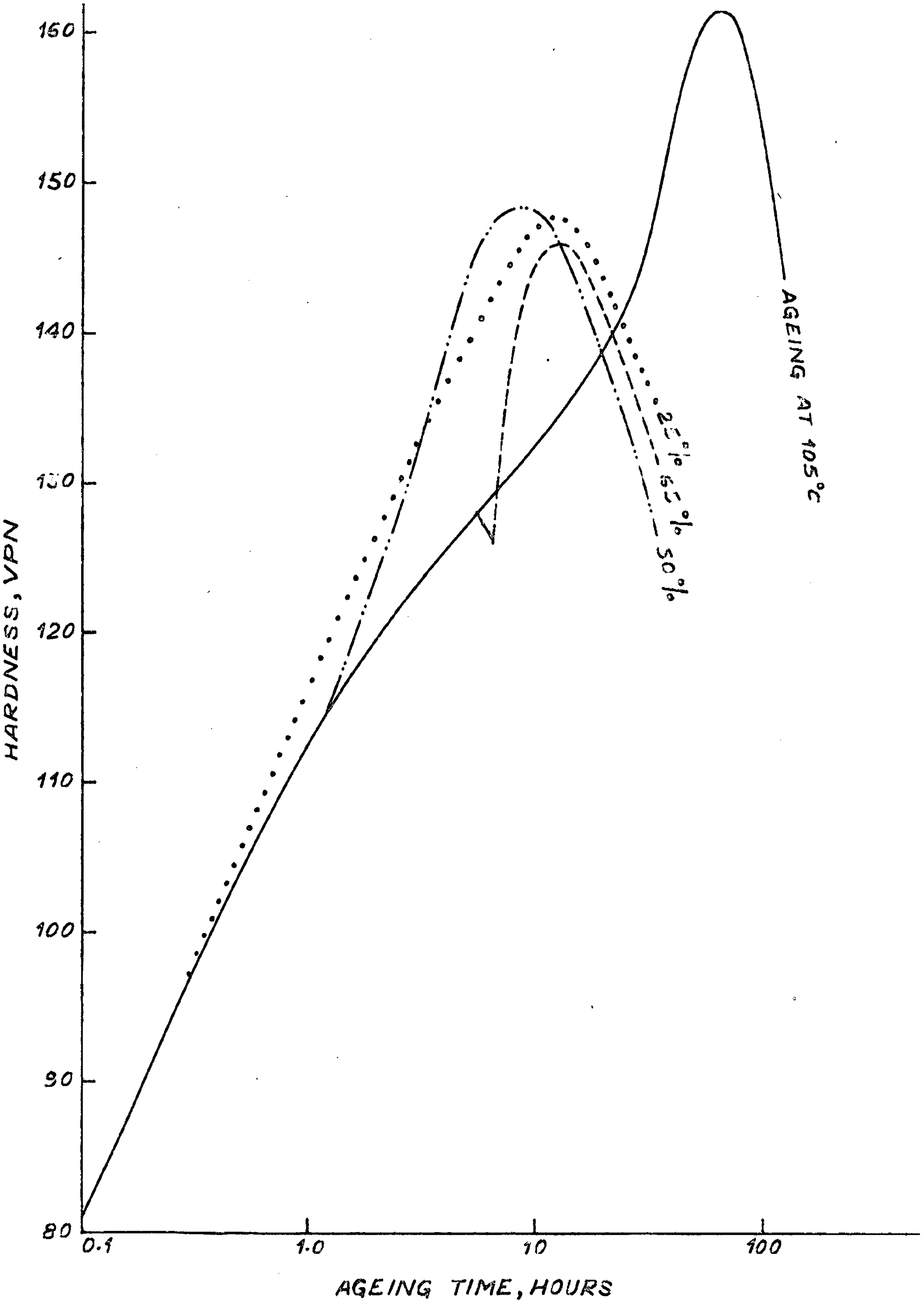


FIG.6 EFFECT OF PERCENTAGE PRE-AGEING AT 135°C ON AGEING AT 120

HARDNESS, VPN
160
150
140
130
120
110
100
90
80
0.1
1.0
10
100
AGEING TIME, HOURS
AGEING AT 105°C
25%
65%
50%

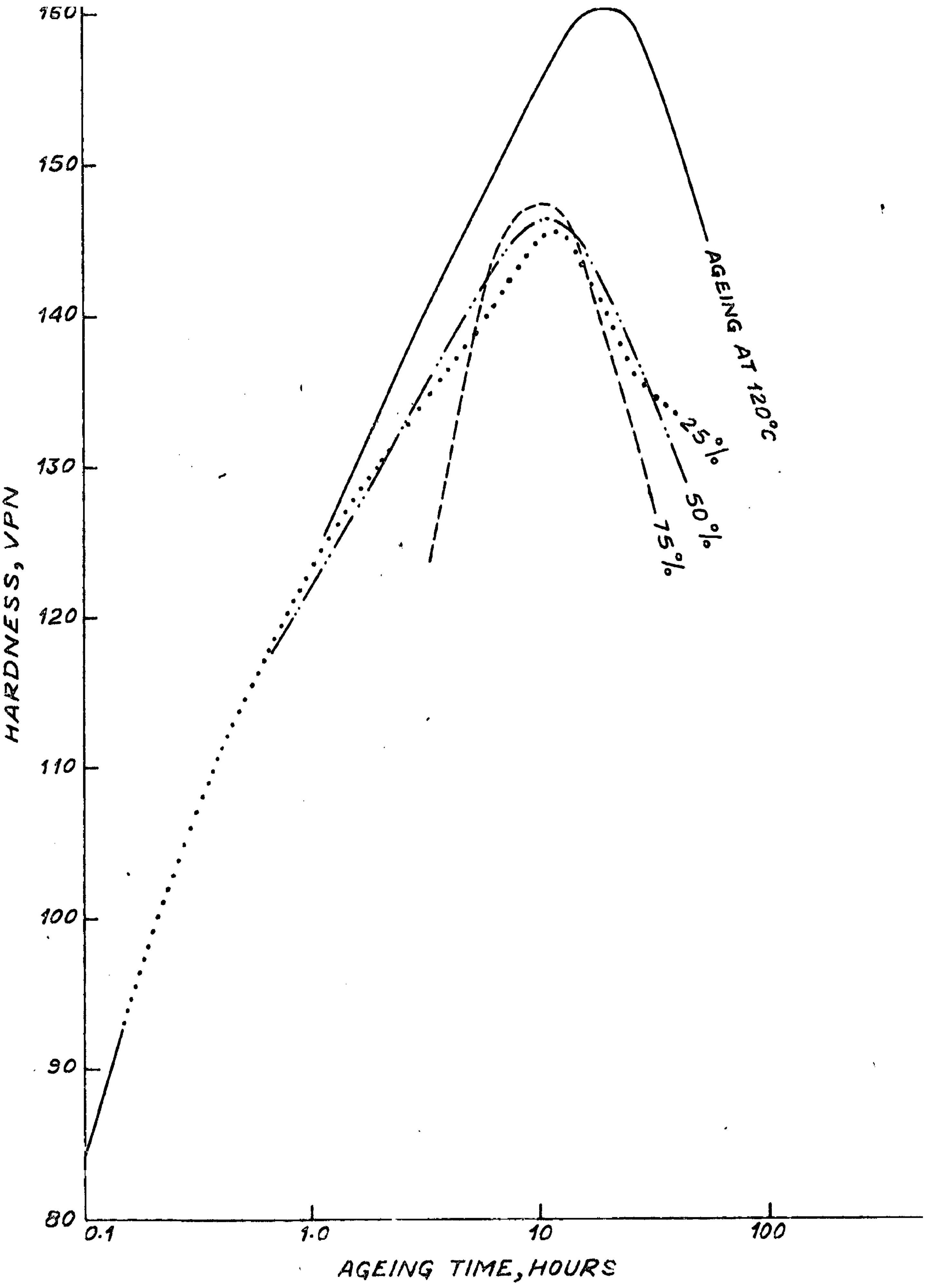


FIG.8 EFFECT OF PERCENTAGE PRE-AGEING AT 120°C ON AGEING AT 135°C.

samples preaged 75 pct. at 120°C.

It can be seen from the figures 3 to 8 that pre ageing of 25 pct. and 50 pct. result in continuous increase in hardness on final ageing except 50 pct. pre ageing at 105°C followed by ageing at 120°C. In this case neither increase nor drop has been observed in the initial stages of final ageing fig. 5. Where as pre ageing 65 pct. (or 75 pct. as the case may be) result in an initial drop in hardness before further hardening takes place on final ageing.

The following points can be concluded from the results:

(1) Pre ageing at 120°C has little effect on peak hardness value on ageing at 105°C where as pre ageing at 135°C has negative effect on peak hardness value. Where as in other cases pre ageing has no considerable effect on peak hardness.

(2) Pre ageing, in all the cases, decreases time required to get peak hardness.

(3) Maximum time can be saved by pre ageing 50 pct. at 105°C or 75 pct. pre ageing either at 120°C or 135°C on final ageing.

Table 10 and 11 show the effect of percentage plastic deformation of preaged samples 50 pct. at 105°C and 75 pct. at 135°C respectively on ageing at 120°C derived from figures 9 and 10.

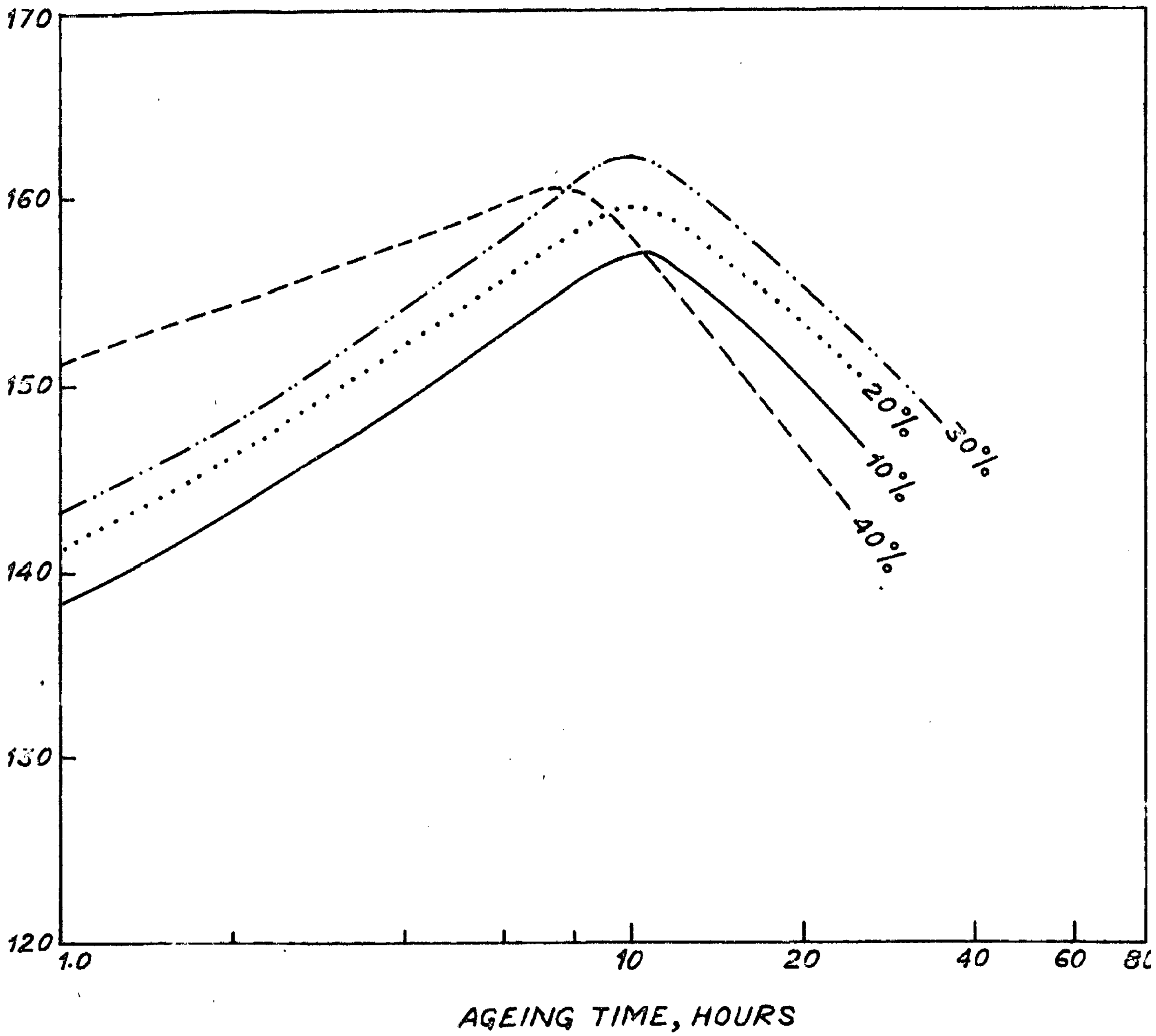


FIG.9 EFFECT OF PERCENTAGE DEFORMATION ON AGEING AT 120°C OF SPECIMENS PRE-AGED AT 105°C

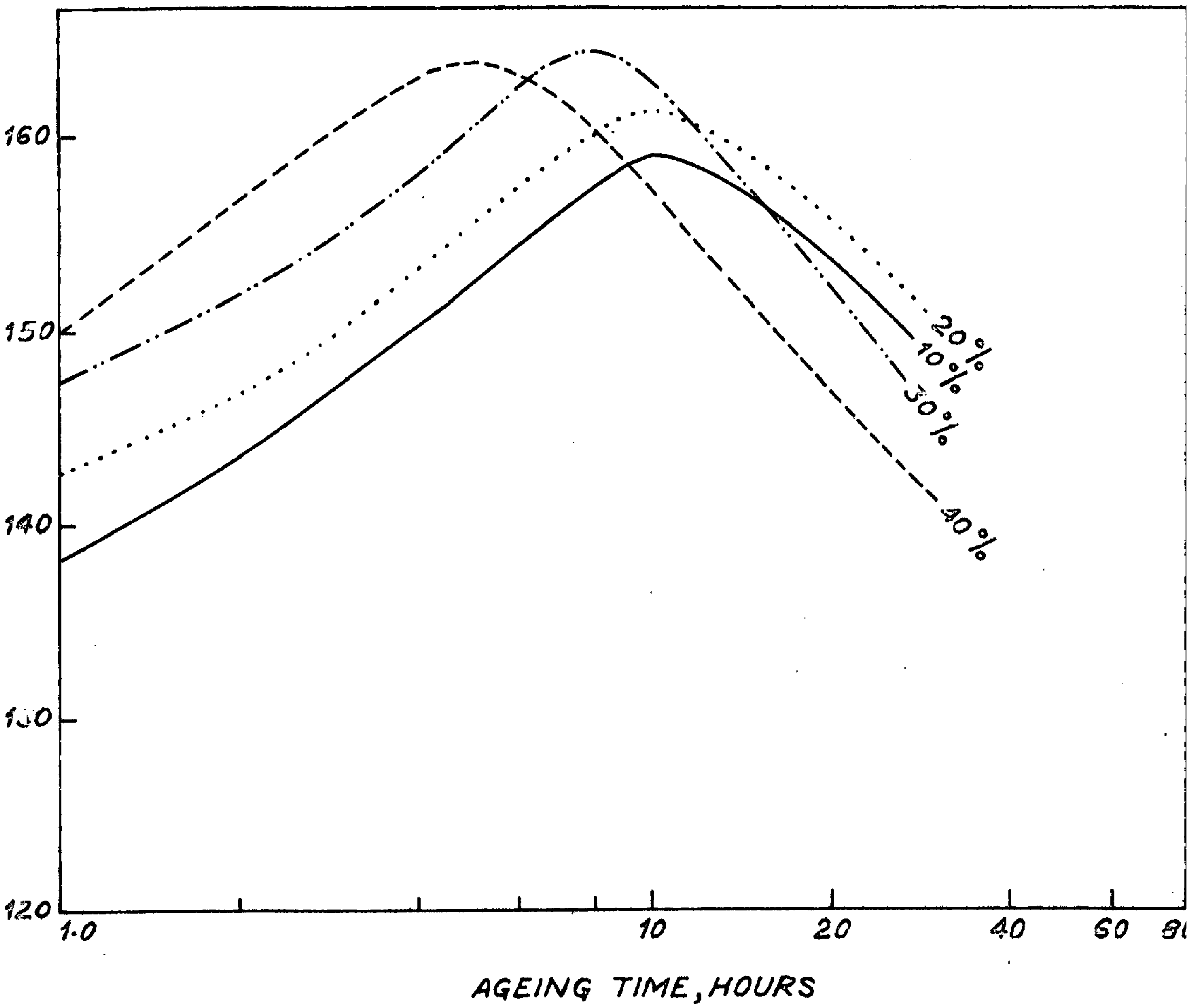


FIG. 10 EFFECT OF PERCENTAGE DEFORMATION ON AGEING AT 120°C OF SPECIMENS PRE-AGED 75% AT 135°C.

It can be seen from table 10 that percentage plastic deformation has little effect on time to reach peak hardness upto 30 pct. (reduction of time from 13 to 11 hours) Total time to reach peak hardness is same upto 30 pct. There is drastic decrease in time to reach peak hardness on reageing 40 pct. deformed samples.

Marginal decrease in time has been observed upto 20 pct. (table 11) from 13 to 12 hours. Time to reach peak hardness is almost same on reageing 10 pct. and 20 pct. deformed samples. Maximum decrease in time has been observed on reageing of 40 pct. deformed samples (13 to 7 hours).

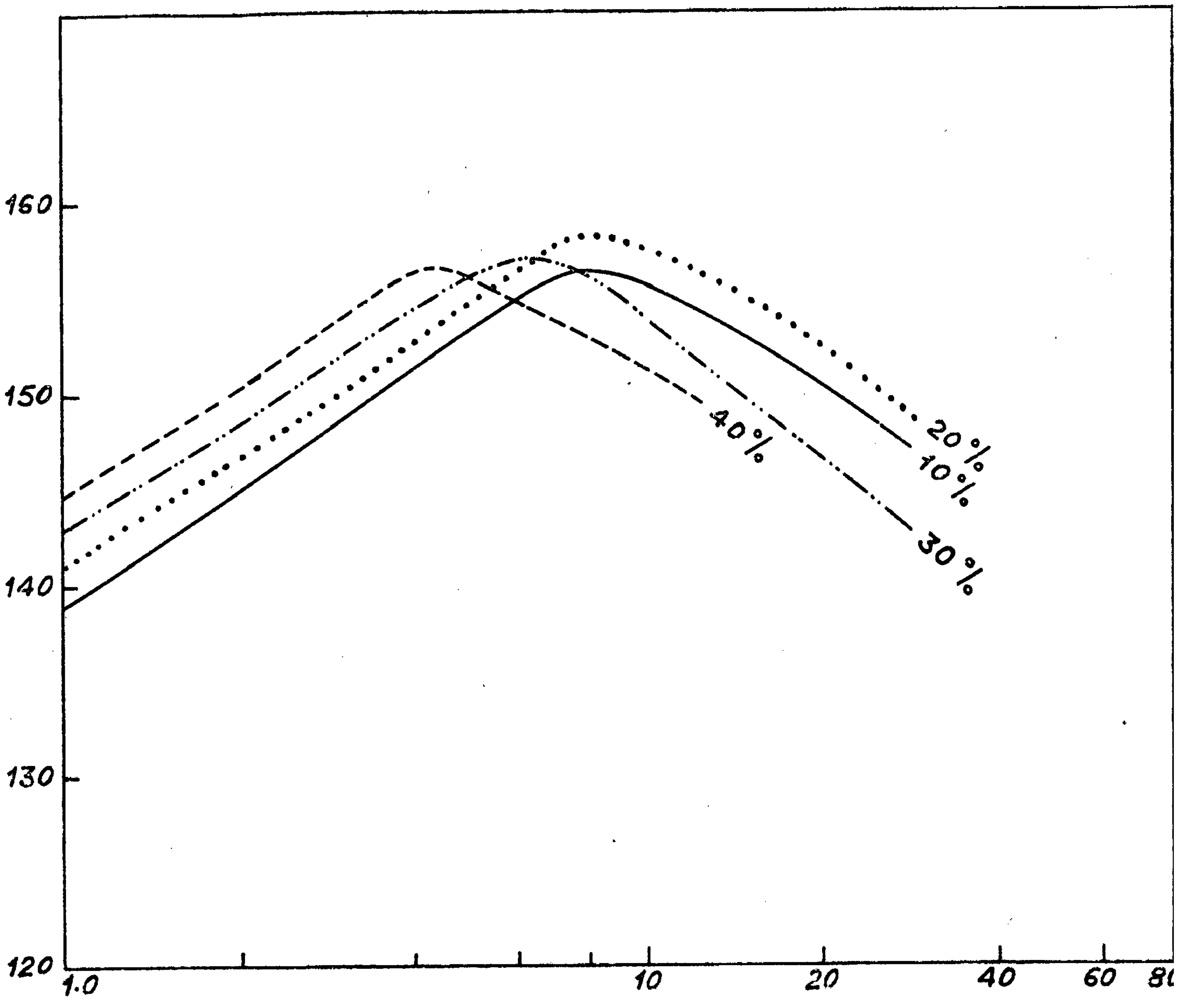
It can be seen from the tables 10 and 11 that the peak hardness value increases with increase of deformation upto 30 pct. But further deformation decreases the peak hardness slightly.

The maximum peak hardness has been observed on reageing 30 pct. deformed samples.

Tables 12 and 13 show the effect of percentage Plastic deformation of preaged samples 50 pct. at 105°C and 75 pct. at 120°C respectively on ageing at 135°C. (fig 11 and 12)

It can be seen from the tables that there is no reduction in time to reach peak hardness upto 20 pct. Beyond this the time decreases with increase of deformation.

The peak hardness increases with increase of deformation upto 20 pct. when the deformation is increased, little drop in



AGEING TIME, HOURS

FIG.11 EFFECT OF PERCENTAGE DEFORMATION ON AGEING AT 135°C OF SPECIMENS PRE-AGED 50% AT 105°C.

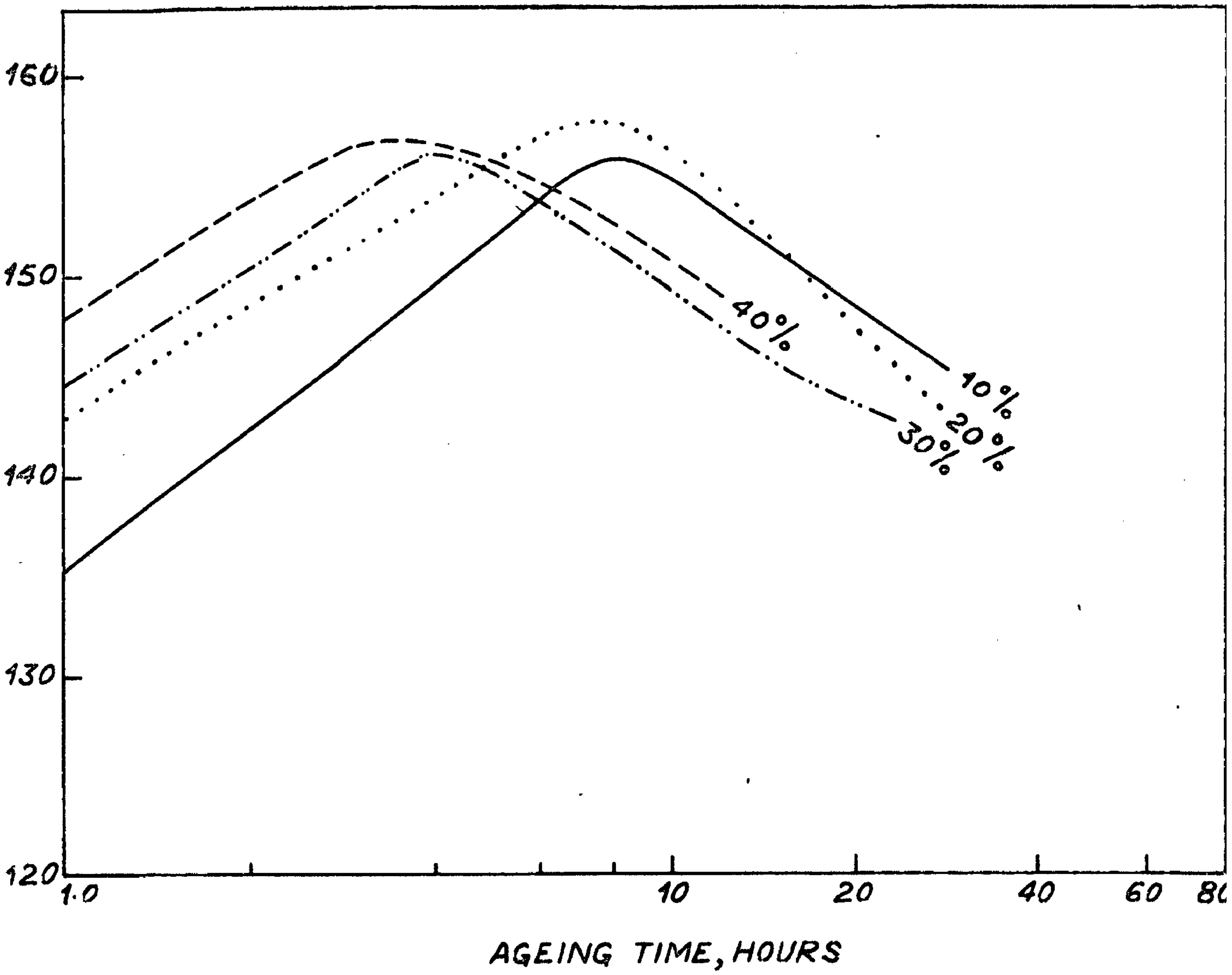


FIG. 12 EFFECT OF PERCENTAGE DEFORMATION ON AGEING AT 135°C OF SPECIMENS PRE-AGED 75% AT 120°C.

peak hardness value has been observed. The amount of increase in peak hardness is however marginal because the in this the precipitate by itself is finely distributed.

Increased peak hardness is due to dislocations introduced by cold work which act as potential sites and results in finer distribution of precipitate particles.

The fact that time to reach peak hardness is same on ageing of deformed samples upto 20 pct (or 30 pct. as the case may be) can be explained as follows. Dislocations produced by plastic deformation act as nucleation sites for the intermediate precipitate. They also act as sinks for vacancies. The presence of dislocations increases nucleation rate for intermediate precipitate and decreases the growth rate of zone formation. If one compensates the other then there will not be any reduction in time by increase of plastic deformation.

When the deformation is increased, the material becomes heavily cold worked and result polygonisation of dislocations and hence peak hardness is reduced on reageing. This explains a drop in peak hardness on ageing of 40 pct. (or 30 pct. as the case may be).

This effect is maximum in case of reageing at 135°C when compared to reageing at 120°C.

The following points can be concluded from the results:

1. Maximum peak hardness is observed in 30 pct. deformed samples on reageing at 120°C and in 20 pct. deformed

samples on reageing at 135°C.

2. Time to reach peak hardness is same for the samples deformed upto 20 pct. (or 30 pct. as the case may be) on reageing at any temperature.

3. Maximum time can be saved on reageing 40 pct. deformed samples.

Table: 14

Ageing Temp. 0_c	Percentage ageing	U.T.S. Kgs/mm^2	Percentage Elongation	Percentage Reduction
120	80(4 hours)	27.5	25	37.5
120	90(13 hours)	38.5	14	27
120	100(20 hours)	50	12	10
120	110(30 hours)	44.5	10	3.4
120	120(40 hours)	43.5	9.2	1/.9

Table 14 shows effect percentage og ageing at 120°C on tensile properties. It can be seen that maximum strength has been observed on ageing at 120 for 20 hours. By increasing the percentage of over ageing the strength and ductility both decreases over ageing results coarser precipitate particles and precipitate becomes in coherent. Because of coarse precipitate the strength of the alloy decreases, ductility decreases due to incoherent precipitate. Several workers suggested over ageing followed by plastic defomation and reageing gives optimum properties at room temperature.

Table: 3

Effect of ageing temperature on peak hardness.

Ageing Temp 0_c	Total time to Reach Peal hardness (HOURS)	Peak hardness VPN	Percent increase
105	58	161	130
120	20	160	130
135	13	151	115.7

Table: 4

Effect of percentage preageing at 120°C on time to reach peak hardness and peak hardness on final ageing at 105.

Pct.pre age	Total time to reach peak (HOURS)	Peak value Hardness VPN
0	58	161
25	55	153
50	55	155
75	55	153

Table: 5

Effect of percentage pre age at 135°C on time to reach peak hardness and peak hardness on final ageing at 105°C.

Pct.pre age	Total time to reach peak hardness (HOURS)	Peak hardness VPN
0	58	161
25	57	143
50	45	145
75	45	146

Table: 6

Pct.pre age	Total time to reach peak (HOURS ime)	Peak hardness VPN at 5 Kgs.
0	20	160
25	20	157
50	13	155
*65	19	156

Effect of percentage preageing at 105°C on time to reach peak hardness and peak hardness on ageing at 120°C.

* For 75 pct. pre ageing at 105°C itself requires 20h which is time required to reach peak hardness at 120°C. So 65 pct. pre ageing has given at 105°C.

Table: 7

Percent pre ageing	Total Time to reach peak (Hours)	Peak hardness value
0	20	160
25	19	155
50	18	153
75	13	156

Effect of percent pre ageing at 135° on time to reach peak hardness and peak hardness on ageing at 120.

Table: 8

Pct"pre age	Total time to peak reach (Hours)	Peak hardness value VPN
0	13	150
25	12	147
50	8-1/2	147
65	12-1/2	145

Effect of percentage preageing at 105° on time to reach peak hardness and peak hardness on ageing at 135°C.

Table: 9

Pct. pre age	Total time to reach peak (Hours)	Peak hardness VPN
0	13	150
25	11-1/2	145
50	10-1/2	146
75	10	147

Effect of percentage pre age at 120° on time to reach peak hardness and peak hardness value on ageing at 135°C.

Table: 10

Pct. Deforma-tion.	Total time to reach peak (Hours)	Peak hardness VPN
0	13	155
10	12	156
20	11	159
30	11	162
40	9	160

Effect of percent deformation of 50 pct. pre aged samples at 105°C on time to reach peak hardness and hardness values on ageing at 120°C.

Table: 11

Pct. Deformation	Total time to reach peak (Hours)	Peak hardness VPN
0.	13	156
10	12	159
20	11-50	161
30	10	165
40	7	164

Effect of pct. deformation of 75 pct. pre aged at 135°C on time to reach peak hardness and peak hardness value on ageing at 120°C.

Table: 12

Pct. Deformation.	Total time to reach peak (Hours)	Peak hardness value VPN
0	8-1/2	147
10	9	156
20	9	158
30	7	157
40	5	156

Effect of pct. deformation of 50 pct. preaged at 105°C on time to reach peak hardness and peak hardness values on ageing at 135°C.

Table: 13

Pct. Deformation	Total time to reach peak (Hours)	Peak hardness VPN
0	10	148
10	10	155
20	10	157
30	6	156
40	5	156

Effect of pct. deformation of 75 pct. pre aged at 120° on time to reach peak hardness and peak hardness on ageing at 135°.

5 CONCLUSIONS

1. The optimum ageing treatment for this alloy is ageing at 120°C for 20 hours.

2. Two stage ageing reduces the overall time for full hardening with little drop in peak hardness value.

3. A slight increase in peak hardness has been observed on reageing of preaged and deformed samples.

4. Effect of percentage deformation is found to increase with amount of cold work. Effect is observed to be maximum at 30 pct. and 20 pct. cold work on reageing at 120°C and 135°C respectively.

SUGGESTION FOR FUTURE WORK:

1. It is evident from the studies of polmear that Ag addition has distinct effect on Al - Zn - Mg and Cu alloys. So the same work can be extended to Al - Zn - Mg - Cu - Ag.

2. Present work can be extended to see the influence of Multiple ageing on mechanical properties.

3. To present work can be extended to see the influence of thermomechanical treatment of fatigue and other properties.

4. Transmission electron microscopic studies may be carried out to judge the effect of multiple ageing and thermomechanical treatment.

5. Staley has developed new alloy x 70 50 which has highest strength and better corrosion resistance than Al 7075. Effect of multiple ageing and thermomechanical treatment can be studied for the alloy 7050.

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