

Chapter 5 Discussions

5.1 Relationship between V_γ and V and C Content in As-hardened State

Relationship between V_γ and V and C content for the specimens hardened from the austenitizing temperatures of 1273 K and 1373 K are shown in Fig. 5-1 and Fig. 5-2, respectively. The V_γ decreases as the V content increases in a series of specimens with different C content. In the case of 1273 K austenitizing, the V_γ is less than 2% in 0.5%C-specimens. In 1.0%C-specimens, V_γ decreases from 14% in 1%V specimen to 1% in 3%V specimen. The V_γ in the 1.5%C-specimens decrease gradually from 34% to 14% as the V content increases from 1% to 3%. This is because an increase in V content promotes carbon consumption for formation of MC carbide and then the amount of carbon dissolved in the austenite matrix decreases. The specimen quenched from 1373 K takes a similar behavior for V_γ to the specimen hardened from 1273 K. However, the V_γ in every specimen increases because more C and V dissolve in the matrix by increasing of austenitizing temperature and there 6% V_γ remains even in 0.5%C-1%V specimen. This phenomenon can be considered from the viewpoint of M_s temperature. In low-alloyed steels, it is well known that the M_s temperature changes by the alloying elements and the following equation (5.1) has been proposed¹³⁾.

$$\begin{aligned} M_s (\text{°C}) &= 550-361x(\%C)-39x(\%Mn)-35x(\%V)-20x(\%Cr) \\ &\quad -17x(\%Ni)-10x(\%Cu)-5x(\%Mo+\%W)+15x(\%Co) \\ &\quad +30x(\%Al) \qquad \qquad \qquad \text{-----}(5.1) \end{aligned}$$

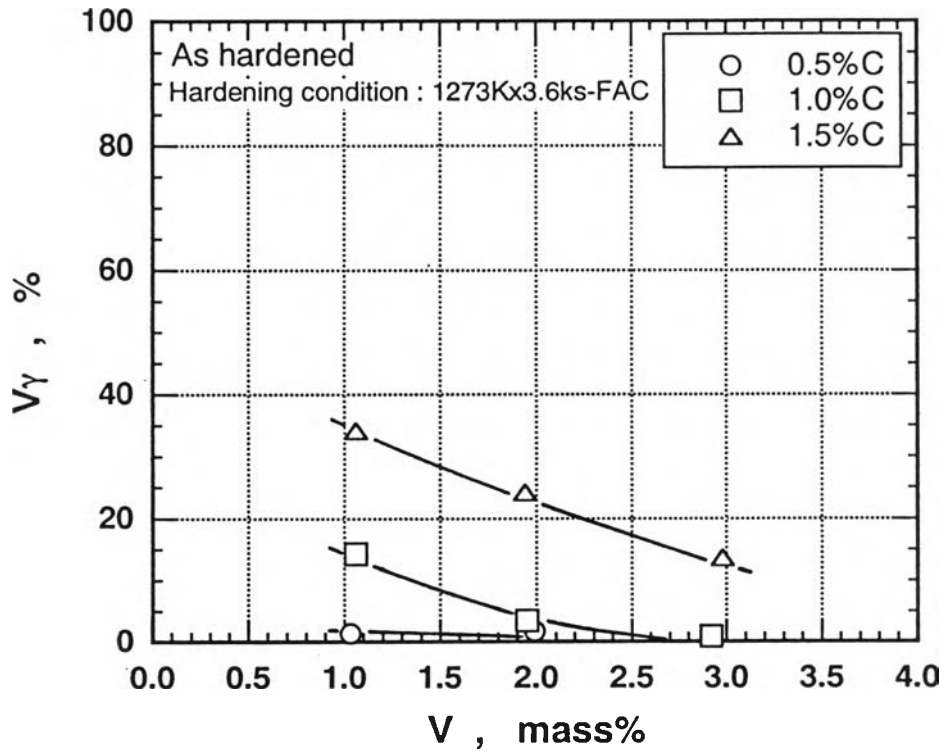


Fig. 5-1 Relationship between volume fraction of retained austenite(V_{γ}) and V and C content of as-hardened specimens austenitized at 1273K.

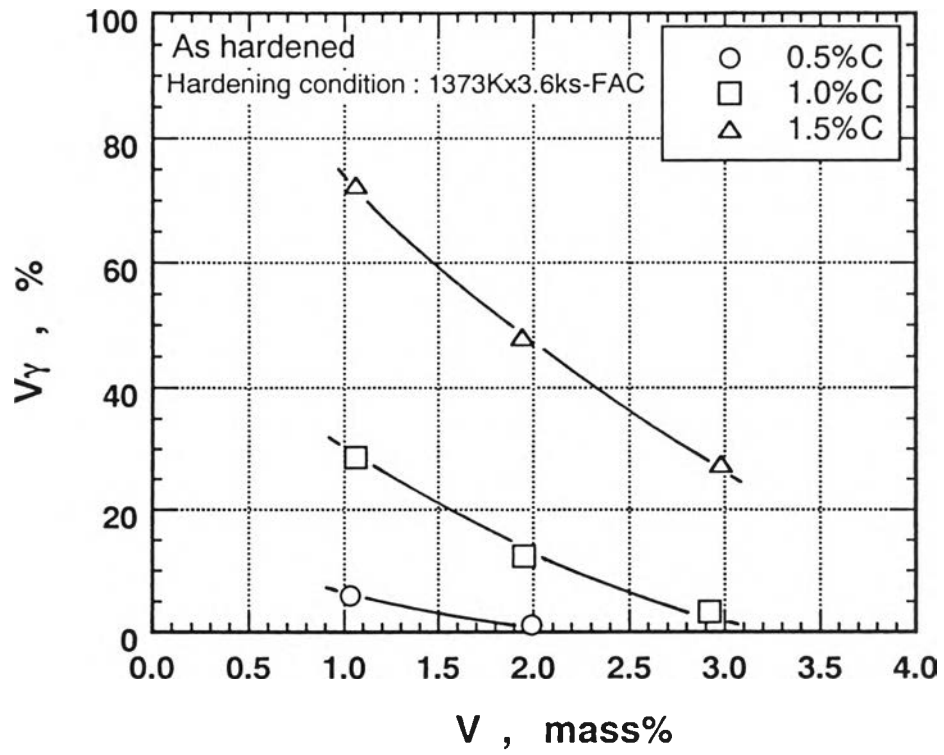


Fig. 5-2 Relationship between volume fraction of retained austenite(V_{γ}) and V and C content of as-hardened specimens austenitized at 1373K.

Though the multi-component cast irons used for this study have eutectic carbides which form due to the combination of carbide forming elements with carbon, the transformation of matrix will depend on the alloy concentration dissolved in the matrix. Therefore, the variation Ms temperature is possibly estimated using the equation (5.1) if the concentration of elements including carbon in the matrix can be measured accurately. It can be said from the above equation that the increase of V and C content as well as that of austenitizing temperature promote the V_{γ} .

5.2 Relationship between Hardness and V and C Content in As-hardened State

Hardness is closely related to the retained austenite. It is known that the hardness increases with decreasing the V_{γ} and hardness of martensite itself becomes harder as the amount of carbon dissolved in the martensite increases. Then, relationship between the hardness and V content is obtained in every C%-specimen. The cases of 1273 K and 1373 K austenitizing are shown in Fig. 5-3 and Fig. 5-4, respectively. The relationships do not always have the same tendency in the specimens hardened from both austenitizing temperatures. This fact suggests that the hardness is greatly influenced by the hardness of martensite itself besides the V_{γ} .

As for the 1.0%C-specimens hardened from 1273 K shown by Fig. 5-3, the hardness decreases in spite of decreasing in the V_{γ} . In 0.5%C-specimens, the hardness decreases as the V content increases. The following reason can be considered. In 1.0 %C-specimens, the V_{γ} are 14% in 1%V, 4% in 2%V and 1.0% in 3%V specimens. Therefore, the V_{γ} in 2% and 3%V specimens influence little on the hardness, and instead, the hardness is mainly affected by the hardness of martensite. In the 1%V specimen with 14% V_{γ} , it is estimated that the hardness may be affected by

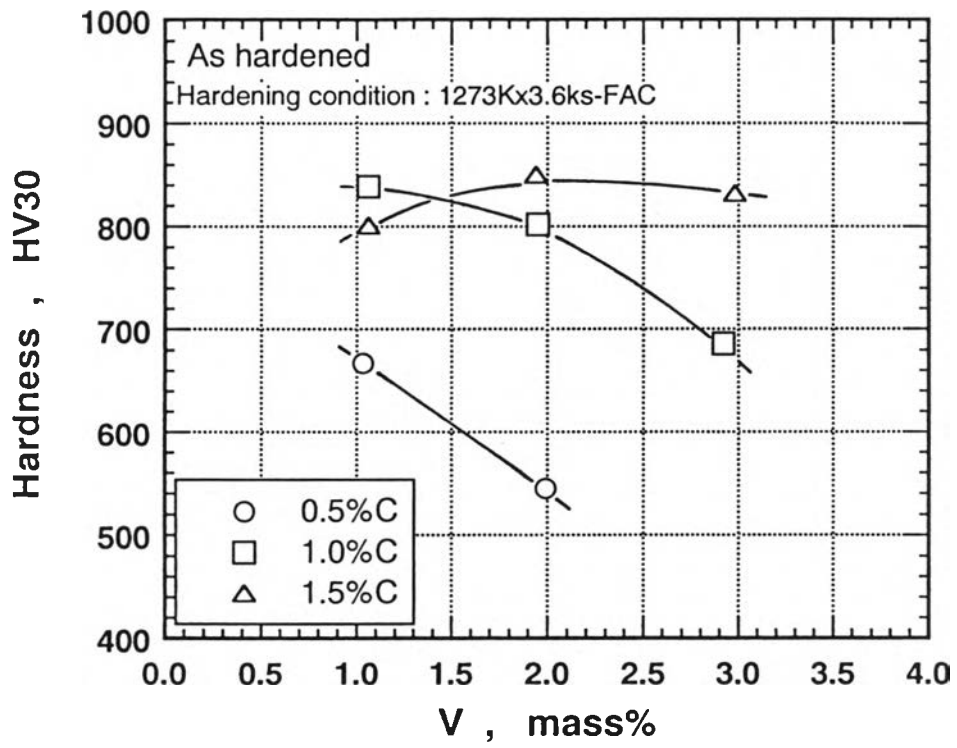


Fig. 5-3 Relationship between hardness and V and C content of as-hardened specimens austenitized at 1273K.

the retained austenite and it decreases for the V_γ value. If the V_γ is small amount like the other two specimens, however, the hardness can increase much higher. It is also estimated that the reason why the hardness decreases with increasing the V content in spite of extremely low V_γ is the decrease in hardness of martensite due to the less dissolution of carbon in martensite. In 1.5%C-specimens with V_γ ranging from 34% to 14%, however, it can be said that the hardness are influenced by both V_γ and hardness of martensite. The hardness of 1% and 2%V specimens is expected to go down remarkably because of high V_γ like 34% and 24%, but the hardness settles down at approximately same degree of hardness of 3%V specimen with 14% V_γ by the martensite with more dissolved carbon.

Next, the results shown in Fig. 5-4 for 1373 K austenitizing are discussed. The trend of 0.5%C-specimens is considered to be same as the trend in 1273 K austenitizing. Since V_γ is at most 6% in 1%V specimen, the hardness of martensite affects mainly on the total hardness and it falls down because less C dissolves in the matrix with an increase in V content. In case of 1.0%C-specimens, the V_γ decreases from 29% to 3% with increasing V content and then the hardness is expected to rise. However, the decrease of C in the matrix brings the decrease in hardness of martensite. As for the 1%V specimen with 29% V_γ , the rise in hardness of martensite could compensate the descent of matrix hardness due to more V_γ . The hardness of 2% and 3%V specimens ought to become higher according to a decrease in V_γ associated with V content. Because the hardness of martensite lowers, however, it can be resumed that similar hardness are obtained in the 1.0%C-specimens with ranging V content from 1% to 3%. In 1.5%C-specimens, V_γ goes down from 73% to 28% as V content increases from 1% to 3%. In this case, the hardness is preferably influenced by V_γ and, therefore, the hardness increases with decreasing the V_γ .

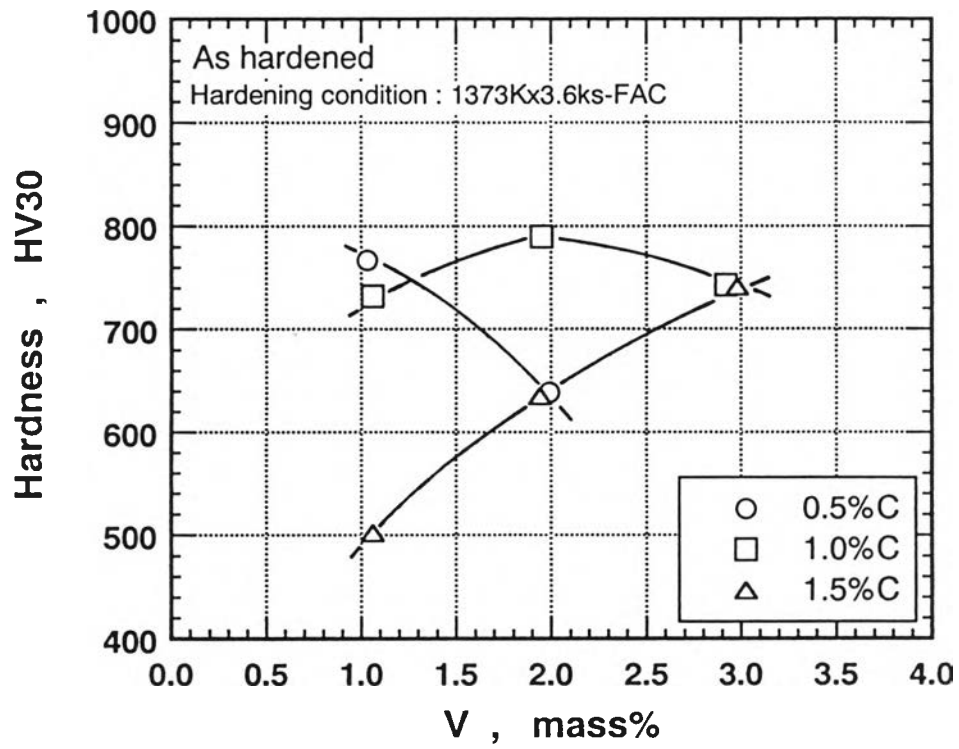


Fig. 5-4 Relationship between hardness and V and C content of as-hardened specimens austenitized at 1373K.

5.3 Relationship between Hardness and Volume Fraction of Retained Austenite in Tempered State

Macro-hardness of specimen is the sum of precipitated carbides and matrix hardness. In case of the specimens used for this experiment, the amount of precipitated carbides is small because of low C content and the hardness is greatly affected by matrix hardness that is also largely influenced by the V_γ . The relations of the macro-hardness and V_γ are obtained for all tempered specimens, and they are shown in Fig. 5-5 for 1273 K austenitized and Fig. 5-6 for 1373 K austenitized specimens. In 1273 K austenitizing, the hardness of the specimens with 0% V_γ range widely from 500 HV to 840 HV and those of 0.5%C-1%V specimen are mostly scattered in the range of 600 HV to 660 HV. The hardness of 0.5%C-2%V specimen exists in the lowest part less than 600 HV. In the range of the same family, the specimens with high hardness are the ones in which retained austenite have just decomposed fully and those in the part of lower hardness are the ones that have over-tempered. The hardness decrease from the maximum values which are obtained at 1-2% V_γ roughly in proportion to the increase in V_γ , and the decreasing rate is similar in the family of specimens. The maximum absolute values of the hardness differ depending on the chemical composition of the specimens, the more the C content and the lower the V content at the same C level, the more the hardness. It should be noted that the hardness is different at the same level of V_γ .

In case of 1373 K austenitizing, the relations of V_γ and hardness display about the same tendency as those in 1273 K austenitizing. Since more alloying elements dissolve in the matrix at higher austenitizing temperature like 1373 K, however, the V_γ in as-hardened state increases and the tempered hardness rises more than those in 1273 K austenitizing. This fact is presumed that the decomposition of retained austenite may

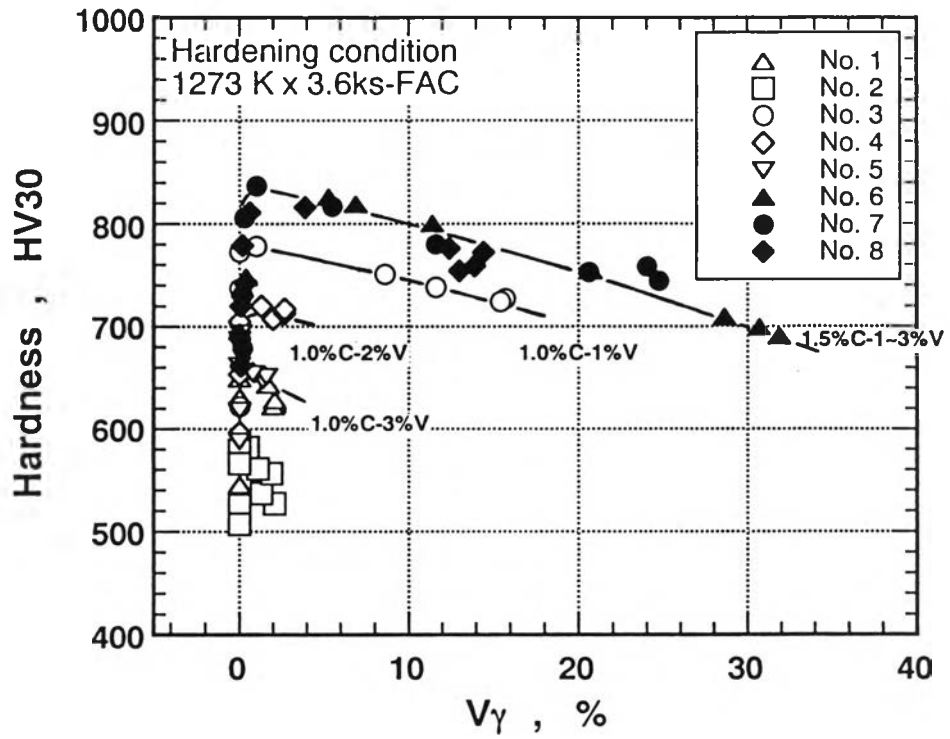


Fig. 5-5 Relationship between hardness and volume fraction of retained austenite of tempered specimens hardened from 1273K.

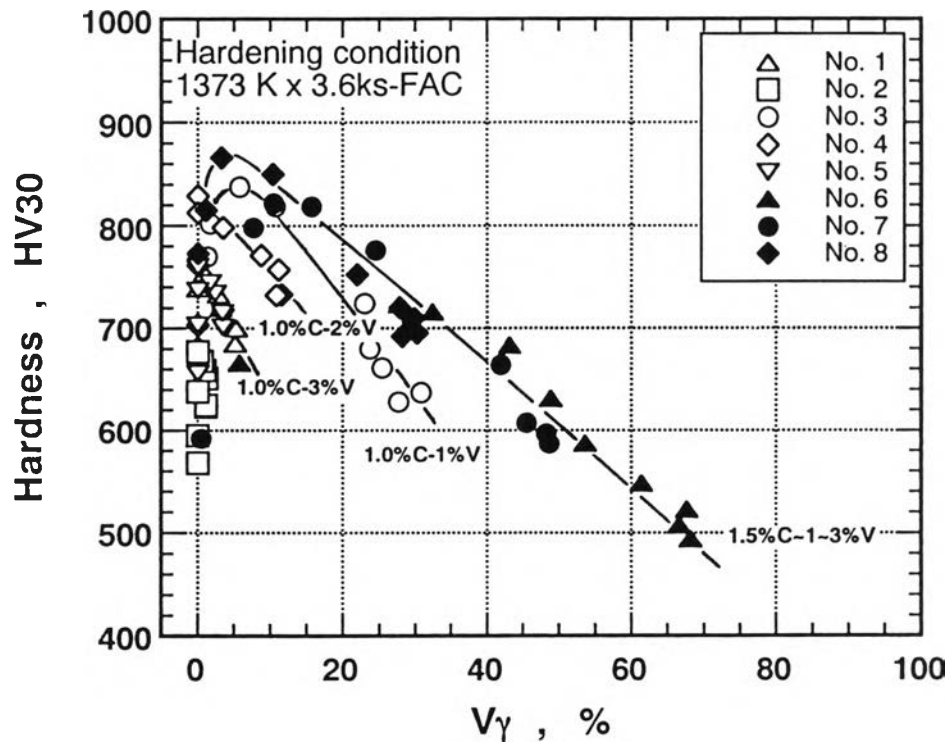


Fig. 5-6 Relationship between hardness and volume fraction of retained austenite of tempered specimens hardened from 1373K.

contribute remarkably to the increase of tempered hardness.

5.4 Correlation among Maximum Tempered Hardness, V and C Content and Carbon Balance

In general, Ms temperatures of multi-component white cast irons are lower and large amount of retained austenite exist in as-hardened state, and it results in low hardness. When they are used as an abrasion wear resistant component, therefore, it is necessary to make the matrix hard for wear resistance by heat treatment. Here, the maximum tempered hardness ($H_{T_{max}}$) was related to the austenitizing temperature, V and C content, and carbon balance (C_{bal}).

5.4.1 Relationship between Maximum Tempered Hardness and V and C Content

The effect of V content on $H_{T_{max}}$ is shown in Fig. 5-7 for 1273 K austenitizing and in Fig. 5-8 for 1373 K austenitizing. Though the absolute values of hardness are different, these relations resemble the same relations in as-hardened state. $H_{T_{max}}$ of specimens tempered after hardening from austenitizing temperature of 1273 K decrease proportionally with an increase in V content, and the more the C content, the more the $H_{T_{max}}$ at the same V content. In 1373 K austenitizing, on the other hand, $H_{T_{max}}$ go down in 0.5% and 1.0%C-specimens as V content rises, but $H_{T_{max}}$ of 1.5%C-specimens go up conversely.

Increase in hardness of special steels containing strong carbide formers like V and Mo by tempering can be carried out by the secondary precipitation of their special carbides from martensite, the decomposition of retained austenite and the transformation of destabilized retained austenite into martensite. From the relation of $H_{T_{max}}$ and V and C content

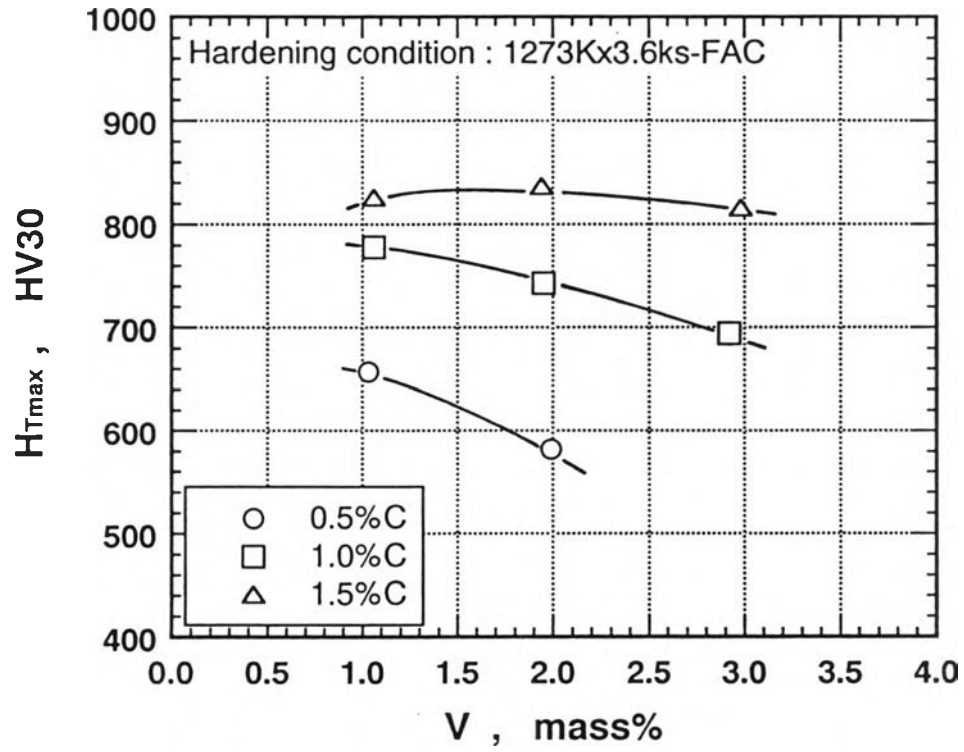


Fig. 5-7 Relationship between maximum tempered hardness(H_{Tmax}) and V and C content. (Hardened from 1273K)

(Fig. 5-7), the $H_{T_{max}}$ of 0.5% and 1.0%C-specimens austenitized at 1273 K decreases as V content increases. The retained austenite exists little in as-hardened 0.5%C-specimens (Fig. 5-1) and so the matrix is mostly martensite. The hardness of martensite itself lowers as V content increases because the amount of carbon dissolved in the matrix decreases. For this reason, only the precipitation of carbides from martensite contributes to the rise in hardness of 0.5%C-specimens. Therefore, the relation of $H_{T_{max}}$ and V content in the tempered state shows same tendency as the similar one in as-hardened state. As V_{γ} in as-hardened state of 1.0%C-1%V specimen is 14%, precipitation hardening due to the decomposition of austenite and the following transformation of the destabilized austenite into martensite can help to raise the hardness and, therefore, the $H_{T_{max}}$ is higher than those of 2%V and 3%V specimens. Over 2%V, $H_{T_{max}}$ decreases on account of the same reason as 0.5%C-specimens.

In 1.5%C-specimens, despite the fact that V_{γ} in as-hardened state changes from 34% to 14% as V content increases from 1% to 3%, V_{γ} at the $H_{T_{max}}$ is less than 5% in every specimen. So, both of decomposition of austenite and the following transformation into martensite and the precipitation of special carbides from martensite could contribute to the $H_{T_{max}}$. In this case, both effects appear remarkably in 1%V specimen with more V_{γ} in as-hardened state. However, 5% V_{γ} still exists in the 1%V specimen after tempering, though V_{γ} in tempered state of 2% and 3%V specimens are a little. The existence of the 5% V_{γ} reduces the hardness of 1%V specimen. In 2% and 3%V specimens, on the other side, the tempering of martensite with less C content leads to decrease in the hardness. Then, $H_{T_{max}}$ of 1%V specimen totally becomes about same hardness as the other two specimens.

As for the specimens hardened from 1373 K (Fig. 5-8), V_{γ} of 0.5%C-specimens range from 1% to 6%, and those at $H_{T_{max}}$ in the tempered specimens are almost 0%. This leads to the continuous decrease

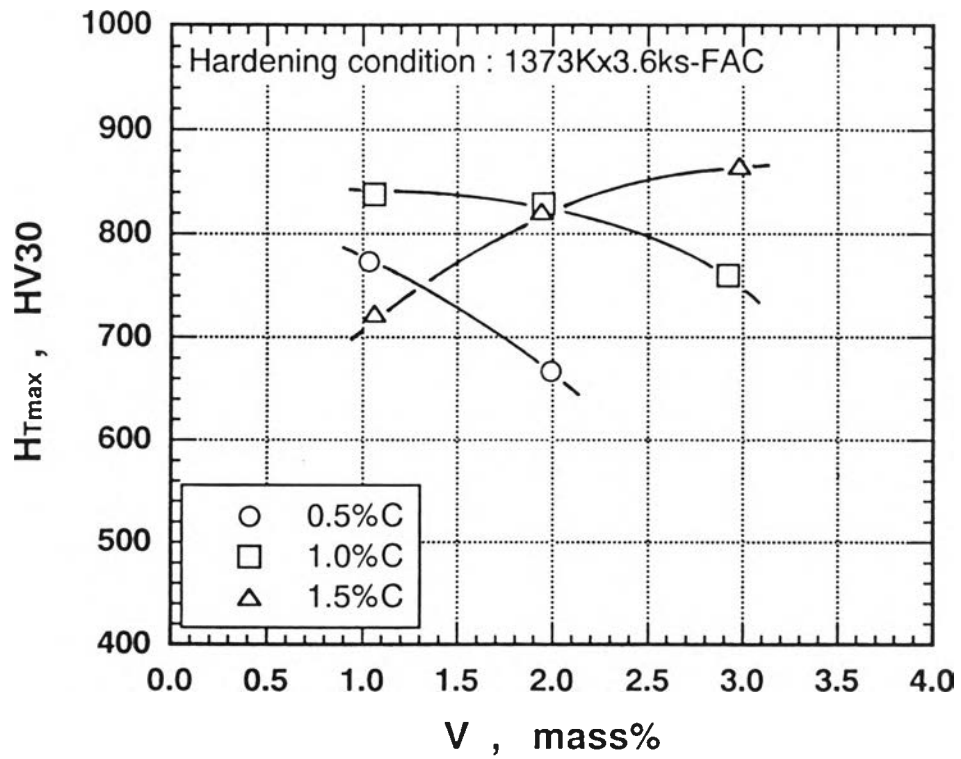


Fig. 5-8 Relationship between maximum tempered hardness(H_{Tmax}) and V and C content. (Hardened from 1373K)

in the hardness with V content due to mostly tempering of martensite. This reason can be explained by the same way described in case of 1273 K austenitizing. In 1% and 2%V specimens with 1.0%C which contain 29% and 12% $V\gamma$, $H_{T_{max}}$ is obtained owing to both hardening of the precipitation of special carbides from martensite and the decomposition of austenite accompanied with following martensite transformation. Particularly, the latter affects the increase of hardness more in such a 1%V specimen with higher $V\gamma$. Therefore, $H_{T_{max}}$ lowers as V content of the specimen increases. $V\gamma$ of 1.5%C-specimens in as-hardened state ranges in high levels from 73% in 1%V to 28% in 3%V specimens. When it is considered that the amount of martensite increases corresponding to the decrease in $V\gamma$, it is reasonable that the hardness increases as V content increases. In tempered state, however, considerably high amount of $V\gamma$ still exists in 1%V and 2%V specimens, 28% and 11%, respectively. This suggests that the decomposition of retained austenite was not enough to increase the hardness greatly. On the other side, less amount of martensite formed in as-hardened specimens with 1% and 2%V may not so much contribute to arise in the hardness. Instead, the austenite remained after tempering will rather acts to descend the tempered hardness much more. Then, $H_{T_{max}}$ rises as V content increases.

It is evident from above results that $V\gamma$ in as-hardened state is closely related to $H_{T_{max}}$ under the same condition of tempering. The $H_{T_{max}}$ is connected to the $V\gamma$ in as-hardened state and the relation is shown in Fig. 5-9. Regardless of the austenitizing temperature, $H_{T_{max}}$ rises as $V\gamma$ increases and gets to the maximum value at approximately 30% $V\gamma$ and then decreases. In the specimens with $V\gamma$ up to 30%, the $V\gamma$ values at which $H_{T_{max}}$ are obtained are almost 0%. Over 30% $V\gamma$, however, $V\gamma$ more than 5% still remain in the specimens and so $H_{T_{max}}$ decreases. It is clear that the alloys designing so as to exist 30% $V\gamma$ in as-hardened state can provide the maximum hardness after tempering regardless of the

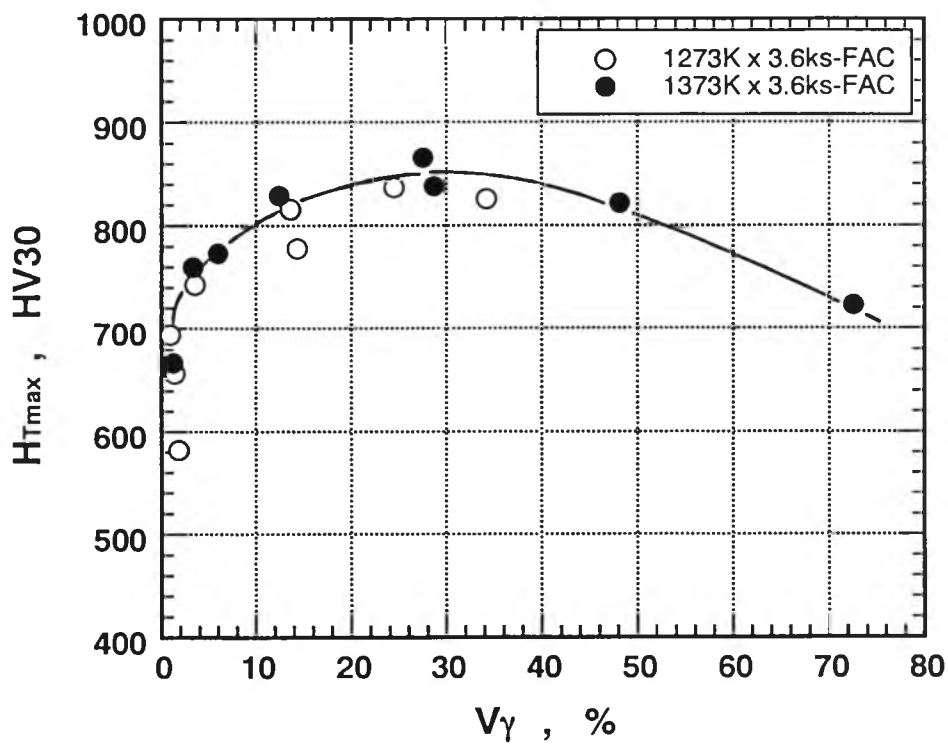


Fig. 5-9 Influence of volume fraction of retained austenite(V_γ) in as-hardened state on maximum tempered hardness(H_{Tmax}).

austenitizing temperature. One of the fulfilling properties for the cold work roll is the hardness more than 800 HV. In case that these multi-component white cast irons will be applied to the cold work rolls, the wide range of $V\gamma$ like 10%-50% is admitted to fulfill the required hardness if the same tempering condition is used. Even if the $V\gamma$ in as-hardened state is more than 50%, double or triple tempering will be able to reduce the $V\gamma$ down to nearly zero.

5.4.2 Relationship between Maximum Tempered Hardness and Carbon Balance

Basis of alloy designing of multi-component white cast iron is to take a parameter of the carbon balance (C_{bal}) into consideration. The C_{bal} determines not only the residual C content in the matrix but also phase transformation behavior and, after all, heat treatment characteristics with alloying elements. In order to make a fixed amount of retained austenite remain in the specimen in as-hardened state, therefore, C_{bal} of the cast iron must be controlled. In case of high speed tool steel, C_{bal} is generally set up in the range from -0.4% to $+0.4\%$. Here, the relationship between H_{Tmax} and C_{bal} is shown in Fig. 5-10, together with $V\gamma$ of as-hardened specimens. The relation of H_{Tmax} and C_{bal} can be expressed by a family in each austenitizing temperature regardless of V and C content of the specimens. This fact suggests that the transformation behavior of the matrix is determined by C_{bal} when the dissolved content of C and other alloying elements in matrix are fixed by the austenitizing temperature. H_{Tmax} rises as the C_{bal} increases and it takes a maximum value at a certain C_{bal} and then decreases. The C_{bal} at the maximum of H_{Tmax} is 0.48% in 1273 K and 0.16% in 1373 K austenitizing. The $V\gamma$ corresponding to each C_{bal} is about 30% . The reason why H_{Tmax} changes depending on C_{bal} regardless of V and C content is that both elements are taken into account in the equations (2.1)

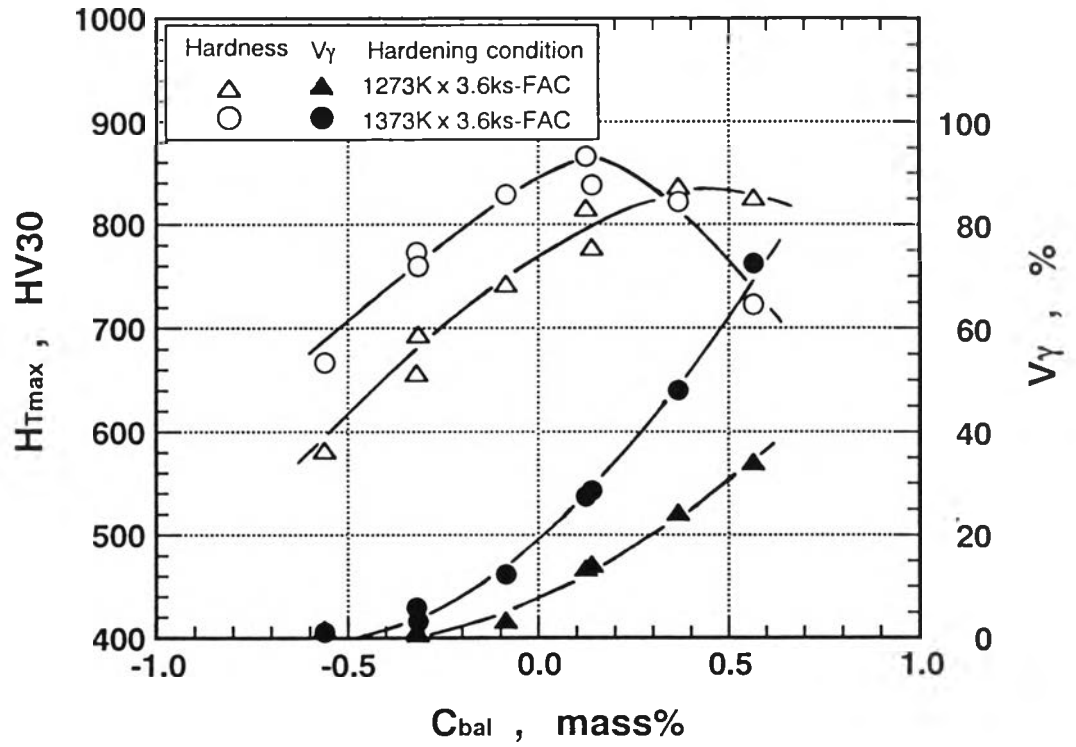


Fig. 5-10 Relationship among the maximum tempered hardness(H_{Tmax}), volume fraction of retained austenite(V_γ) in as-hardened state and carbon balance(C_{bal}).

and (2.2) of chapter 2. The reason why the C_{bal} at the peak of $H_{T_{max}}$ shifts to the smaller side according to an increase in austenitizing temperature is to increase the solubility of C and the other alloying elements to the matrix and low C_{bal} is enough to have the V_{γ} necessary for $H_{T_{max}}$ at 1373 K austenitizing.

5.5 Correlation among Tempering Temperature to obtain Maximum Tempered hardness, V and C Content and Carbon Balance

5.5.1 Relationship between Tempering Temperature to obtain Maximum Tempered Hardness and V and C Content

The relationship between tempering temperature ($T_{HT_{max}}$) to obtain the maximum tempered hardness ($H_{T_{max}}$) and V and C content is shown in Fig. 5-11 in 1273 K and Fig. 5-12 in 1373 K austenitizing. In 0.5%- and 1.0%C-specimens austenitized at 1273 K, $T_{HT_{max}}$ are in the range of 770 to 780 K even if V content changes. When C content in the specimen is raised to 1.5%, $T_{HT_{max}}$ rises to 823 K in 1%V specimen. Then, it drops to 798 K at 2%V, and to 773 K at 3%V which is same as $T_{HT_{max}}$ of low C-specimens. In case of higher austenitizing at 1373 K, $T_{HT_{max}}$ of 0.5%C-specimens are constant at 798 K. However, the $T_{HT_{max}}$ of 1.0%C- and 1.5%C-specimens lower with an increase in V content. When compared at the same V content, the more the C content in the specimen, the higher the $T_{HT_{max}}$. $T_{HT_{max}}$ are higher in the specimens austenitized at 1373 K than those at 1273 K. It can be understood from the above results that the large amount of austenite formed in as-hardened state due to either reducing the V content or increasing the austenitizing temperature will be fully decomposed by means of higher temperature and longer time in tempering. Since the tempering time is constant (12 ks) in this experiment, it can't but rely on the increase in temperature or the repeat of tempering to improve the

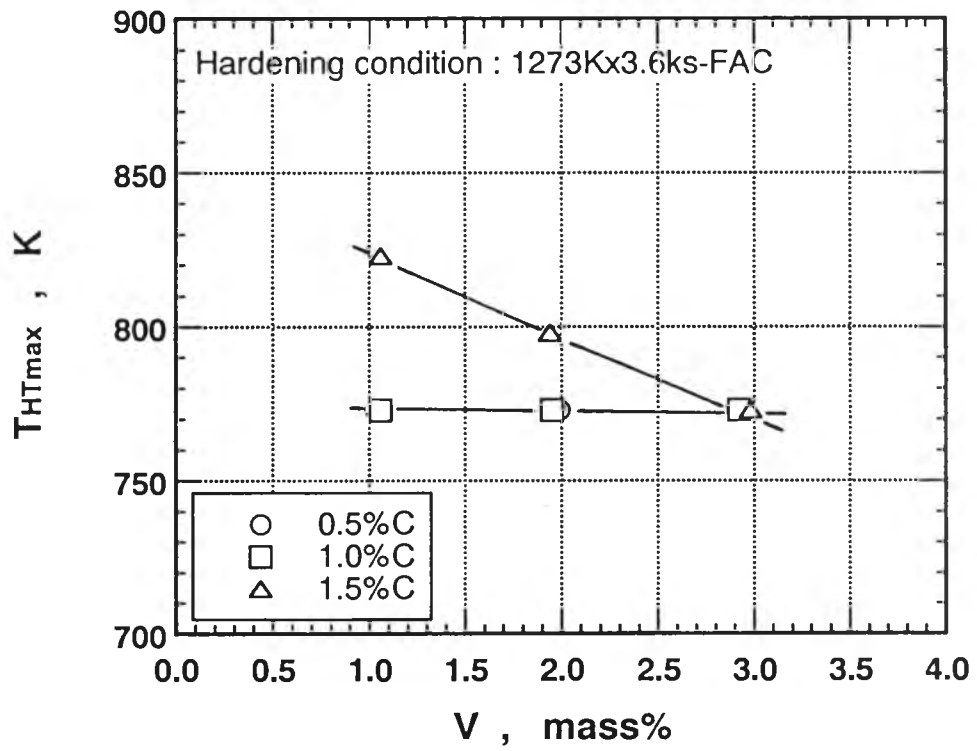


Fig. 5-11 Relationship between tempering temperature(T_{HTmax}) to obtain maximum tempered hardness and V and C content. (Hardened from 1273K)

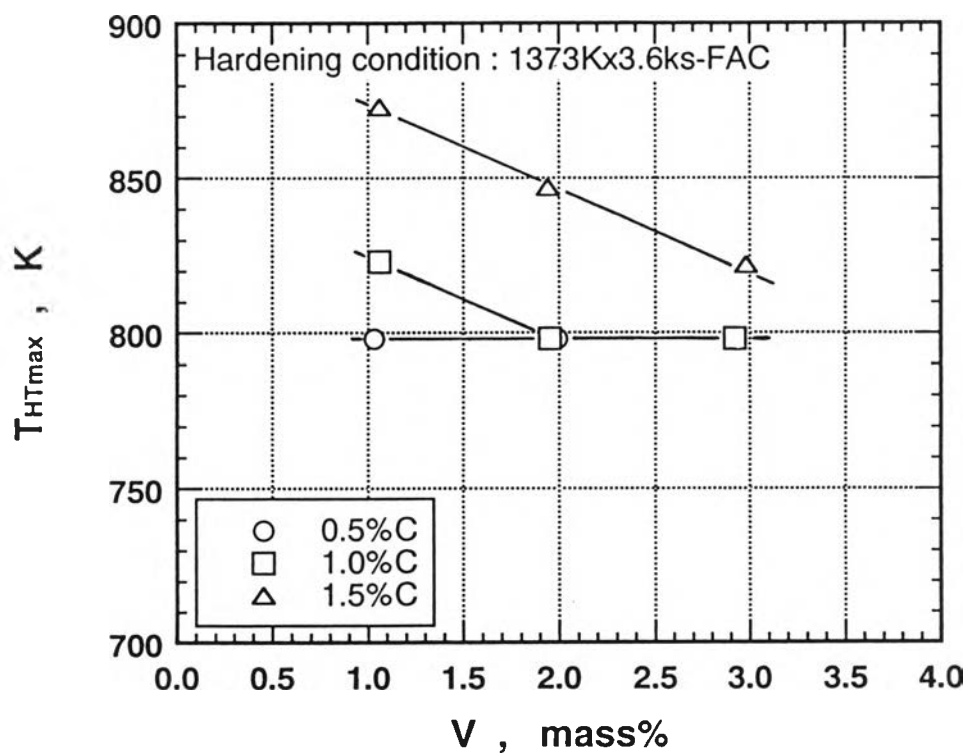


Fig. 5-12 Relationship between tempering temperature(T_{HTmax}) to obtain maximum tempered hardness and V and C content. (Hardened from 1373K)

tempered hardness by decomposing the retained austenite.

5.5.2 Relationship between Tempering Temperature to obtain Maximum Tempered Hardness and Carbon Balance

It seems that the T_{HTmax} can be also related to C_{bal} at every austenitizing temperature as shown in Fig. 5-13. There appear critical values of C_{bal} , 0.13% at 1273 K and -0.10% at 1373 K austenitizing temperature. At C_{bal} over the critical value, T_{HTmax} must be increased with increasing the C_{bal} of specimen to control the $V\gamma$.

5.6 Relationship between Tempering Temperature to get 2% $V\gamma$ and Carbon Balance

In the practical applications of these multi-component white cast irons for rolls, the retained austenite is disliked because of its dimensional change due to the decomposition and the following martensite transformation of austenite. Therefore, the sufficient tempering is requested to reduce the $V\gamma$ to a safety amount, for example, less than 2%. The tempering temperatures at which the $V\gamma$ is 2% ($T_{2\% \gamma}$) are obtained from the diagrams of Fig. 4-4 to Fig. 4-11 in chapter 4 and they were connected to the C_{bal} . The relations are shown in Fig. 5-14. At any austenitizing temperatures, the $T_{2\% \gamma}$ increases in proportion to C_{bal} , and the relations are given by the next equations,

At 1273 K austenitizing,

$$T_{2\% \gamma} \text{ (K)} = 776 + 121 \times \%C_{bal} \quad (R=0.98) \quad \text{-----}(5.2)$$

At 1373 K austenitizing,

$$T_{2\% \gamma} \text{ (K)} = 822 + 198 \times \%C_{bal} \quad (R=0.98) \quad \text{-----}(5.3)$$

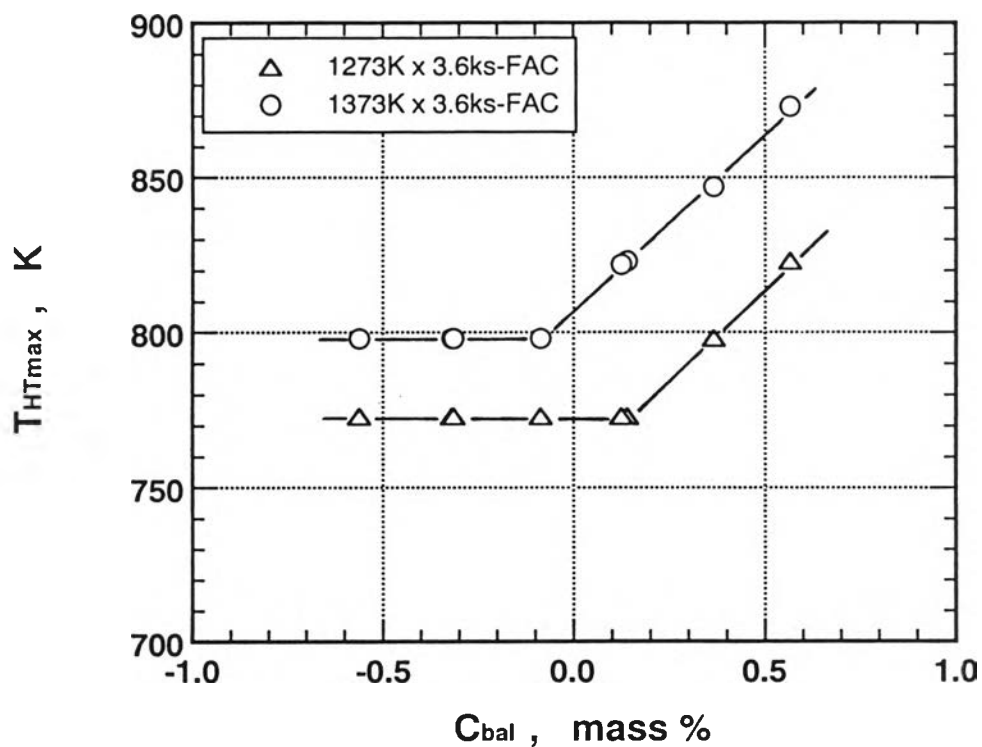


Fig. 5-13 Relationship between tempering temperature (T_{HTmax}) to obtain maximum tempered hardness and carbon balance (C_{bal}).

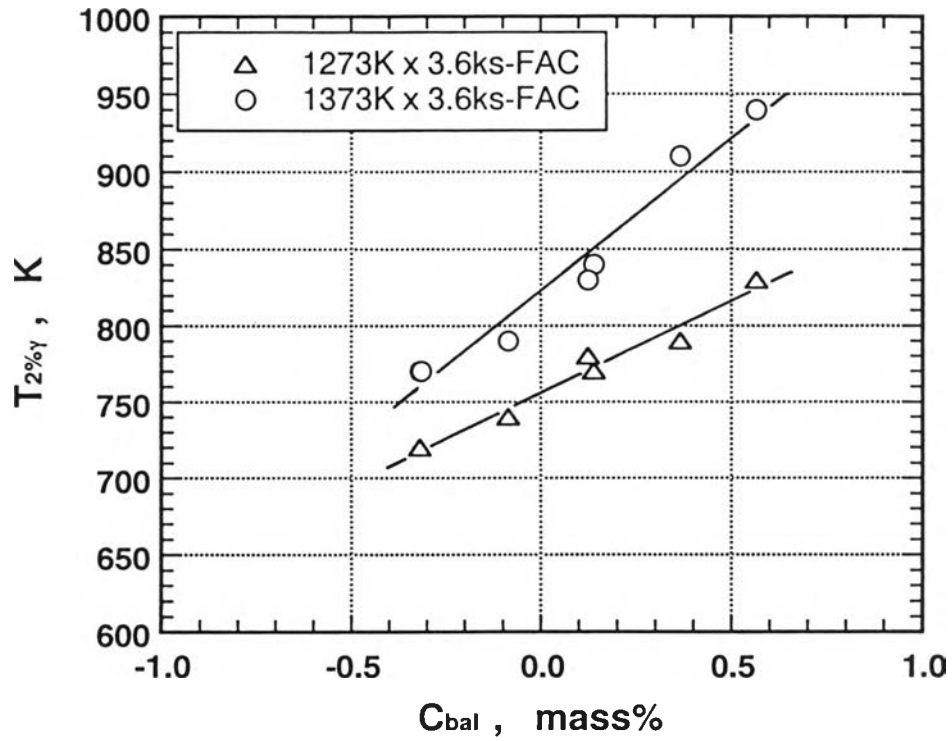


Fig. 5-14 Relationship between tempering temperature($T_{2\% \gamma}$) to get 2% V_{γ} and carbon balance(C_{bal}).

It is clear in both cases of austenitizing that the more the C_{bal} , the higher the $T_{2\% \gamma}$, to decrease V_{γ} less than 2%. This is because higher tempering temperature is necessary to decompose the austenite in which more carbon dissolves at high C_{bal} . From the viewpoint of austenitizing temperature, $T_{2\% \gamma}$ rises in the specimen austenitized at higher temperature, even if the C_{bal} is the same. This is explained that higher tempering temperature is needed to decompose the increased austenite which is stabilized by C and alloying elements dissolved much more due to the increase in the austenitizing temperature.

5.7 Transformation Behavior of Matrix

Transformation behavior of matrix in the multi-component white cast iron is closely related to the change in hardness. Then, the microstructures of typical specimens were investigated using SEM.

As for the 1.5%C-1%V alloy (No.6), SEM microphotographs of specimens hardened from 1373 K austenitizing are shown in Fig. 5-15, and those of specimens tempered at 873 K taking the maximum hardness (H_{Tmax}), and at 923 K and 823 K which are pluses and minuses of 50 K apart from the temperature at H_{Tmax} are shown in Fig. 5-16 for 10^3 magnifications and Fig. 5-17 for 10^4 magnifications. When observed under the 10^3 magnifications, it can be seen that the amount of austenite in as-hardened matrix decreases coping up with an increase in martensite transformed from the decomposed austenite, as the tempering temperature rises. The transformed areas are greatly expanded in the specimen tempered at 923 K over the temperature at which H_{Tmax} is obtained. In this magnification, the detailed behavior during tempering of martensite and decomposing of retained austenite cannot be confirmed by these photographs. From the microphotograph taken at 10^4 magnifications shown in Fig. 5-15(b), it can be seen that needles of martensite in

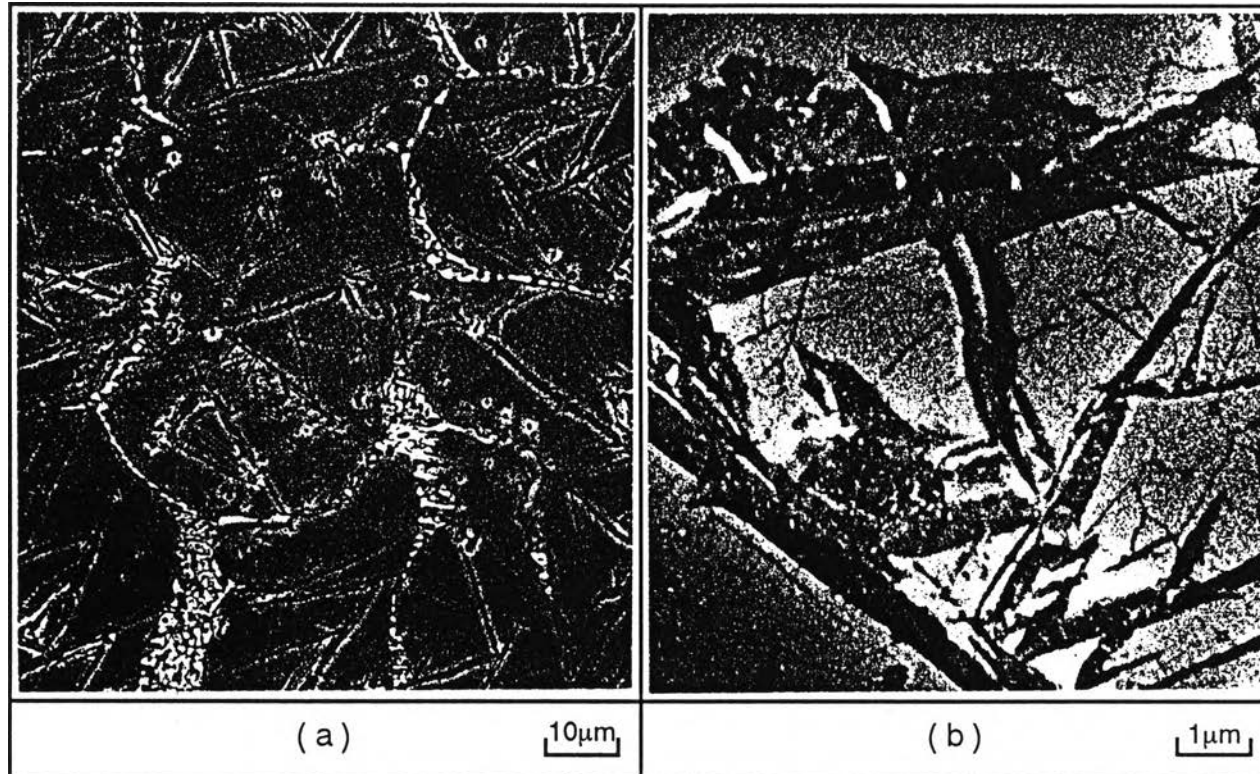
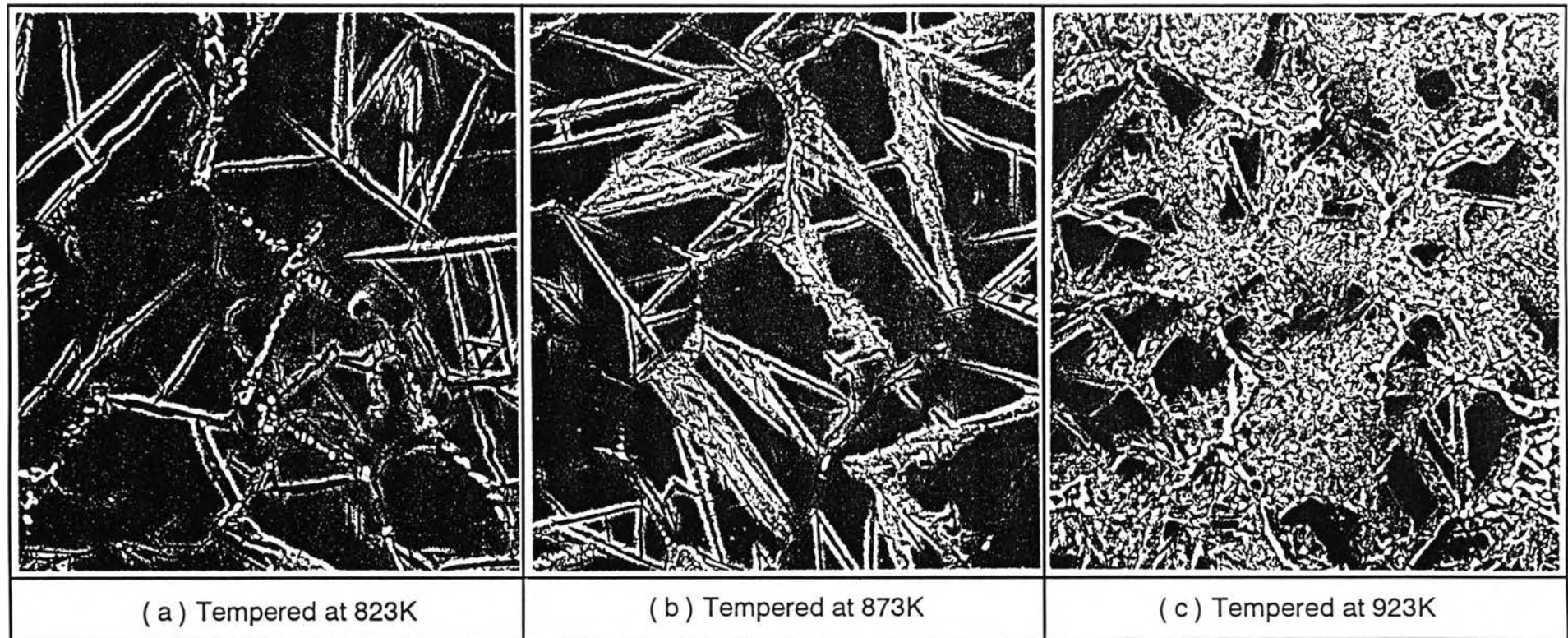


Fig. 5-15 SEM microphotographs of 1.5%C-1%V alloy(No.6) hardened from 1373K.
Magnifications : (a) x 1000, (b) x 10000



10 μ m

Fig. 5-16 SEM microphotographs of 1.5%C-1%V alloy(No.6) tempered at three different temperatures after hardening from 1373K. Magnifications : x1000

as-hardened specimen are clear and no precipitation of carbide takes place in the austenite region. However, precipitation of some carbides in the martensite are observed without changing the shape of martensite in the specimen tempered at 823 K (a) in Fig. 5-17. In the specimen (b) with $H_{T_{max}}$ tempered at 873 K, lots of fine carbides are found in a granular or a string-like morphology and still a considerable amount of austenite remains. The precipitation of carbides is spread through out matrix and a large amount of austenite disappears in the specimen tempered at 923 K (c).

As for the specimen tempered at 873 K, it is considered from above observation that the precipitation of fine special carbides due to both the “carbide reaction” which occurs in the process of tempering and the decomposition of retained austenite, and its transformation into martensite will give the maximum hardness. This can be also estimated from the fact that 28% V_{γ} still left in the tempered specimen in spite of taking the maximum hardness. Thereupon, the specimen was tempered again under the same condition, and as a result of it, the V_{γ} reduces less than 3% and the hardness rises about 30 HV. Because the degree of increase in hardness by the double tempering seems to be too small corresponding to the decrease of retained austenite, the observation by SEM was carried out for the specimen, and the microphotographs are shown in Fig. 5-18. Comparing it with microstructures of single tempered specimen (Fig. 5-16(b) and Fig. 5-17(b)), it is clear even from the photograph with 10^3 magnifications of the specimen double-tempered at 873 K (Fig. 5-18(a)) that more austenite are decomposed and it is also distinct from microphotograph with 10^4 magnifications that the carbides formed by the carbide reaction from martensite and those precipitated by the decomposition of the retained austenite are coarsened. The decrease in hardness due to the coarsening of carbides may suppress the increase in hardness due to more precipitation of carbides by tempering.

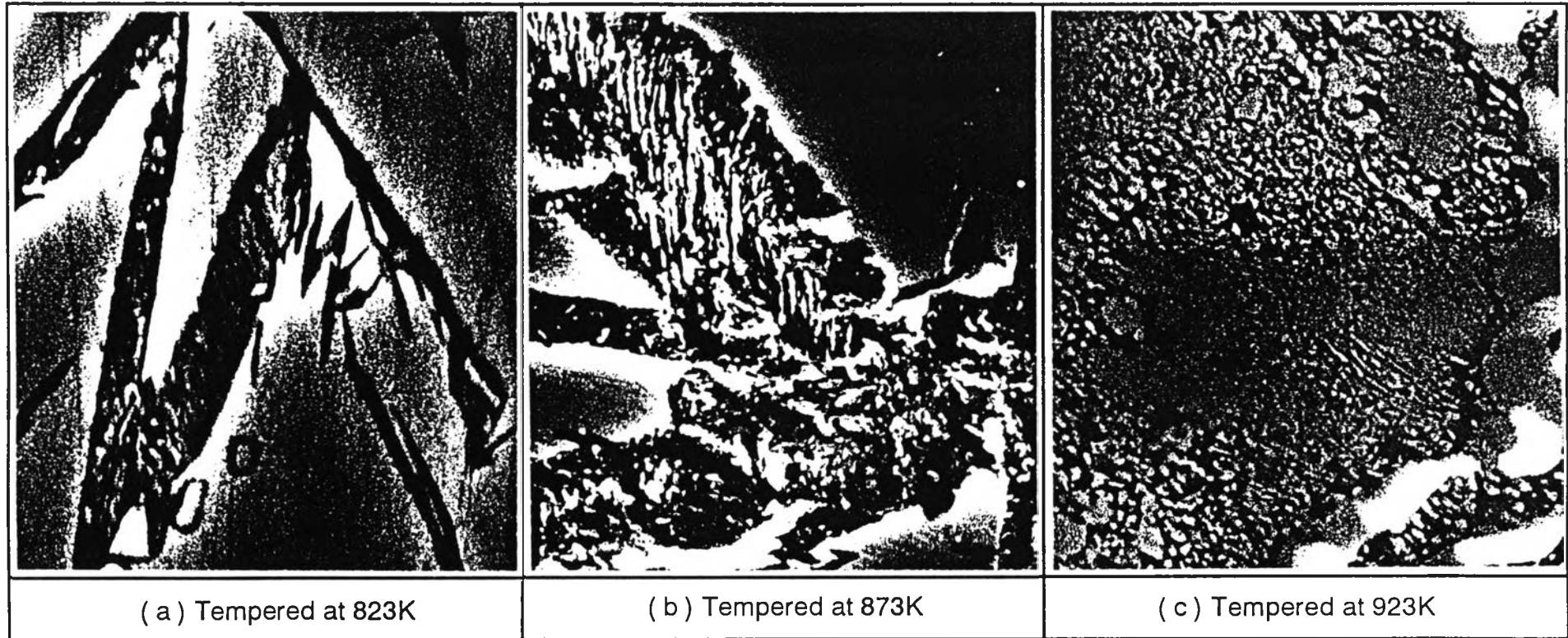


Fig. 5-17 SEM microphotographs of 1.5%C-1%V alloy(No.6) tempered at three different temperatures after hardening from 1373K. Magnifications : x10000

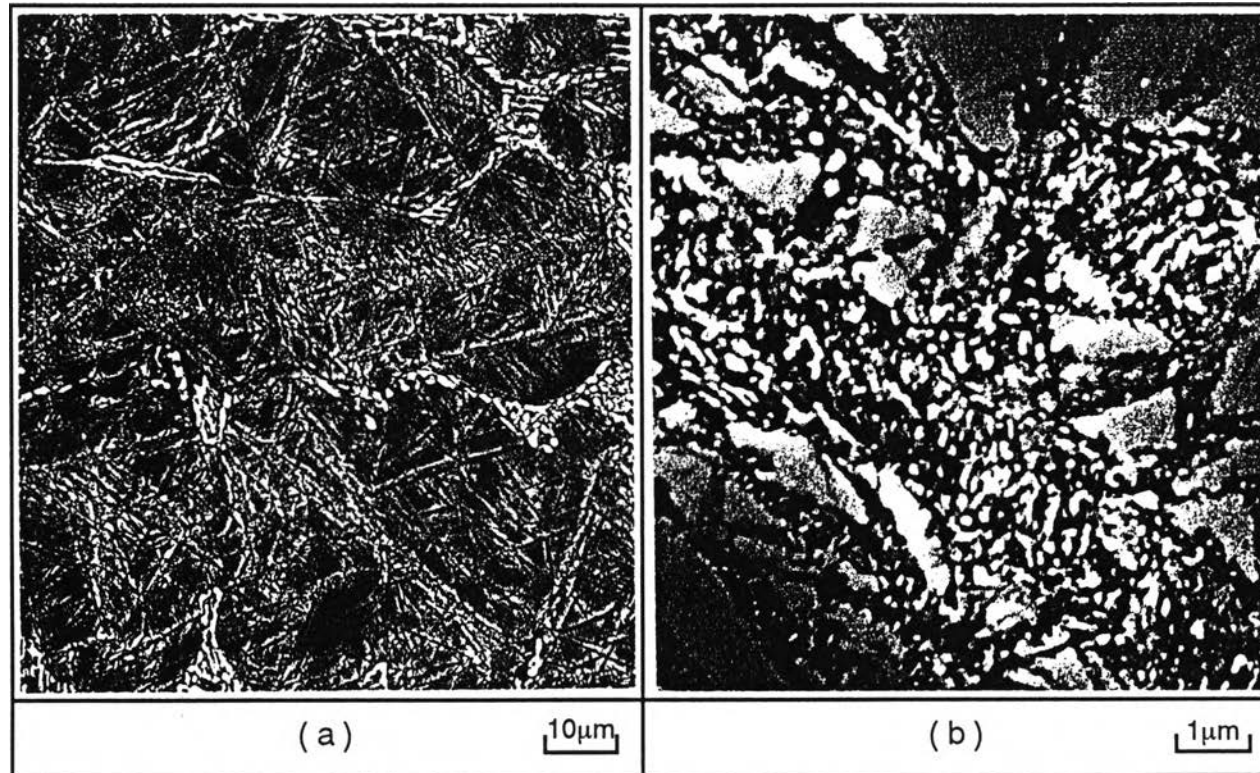


Fig. 5-18 SEM microphotographs of double tempered specimen(No.6).
(Austenitizing temp.: 1373K, Tempering temp. : 873K)
Magnifications : (a) x 1000, (b) x 10000

Next, the influence of austenitizing temperature on the microstructural variation of matrix was investigated using the tempered specimen with 1.5%C-3%V (No.8). SEM microphotographs of specimen hardened from 1273 K austenitizing and the tempered specimens are shown in Fig. 5-19. The difference in the microstructure of matrix according to the tempering temperatures cannot be clarified from these photographs with 10^3 magnifications. When looking at the microphotographs taken by 10^4 magnifications, however, the differences can be distinguished as shown in Fig. 5-20. The spheroidal carbides in the microstructure of as-hardened specimen shown in Fig. 5-20(a) still exist in the tempered specimens in the same size as shown in Fig. 5-20(b), (c) and (d). This tells that they had already formed at the time when the austenitization was finished. There are martensites among the spheroidal carbides and the minute secondary carbides in the specimen tempered at 673 K (b), and they might be transformed during cooling after tempering. The precipitation of the minute carbides increases more in the specimen with $H_{T_{max}}$ tempered at 773 K (c) and on the contrary the retained austenite decreases. When the tempering temperature is increased to 873 K, it seems that the precipitated carbides are increased but coarsened. So, the maximum hardness was obtained in the specimen tempered at 773 K among these three levels of tempering.

In order to identify the kind of carbide, it will be necessary to introduce an investigation by TEM. In the previous work¹⁴⁾ on the TEM analysis of secondary carbide precipitated in multi-component white cast iron with W (Fe-5%Cr-5%Mo-5%W-5%V-2%Co-2%C alloy), M_6C carbide was identified and, therefore, the carbides precipitated secondarily by tempering can be presumed to be VC, Mo_2C or M_6C and/or their mixture.

SEM microphotographs of an as-hardened specimen (No.8) quenched from 1373 K austenitizing and tempered specimens at 773 K, 823 K and 873 K are shown in Fig. 5-21. The behavior of matrix due to the

variation of heat treatment is similar to that of specimens hardened from austenitizing temperature of 1273 K. The amount of austenite in the as-hardened specimen (a) is more than that in 1273 K austenitizing, and the residual carbides or the indissoluble ones, which were formed by former annealing, exist little in the matrix at the time when the specimen begins to be quenched. Therefore, most of the carbides are considered to dissolve into matrix because of the increased austenitizing temperature. A small amount of minute carbide and a considerable amount of austenite exist in the matrix of specimen tempered at 773 K (b) but the number of carbide increases remarkably in the specimen tempered at 823 K (c) and in the specimen tempered at 873 K (d), the carbides are greatly grown in size. On the other side, the amount of martensite decreases as the tempering temperature rises. It is understood from the behavior of matrix structure that the carbides secondarily precipitated by tempering at 823 K are most in the amount and finest in every tempering temperature. These results are in good accordance with the fact that the hardness of the specimen tempered at 823 K shows the maximum value.

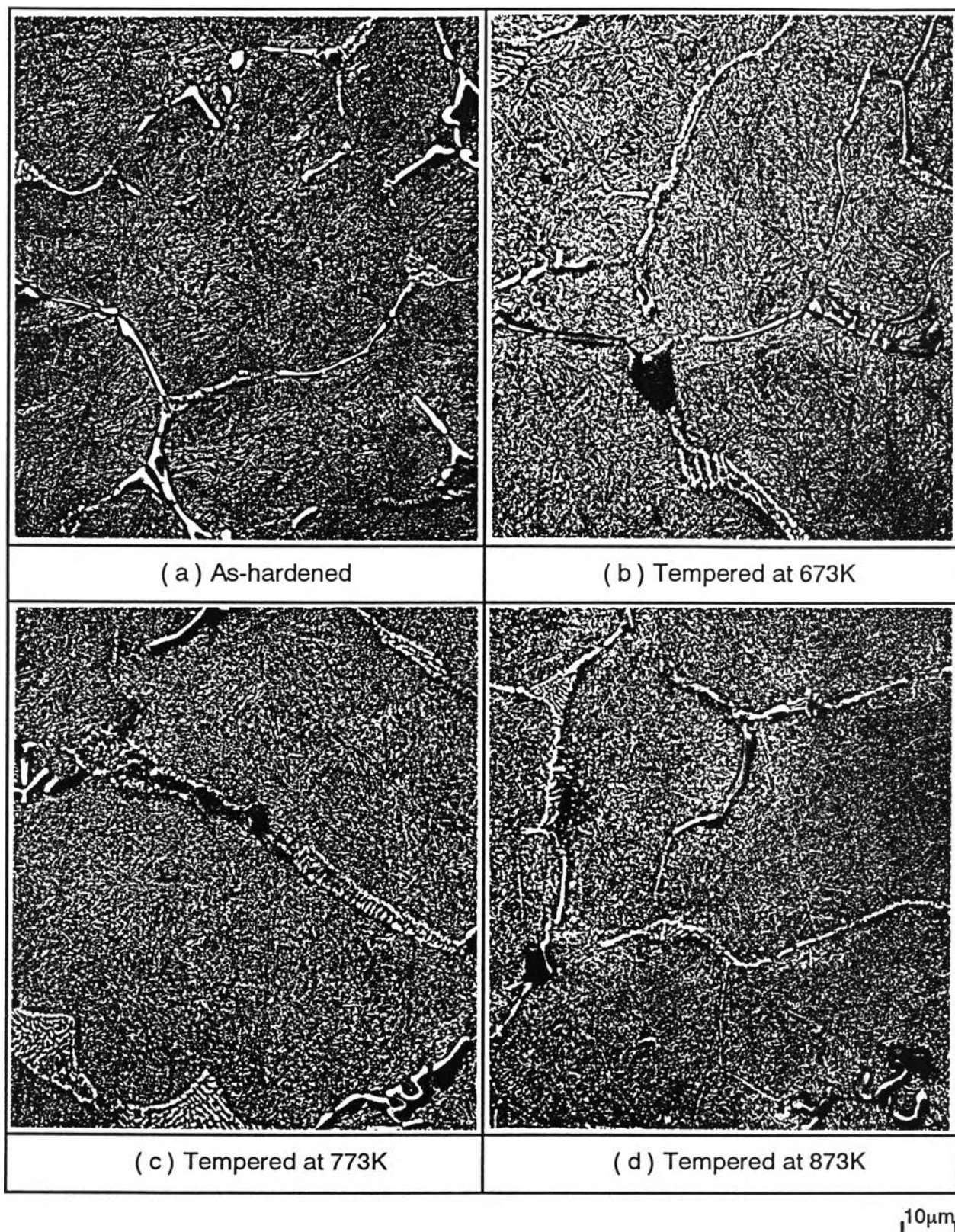


Fig. 5-19 SEM microphotographs of 1.5%C-3%V alloy(No.8) hardened from 1273K and tempered at three different temperatures.
(a) : As-hardened state, (b)(c)(d) : Tempered state
Magnifications : x 1000

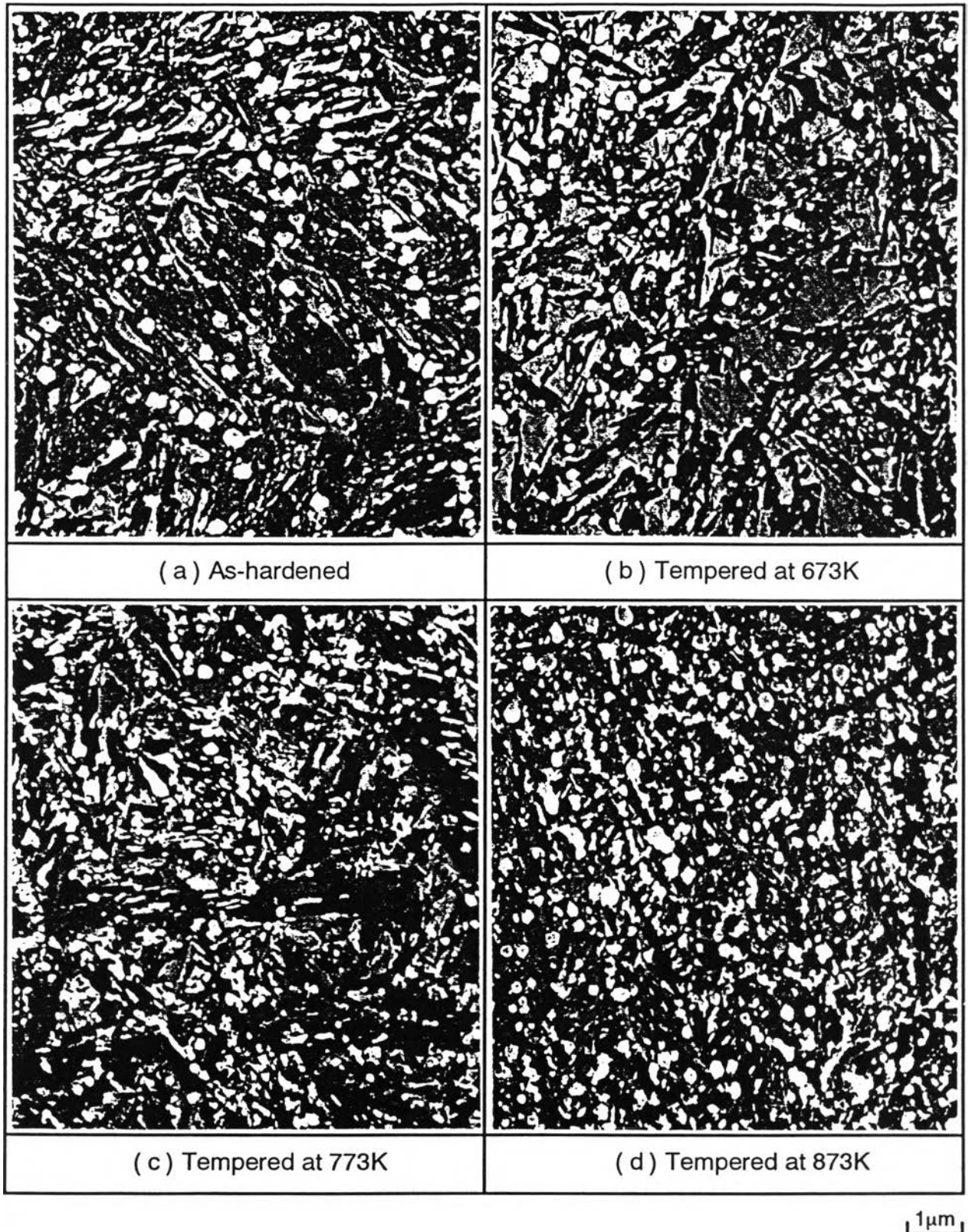


Fig. 5-20 SEM microphotographs of 1.5%C-3%V alloy(No.8) hardened from 1273K and tempered at three different temperatures.
(a) : As-hardened state, (b)(c)(d) :Tempered state
Magnifications : x 10000

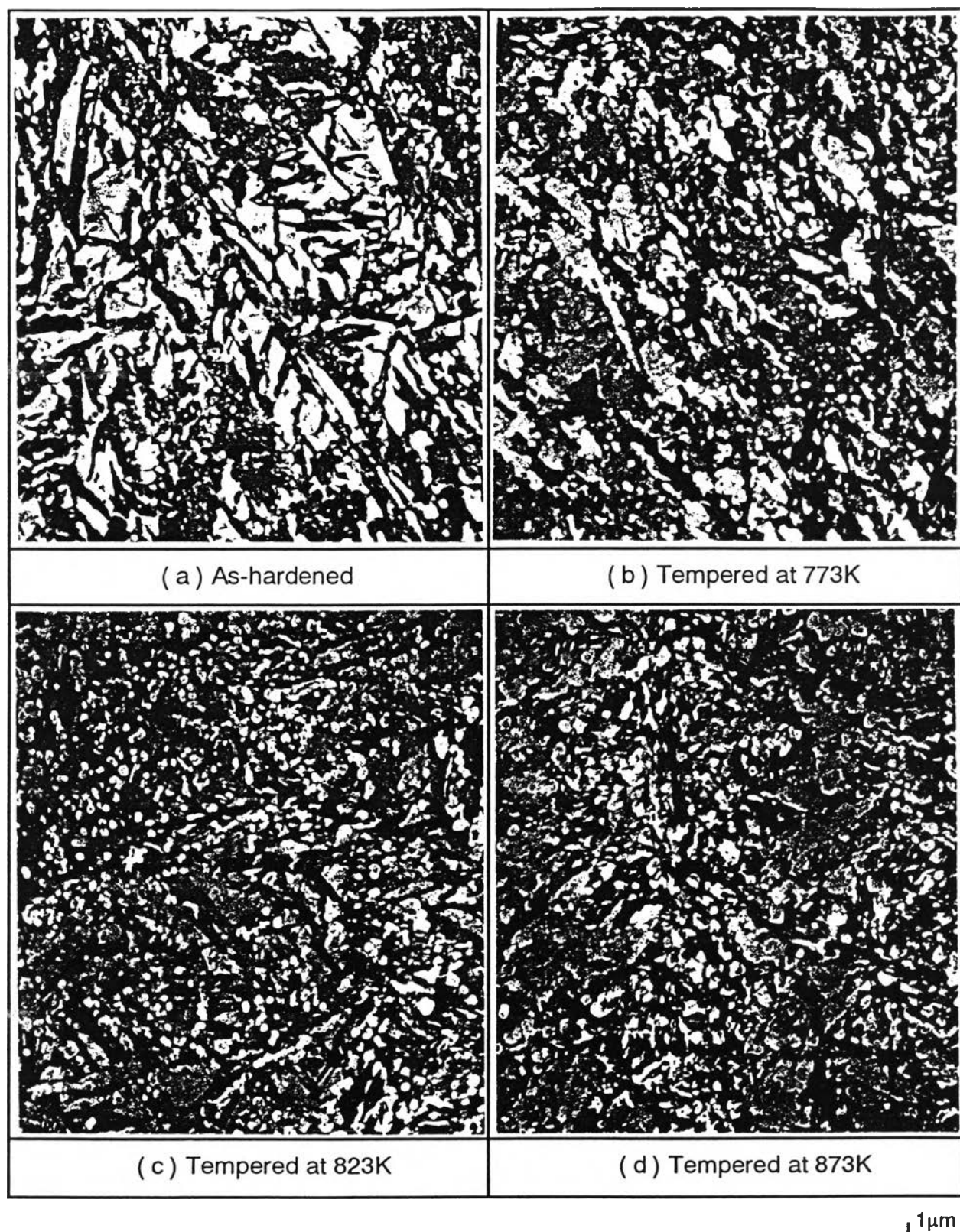


Fig. 5-21 SEM microphotographs of 1.5%C-3%V alloy(No.8) hardened from 1373K and tempered at three different temperatures.
(a) : As-hardened state, (b)(c)(d) : Tempered state
Magnifications : x 10000