Experimental Study of the Effect of Austenitizing Temperature and Multiple Tempering on the Microstructure of AISI 410 Martensitic Stainless Steel

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ABSTRACT

This research involved a study of the effect of heat treatment conditions on the microstructure of martensitic stainless steel type AISI 410. Heat treatment process was hardening of the metal by quenching at different temperature 900°C, 950°C, 1000°C, 1050°C and 1100°C, followed by double tempering at 200°C, 250°C, 300°C, 350°C, 400°C, 450°C, 500°C, 550°C, 600°C, 650°C and 700°C, were evaluated and study the effect of heat treatment on the microstructure of the alloy.

The experimental results showed that the undissolved coarse grain of chromium carbide at low quenching temperature 900°C, whereas at high quenching temperature from 950°C to 1100°C, the chromium carbide dissolved at grain boundaries caused weakened of the material and initiation of brittle cracking. The hardening and tempering give a microstructure be essentially of fine tempered martensite due to double tempering and coexisting of ferrite phase or blended of ferrite and martensite with small particles of nonmetallic inclusions depends on the quenching and tempering temperature and type of the alloy.

KEY WARDS: austenitizing temperature, multiple tempering, microstructure, AISI 410 Martensitic Stainless Steel

دراسة عملية لتأثير درجة حرارة الاخماد والمراجعة المتعددة على التركيب المجهري للصلب المارتنسايتي المقاوم للصدأ نوع (AISI 410)

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الخلاصة :-

تضمن هذا البحث دراسة تأثير بعض انواع المعالجات الحرارية على التركيب المجهري للصلب المارتنسايتي المقاوم للصدأ من نوع AISI 410. المعالجات الحرارية كانت عملية تقسية للمعدن من درجات حرارة اخماد 900°C، 950°C، 1000°C، 1050°C و 1100°C، متبوعة بعملية تطبيع بمرحلتين بدرجات حرارة 200°C، 250°C، 300°C، 350°C، 400°C، 450°C، 500°C، 550°C، 600°C، 650°C و 700°C، تم تقييم ودراسة تأثير بعض انواع المعالجات الحرارية على التركيب المجهري للمعدن. وجد ان درجات حرارة الاخماد الواطئة من 900°C تؤدي الى ظهور كاربيدات كبيرة الحجم غير متحللة وزيادة درجات حرارة الاخماد اعلى من 950°C الى 1100°C ادت الى تحلل الكاربيد عند حدود الحبيبات الذي ادى الى اضعاف البنية البلورية وزيادة هشاشية المعدن . كذلك التقسية والتطبيع تعطي بناء مجهري يكون اساسا" من طور المارتنسايت الدقيق الذي حدث له تطبيع وظهور طور الفرايت او خليط من طور الفرايت والمارتنسايت مع تواجد القليل من الشوائب الناتجة من المواد اللامعدنية وهذا يعتمد على درجات حرارة الاخماد والتطبيع ونوع المعدن.

1. INTRODUCTION

Stainless steels are iron-base alloys containing at least 10.5% Cr. Few stainless steels contain more than 30% Cr or less than 50% Fe. Other elements added to improve particular characteristics include nickel, molybdenum, copper, titanium, aluminum, silicon, niobium, nitrogen, sulfur, and selenium. Carbon is normally present in amounts ranging from less than 0.03% to over 1.0% in certain martensitic grades (ASM Metals Handbook, 2005).

Martensitic stainless steels are essentially alloys of chromium and carbon that possesses a distorted body centered cubic BCC crystal structure martensitic in the hardened condition. They are ferromagnetic, hardenable by heat treatments, and generally resistant to corrosion (Bulent Kurt et al, 2009). Chromium content is generally in the range of 10.5% to 18%, and carbon content may exceed 1.2% (MA Dang-shen et al, 2012). Molybdenum is added to improve the steel's corrosion resistance, while Nickel is added to stabilize γ-austenite at high temperatures, preventing the formation of δ-ferrite. Carbon content has been reduced to as little as 0.01 wt. % to improve weldability (C.A. Della Rovere et al, 2013).

The austenitizing temperature employed during heat treatment to determines the partitioning of carbon and alloying elements between the austenite and carbide phases, with an increase in temperature leading to increased carbide dissolution and higher dissolved alloying element contents. In solid solution at temperatures above the carbide dissolution temperature, these carbide forming elements affect the transformation to martensite by depressing the martensite transformation range and reducing the martensite start M_S and martensite finish M_f temperatures. If the M_f temperature is depressed to below room temperature or even to below 0°C, retained austenite may be present in the as-quenched microstructure as a result of the martensite transformation not going to completion (L. D. Barlow and M. Du Toit, 2011).

An overview of the relevant available literatures**,** C. Garcia de Andres, et al. 1998 investigated the effects of carbide forming elements on the response to thermal treatment of the martensitic stainless steel. Heat treatments consisted of austenitizing for 60 s at temperatures ranging from 1000°C to 1250°C. The higher is the solution treatment temperature, the less $M_{23}C_6$ carbide is left out of solution in the austenite. As a result, the concentration of carbon and alloying elements in the martensite increases and, an increase in the hardness until a maximum value was found at austenitizing temperatures of 1120°C and 1130°C. At higher austenitizing temperatures, the presence of retained austenite was observed, which leads to a lowering of the hardness value.

S. H. Salleh, et al., 2009, described the effect of heat treatments on microstructures of martensitic stainless steel. Solution treatment was carried out at 1150°C and 60 minutes holding time, followed by tempering process at 660°C with various holding time. In the as-quenched sample, existence of M_7C_3 carbides within the martensitic structures. While after tempering, $M_{23}C_6$ carbides were identified along with M_7C_3 carbides.

L. D. Barlow, M. Du Toit, 2011, examined the effect of austenitizing temperature on the microstructure of two martensitic stainless steels. It supplying heat treatment to ensure a martensitic structure with minimal retained austenite, evenly dispersed carbides after quenching and tempering. Steel samples were austenitized at temperatures between 1000°C and 1200°C, followed by oil quenching. The as-quenched microstructures were found fully martensitic structures with up to 35% retained austenite after quenching, with varying amounts of carbides.

H. R. Bakhsheshi-Rad, et al., 2011, investigated the effect of multi-step tempering on retained austenite content. The results of retained austenite decreased about 2% after multi-step tempering. Content of retained austenite increased from (3.6 to 5.1) % by increasing multi-step tempering temperature.

The objectives of the present work is to Study the effect of the austenitizing and tempering temperature on microstructure of martensitic stainless steel to select suitable microstructure for engineering application.

2. CHEMICAL COMPOSITION OF AISI 410 MARTENSITIC STAINLESS STEEL

Grade AISI 410 martensitic stainless steel is commercially available in a Low-Carbon which contains 0.15% Carbon supplied for the purpose of this investigation, often used in as-hardened/tempered state, through which the steel combines good mechanical properties with moderate corrosion resistance. Typical used for cutlery, turbine engines, petrochemical equipment, surgical and dental instruments, scissors, valves, gears, cams and ball bearings. Table 1 explains the chemical composition of the AISI 410 martensitic stainless steel conducted by "METEK" spectrographic analysis Instrument GmbH, Boschstrasse, kleve, Germany.

The sample contains 12.08% chromium, with small additions of copper, nickel, vanadium, silicon, manganese and molybdenum. Molybdenum is expected to increase the hardenability, resistance and improve the high temperature strength of the alloy, Fig.1 shows the microstructure estimated of experimental material by Schaeffler diagram containing approximately the average amounts of 5 % ferrite and 95 % martensite and the result is accordant with the Schaeffler diagram (Cheng-Hsun Hsu and Hwei-Yuan Teng, 2005).

3. MICROSTRUCTURAL ANALYSIS

Optical microscopy was utilized to examine as received materials microstructure. The specimens were grinded by emery paper 230, 400, 800,1000 and 1200 µm, respectively then polished and etched vilella's reagent (5 ml HCl + 1g Picric acid + 100 ml ethanol) according to the ASTM Standard (E 407 - 99) (ASTM Standards E 407 – 99, 2003). Fig.2 shows the microstructures of As-received stainless steel. Fifty-five microstructure specimens are prepared as circular disks of 12 mm diameter and 10 mm thickness, Fig.3 shows specimens dimensions.

4. EXPERIMENTAL PROGRAM

The sample tests were taken by the following stages:

1. Forming the samples of a test and annealed condition for all samples, Set the indicator of the furnace at 750°C and leave it for a time to get a stable reading for 2 hours (Calliari, 2008), followed by slow cooling inside the furnace to 25°C for 20 hours to facilitate the formation of chromium carbides in a ferrite matrix and to obtain maximum softness for forming.
2. Dividing the samples into five groups, each group has eleven samples of test.
3. Performing the heat treatment condition for all samples at the determined temperature then cooling by the Oil quenching media. Engine Oil is used as quenching media has Specification of (HD 50). Set the indicator of the furnace at 900°C austenitizing temperature and leave it for a time to get a stable reading, then putting eleven samples of test inside the furnace for the period of treatment 30 minutes.
4. Extract the samples from the furnace and cool them rapidly by oil to 25°C.
5. Put the indicator of furnace at 950°C austenitizing temperature and leave it for a time to get its stability and then putting the eleven samples of test inside the furnace for the period of treatment 30 minutes and then extract the samples from the furnace and then cooling them rapidly by oil to 25°C.
6. Repeat the Performance at 1000°C, 1050°C, and 1100°C austenitizing temperatures for the eleven samples of test with period of treatment 30 minutes and then cooling them rapidly by oil.
7. After cooling the sample, taken one sample from each group as-quenching and then tempering by setting temperature at 200°C tempering temperature and leaving it for a time to get its stability of reading and ensuring the thermal balance, putting the samples

inside the furnace for the period of tempering 2 hours, then cooling by air outside the furnace to room temperature.

8. Repeat the Procedure at 250°C, 300°C, 350°C, 400°C, 450°C, 500°C, 550°C, 600°C, 650°C and 700°C tempering temperature for one sample from each group as-quenching for the period of tempering 2 hours. Then cooling by air outside the furnace to room temperature.
9. Repeat the Procedure at double tempering at 200°C, 250°C, 300°C, 350°C, 400°C, 450°C, 500°C, 550°C, 600°C, 650°C and 700°C, for the period of tempering 2 hours. Then cooling by air outside the furnace to room temperature. Fig.4 shows schematically representation of austenitizing and tempering of heat treatments.

5. RESULTS AND DISCUSSION

5.1. Chemical Composition and Microstructure As-Received Samples

The chemical composition of the AISI 410 martensitic stainless steel is listed in Table 1. The Ni-Cr equivalent values of this material calculated by Schaeffler formula are 6.032 % and 13.801 %, respectively (ASTM Standards E 407 – 99, 2003). According to both of the equivalents in Schaeffler diagram as shown in Fig.1, it can be seen that microstructure of the used material containing of approximately the average amounts of 5 % ferrite and 95 % martensite phases. In this work, the amount of microstructural constituents was measured by Optical microscopy was utilized to examine the materials microstructure.

Fig.5 show the microstructures of as-received stainless steel consisting of partly Spheroidise particles of $M_{23}C_6$ primary chromium carbide in a ferrite matrix compared with ASM standard (S. H. Salleh, et al, 2009 and Heat Treatment Guide, ASM International, 2nd Edition, (1995)).

5.2. Spheroidise Annealing Condition

The Spheroidise annealed condition gave the best compromise between annealing temperature and holding time is obtained by annealing at a temperature of 750°C for 2 hours (I. Calliari, M. Zanesco et al, 2008), followed by slow cooling inside the furnace to temperature at 25°C for 20 hours to obtain maximum softness for forming.

The aim of this process is to release the work hardening generated during the manufacturing process, particularly during cold rolling. After the annealing process, the stainless steel shows a homogenous grain size structure.

A scanning electron micrograph of AISI 410 stainless steel after annealing at 750°C for 2 hours consisting of ferrite and chromium-rich $M_{23}C_6$ carbides (C. Garcia de Andrés, et al, 1998). Fig.6 shows the microstructures of stainless steels consisting of matrix of ferrite with randomly dispersed particles of $M_{23}C_6$ chromium carbide compared with ASM standard (ASM Metals Hand book, 1972).

5.3. The Effect of Austenitizing and Tempering Temperature on the Microstructure

The solid solution at temperatures above the carbide dissolution temperature, carbon and carbide-forming elements affect the transformation to martensite by depressing the martensite transformation range and reducing the martensite start (Ms) and martensite finish (Mf) temperatures. If the (Mf) temperature is depressed below room temperature or even below 0°C, then the retained austenite may be present in the as-quenched microstructure. However, retained austenite occurs in steels when the Ms-Mf range extends below room temperature, as the case for the martensitic stainless steels (L. D. Barlow and M. Du Toit, 2011 and A.F. Candelaria and C.E. Pinedo, 2003).

When alloying elements dissolve in the stainless steel at high temperatures, the martensite transformation temperatures are depressed. This is illustrated by equation 1, which prescribe the effect of various alloying elements on the martensitic start temperature Ms of 12 % chromium steels (all alloy contents in weight percentage) (L. D. Barlow and M. Du Toit, 2011 and A.F. Candelaria and C.E. Pinedo, 2003).

$$Ms\ (°C) = 500 - 333C - 34Mn - 35V - 20Cr - 17Ni - 11Mo - 10Cu - 5W - 15Co + 30Al \qquad (1)$$

Equation 1, yields predicted martensite start temperatures of 150.994°C, this martensite transformation temperature was suggesting unlikely to go to completion (unless sub-zero treated). Therefore, very little retained austenite is expected after quenching. Since the carbides increasingly dissolve with an increase in austenitizing temperature, the martensite start temperature is expected to decrease with higher austenitizing temperatures. The presence of additional molybdenum in stainless depresses the martensite start temperature predicting a higher risk of retained austenite after quenching at room temperature.

Optical metallography was carried out in the tempered condition to identify the variation of microstructure such as dissolved and undissolved carbides $M_{23}C_6$ secondary chromium carbide, lath martensite type and ferrite of the metal. The selection important austenitizing temperature at 900°C, 1050°C and 1100°C with corresponding to tempering temperature at 200°C, 450°C, 500°C, 550°C and 650°C, whereas austenitizing temperature at 950°C and 1000°C and tempering temperature at 250°C, 300°C, 350°C 400°C, 600°C and 700°C were ignored because no important change in microstructure.

Fig.7 shows Cr-Fe-C ternary phase diagram at weight percentages carbon values of 0.10 % C and 12 % Cr. The position of the used material shows the microstructures at 900°C lower austenitizing temperature selection, consisting of three constituent, (α) ferrite, (γ) austenite and $M_{23}C_6$ chromium carbide. Whereas, at 950°C to 1000°C intermediate austenitizing temperature consisting of two constituent, (α) ferrite, (γ) austenite, and from 1000°C to 1100°C higher austenitizing temperature only (γ) austenite exists. The composition range for AISI 410 martensitic stainless steel has been included on the 0.1%C vertical section. The increased % C up to 0.15% C causes the (γ) region to expand to higher % Cr values as indicated by the dashed line labeled "more % C". AISI 410 martensitic stainless steels are expected to be fully austenite in a narrow temperature range of roughly 1000°C to 1200°C, if the stainless steel is austenitized slightly above or below this range it will contain some ferrite that will reduce the hardness of the quenched stainless steel (Heat Treatment Guide, 2nd Edition, (1995)).

The austenite phase transforming to martensite on quenching processes with small constituent of retained austenite. The martensite transformation does not go to completion and the as-quenched microstructure contains increasing amounts of retained austenite, this retained austenite is soft compared to the martensite, due to this austenite that the hardness is found to decrease (A.F. Candelaria and C.E. Pinedo, 2003).

The Carbon percentage from 0 to 0.6 % C the martensite is called lath martensite and above 1 % C it is called plate martensite. Lath martensite will not have significant amounts of retained austenite, whereas plate martensite will have significant and rapidly increasing amounts of retained austenite as Carbon increases (ASM Metals Hand book, 1972).

Alloying elements added to stainless steel either dissolve in the ferrite or austenite matrix, or react with carbon to form alloy carbides (R.E. Reed–Hill, 2008).

According to the available literature chromium-rich $M_{23}C_6$ carbides dissolve at 950°C to 1050°C austenitizing temperatures ranges. Therefore, a higher austenitizing temperature causes more carbide dissolve (L. D. Barlow and M. Du Toit, 2001). This is in agreement with the observations of S. Salem, 1993, who reported that the $M_{23}C_6$ chromium carbides dissolve at 950°C to 1050°C austenitizing temperatures ranges. S. H. Salleh, et al., 2009 concluded that the $M_{23}C_6$ carbides precipitate only after the tempering process.

The presence of only $M_{23}C_6$ (M: Cr mainly) carbides particles revealed due to exists of chromium, but M_7C_3 (M: V mainly) disappear because no existing of vanadium in chemical compositions of the used material. Where M means Fe+X, with X referring to the added alloying element. In a Fe-Cr-C alloy, the X would be Cr (D. Peckner and I. M. Bernstien, 1979). However, the primary (coarse) chromium carbide existing in stainless steels before heat treatment, whereas, secondary chromium carbide (fine) exists at austenitizing condition and chromium-rich carbide after tempering. Sometime tempering at higher temperature caused the carbides disappear (A. Rajasekhar, et al., 2009).

Molybdenum in solid solution is a strong ferrite-forming element, which enlarges the austenite phase field and retards the transformation of ferrite to austenite on heating. Molybdenum may also form part of the complex $M_{23}C_6$ carbide that precipitates on slow cooling from the austenite phase field (R.A. Higgins, 1996).

The presence of carbides within the martensite matrix produces increased hardness because the carbides are even harder than the martensite. But the presence of large carbides caused reduces the impact energy. It is important in such stainless steels to keep the carbides as small as possible; even then, impact energy will be inherently low (A. Grossmann and E. C. Bain, 1964).

Chih-Chung Lin and Yuli Lin, 2009 show that a small size of secondary carbides was found after tempering temperature range 200°C to 600°C. The amount of secondary carbides was found increased as increase the tempering temperature.

Figures from 8 to 9 represent the microstructure of stainless steel spacemen after austenitized at 900°C, 1050°C and 1100°C with tempering temperatures 200°C, 450°C, 500°C, 550°C and 650°C. These structures were compared with atlas of microstructures of industrial alloys (ASM Metals Hand book, 1972).

Figures 8 (a), (b), (c) show the microstructures of stainless steels austenitized at 900°C and tempered at 200°C, 450°C, 500°C respectively, have same structures, consisting of precipitated coarse grain $M_{23}C_6$ secondary chromium carbide particles (white) randomly dispersed, and undissolved islands of carbide particles (gray), with pool free ferrite (white), and globules nonmetallic inclusions (dark), into a matrix of tempered martensite. These microstructures are similar with that of reference (ASM Metals Hand book, 1972). From these structures result, that the different tempering temperature does not have any effective change in the microstructures of stainless steels austenitized at 900°C. However, S. Salem, 1993 reported that the $M_{23}C_6$ chromium carbides dissolve at 950°C to 1050°C temperature ranges. Therefore, austenitizing at 900°C called underheating caused undissolved carbide particles.

Figure 8 (d) shows the microstructures of stainless steels austenitized at 900°C and tempered at 550°C, consisting of ferrite (white) into a matrix of lath tempered martensite with small particles of $M_{23}C_6$ secondary chromium carbide and randomly dispersed small spheroidal particles of nonmetallic inclusions.

Figure 8 (e) shows the microstructures of stainless steels austenitized at 900°C and tempered at 650°C, consisting of free ferrite (fine grain white) into matrix of lath tempered martensite with randomly dispersed small particles of nonmetallic inclusions (dark).

Figure 9 (a) shows the microstructures of stainless steels austenitized at 1050°C and tempered at 200°C, consisting of spheroidal particles $M_{23}C_6$ secondary chromium carbide (gray) with some undissolved pool (globules) carbide particles (gray) and randomly dispersed spheroidal particles of nonmetallic inclusions (dark) into matrix of lath tempered martensite.

Figure 9 (b) shows the microstructures of stainless steels austenitized at 1050°C and tempered at 450°C, consisting of precipitated fine grain $M_{23}C_6$ secondary chromium carbide particles (dark) randomly dispersed at grain boundaries, and small islands of ferrite (white) are present into matrix of lath tempered martensite.

Figure 9 (c) shows the microstructures of stainless steels austenitized at 1050°C and tempered at 500°C, consisting of precipitated fine grain $M_{23}C_6$ secondary chromium carbide particles (dark) at grain boundaries, and islands of ferrite (white) are present at grain boundaries into matrix of (coarse grain) lath tempered martensite.

Figure 9 (d) shows the microstructures of stainless steels austenitized at 1050°C and tempered at 550°C, consisting of precipitated fine grain $M_{23}C_6$ secondary chromium carbide particles (dark) at grain boundaries, and islands of ferrite (coarse grain white) are present at grain boundaries into matrix of (coarse grain) lath tempered martensite.

Figure 9 (e) shows the microstructures of stainless steels austenitized at 1050°C and tempered at 650°C, consisting of precipitated fine grain $M_{23}C_6$ secondary chromium carbide particles (dark) randomly dispersed at grain boundaries, and matrix consists of blended ferrite-free (fine grain white) with lath tempered martensite.

Figure 10 (a) shows the microstructures of stainless steels austenitized at 1100°C and tempered at 200°C, consisting of islands of ferrite (coarse grain white), and small particles spheroidal of $M_{23}C_6$ secondary chromium carbide (gray) and randomly dispersed spheroidal particles of nonmetallic inclusions (dark) into matrix of (large grain) lath tempered martensite.

Figure 10 (b) shows the microstructures of stainless steels austenitized at 1100°C and tempered at 450°C, consisting of islands of ferrite (coarse grain white) into matrix of lath tempered martensite.

Figure 10 (c) shows the microstructures of stainless steels austenitized at 1100°C and tempered at 500°C, consisting of islands of ferrite (coarse grain white) and precipitated fine grain $M_{23}C_6$ secondary chromium carbide particles (dark) clearly dispersed regularly at grain boundaries into matrix of (coarse grain) lath tempered martensite.

Figure 10 (d) shows the microstructures of stainless steels austenitized at 1100°C and tempered at 550°C, consisting of islands of ferrite (coarse grain white) and precipitated fine grain $M_{23}C_6$ secondary chromium carbide particles (dark) randomly dispersed at grain boundaries with randomly dispersed spheroidal particles of nonmetallic inclusions (dark) into matrix of lath tempered martensite.

Figure 10 (e) shows the microstructures of stainless steels austenitized at 1100°C and tempered at 650°C, consisting of islands of ferrite (coarse grain white), and particles of $M_{23}C_6$ secondary chromium carbide (dark) at grain boundaries with nonmetallic inclusions (dark) into matrix of lath tempered martensite.

6. CONCLUSIONS

1. The mechanical properties and microstructure of martensitic stainless steel were improved due to quenching at temperature of 1050 °C and 1100 °C, with tempering at 450°C. The result shows microstructure with intensive small grain size.

2. The grain size was increased with increasing the tempering temperature from 450 to 550 ºC which lead to decrease hardness of quenching metal.

3. It was found that at quenching temperature of 900 °C, undissolved coarse grain of chromium carbide in the microstructure of quenching metal.

Table 1 Chemical Compositions of the AISI 410 Martensitic Stainless Steel examined during the course of this investigation (weight percentage, balance Fe)

Element	C %	Cr %	Mn %	Si %	Mo %	Ni %	P %	S %
As-Received	0.15	12.08	1.16	1.06	0.131	0.952	0.04	0.03
AISI 410	0.08-0.15	11.5-13.5	1.0	1.0	1.0	0.75	0.04	0.03

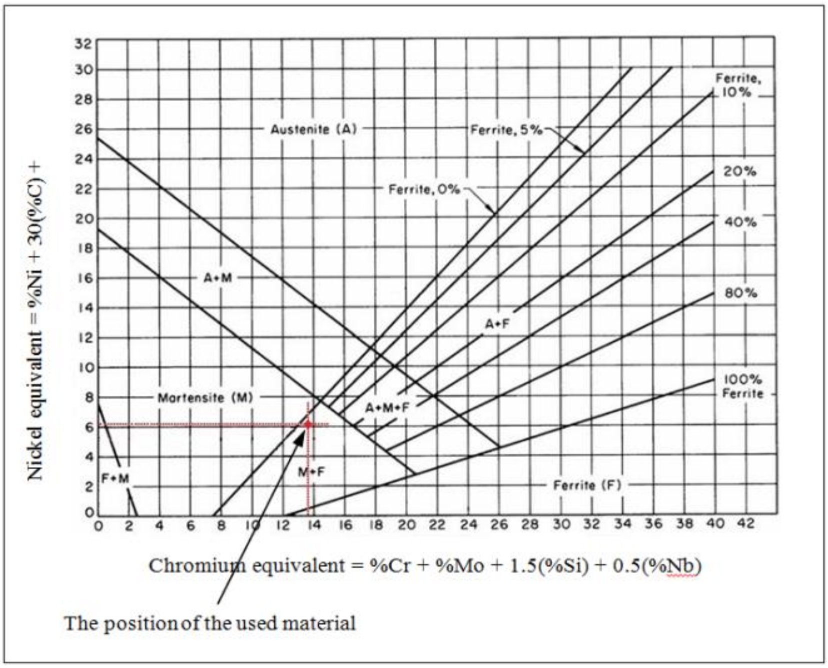

Fig.1 The Microstructure Estimated of Experimental Material by Schaeffler Diagram (Cheng-Hsun Hsu, Hwei-Yuan Teng, 2005)

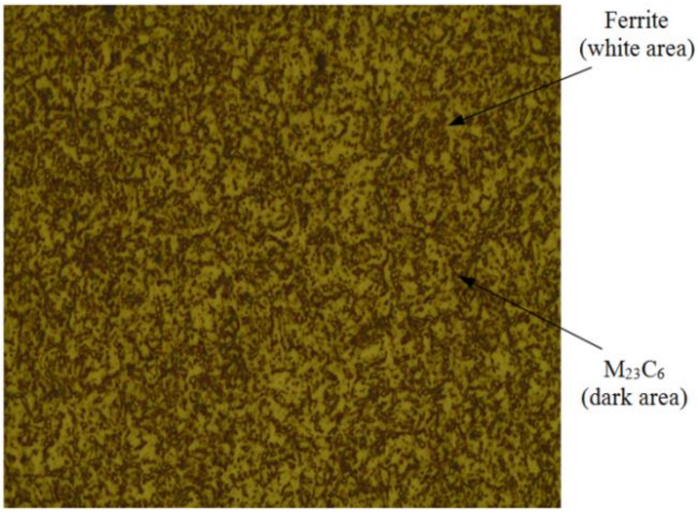

Fig.2 As-received microstructures consisting of partly Spheroidise particles of $M_{23}C_6$ chromium carbide in a ferrite matrix. (Magnification: X500)

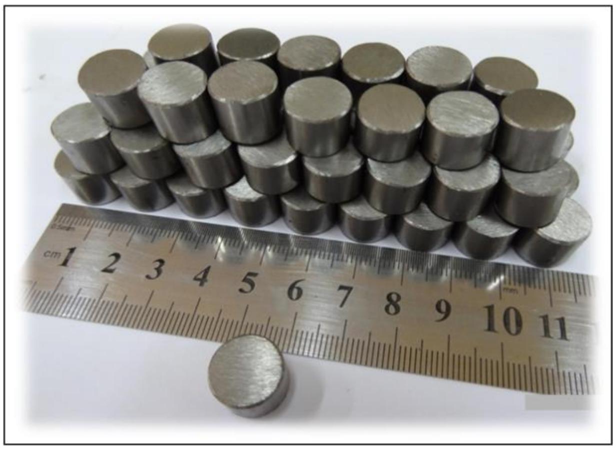

Fig.3 Overall microstructure specimens

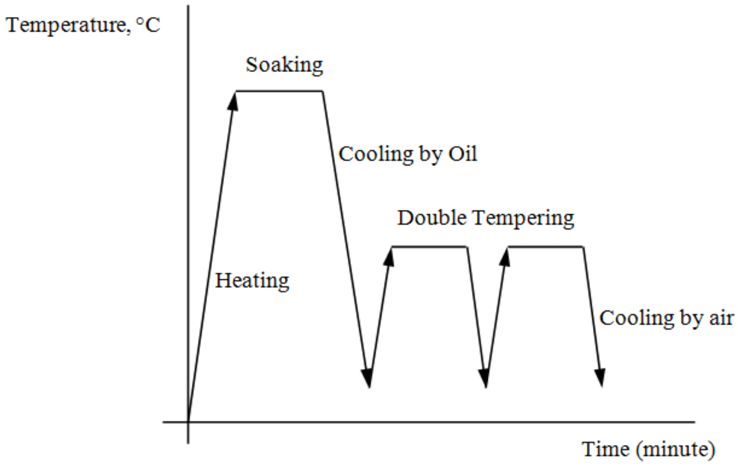

Fig.4 Schematically representation the austenitizing and tempering of heat treatments.

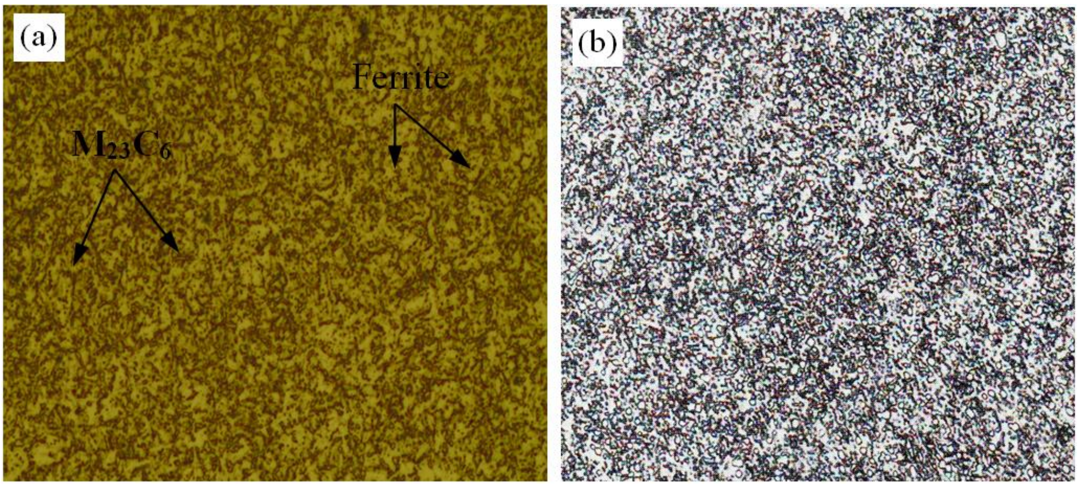

Fig.5 The microstructure consisting of partly Spheroidise particles of $M_{23}C_6$ primary chromium carbide in a ferrite matrix; (a) As-received stainless steel, (b) ASM standard. (Magnification: X500)

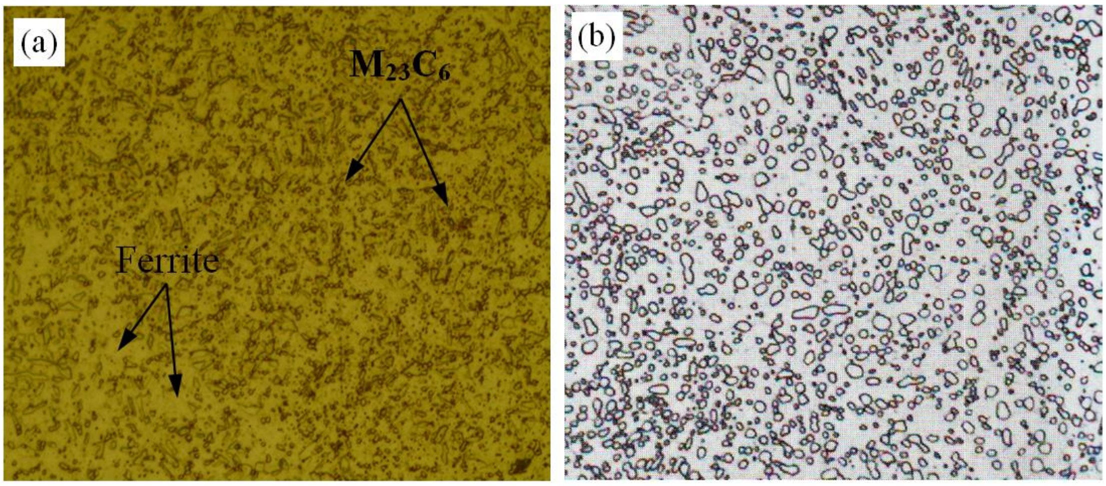

Fig.6 Microstructure consisting of randomly dispersed particles of $M_{23}C_6$ chromium carbide in ferrite matrix; (a) Spheroidise annealed condition, (b) ASM standard. (Magnification: X500)

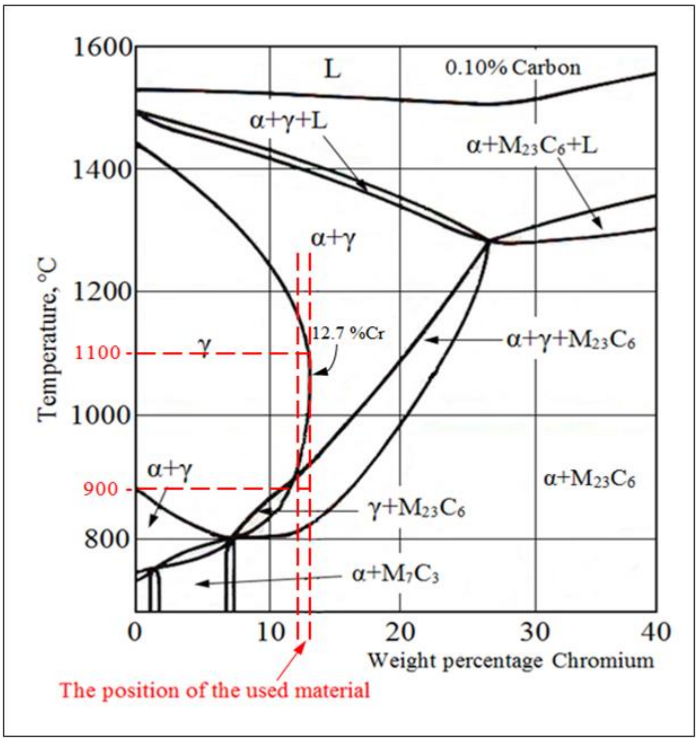

Fig.7 Cr-Fe-C ternary phase diagram at Wt. % C values of 0.10 % (ASM Metals Hand book, 1973)

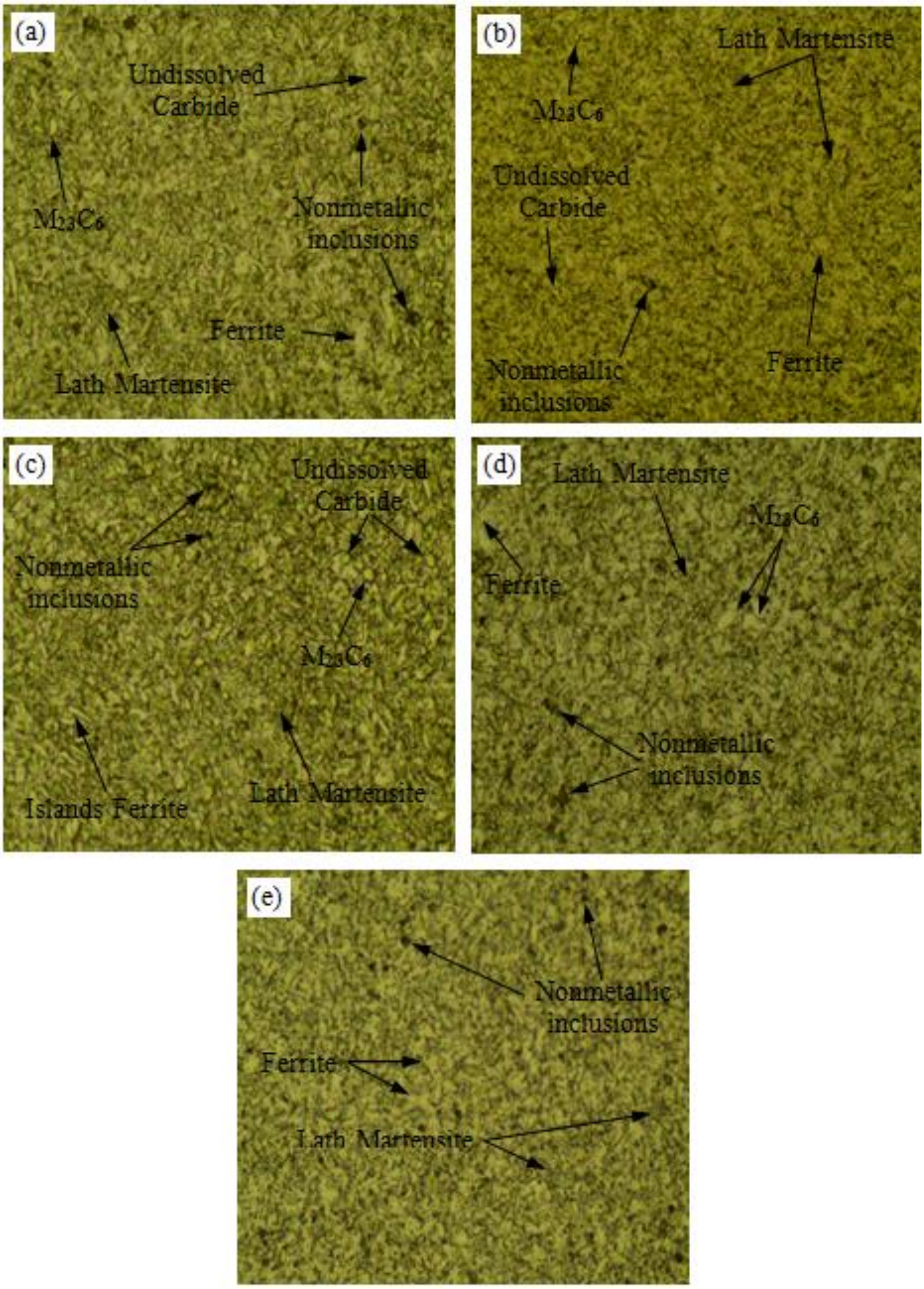

Fig.8 The microstructures of AISI 410 martensitic stainless steels austenitized at 900°C and tempered at, (a) 200°C, (b) 450°C, (c) 500°C, (d) 550°C and (e) 650°C. (Magnification: X500)

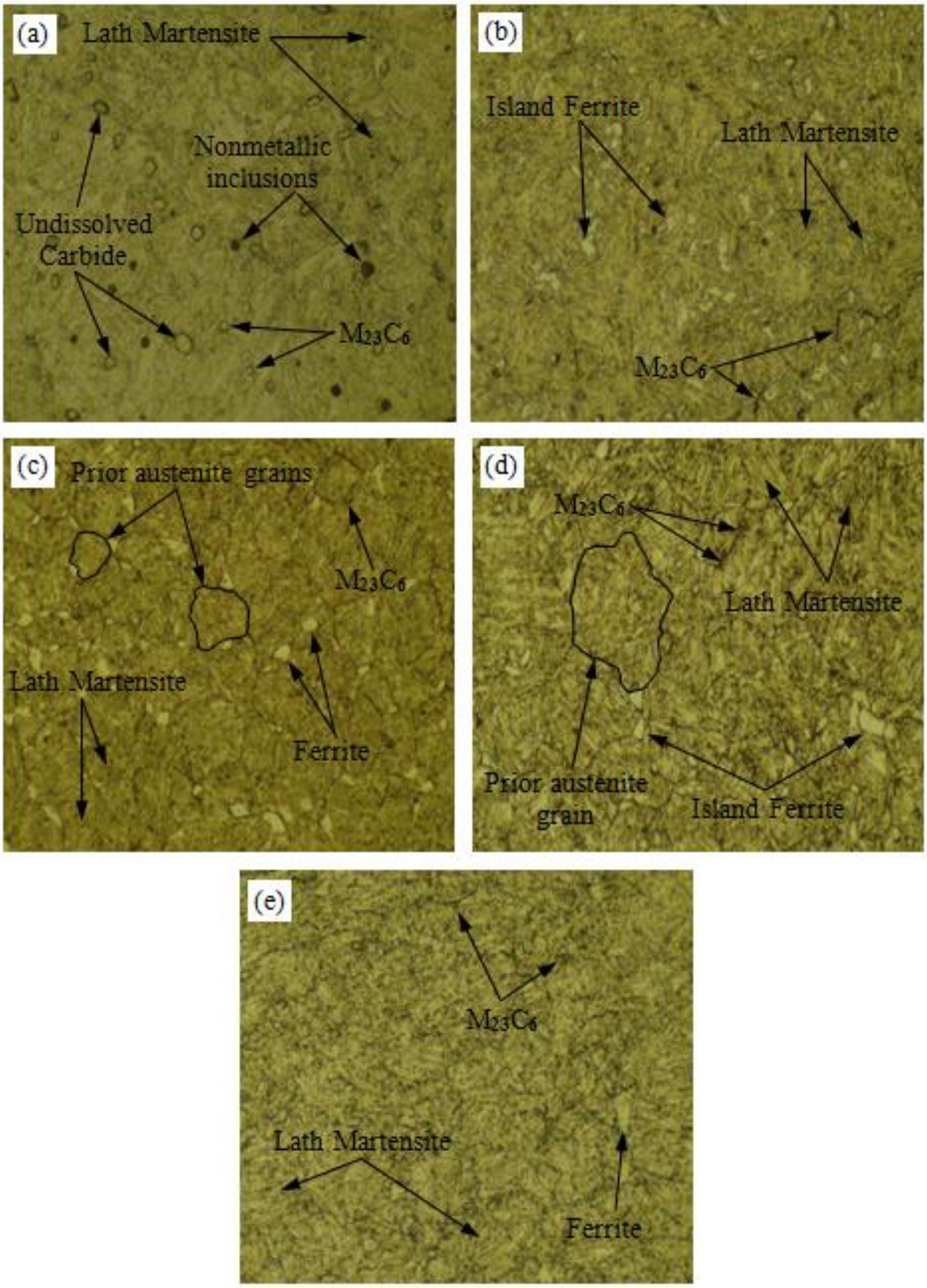

Fig.9 The microstructures of AISI 410 martensitic stainless steels austenitized at 1050°C and tempered at, (a) 200°C, (b) 450°C, (c) 500°C, (d) 550°C and (e) 650°C. (Magnification: X500)

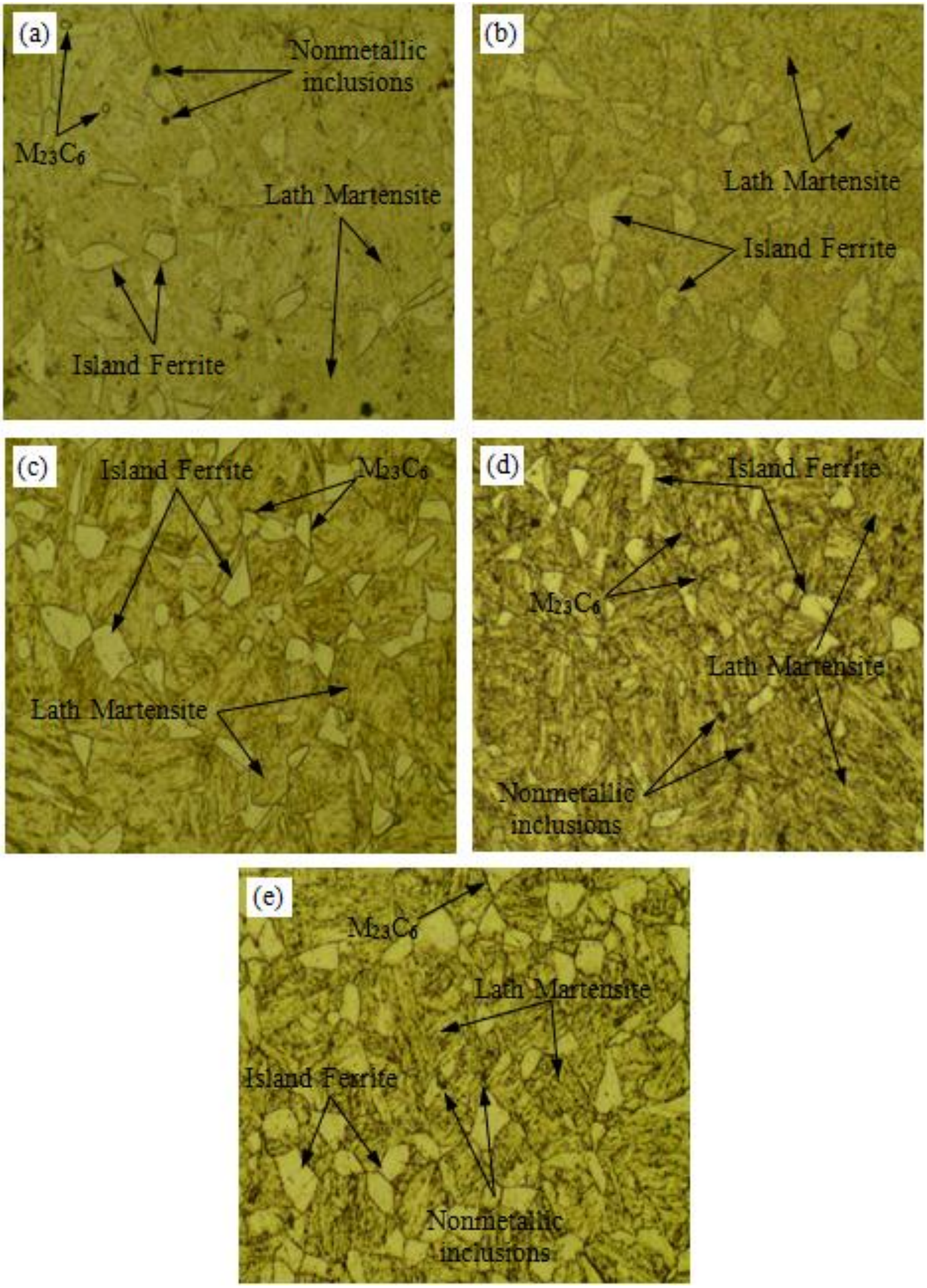

Fig.10 The microstructures of AISI 410 martensitic stainless steels austenitized at 1100°C and tempered at, (a) 200°C, (b) 450°C, (c) 500°C, (d) 550°C and (e) 650°C. (Magnification: X500)

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