EFFECT OF HEAT TREATMENT ON CORROSION BEHAVIOR OF 2205 DUPLEX STAINLESS STEEL IN ORTHODONTIC APPLICATIONS

Ali Sabea Hammood [a], **Ahmed Faraj Noor** [a], **Mohammed Talib Alkhafagy** [b]
alis.altameemi@uokufa.edu.iq, ahmedf.aljabery@student.uokufa.edu.iq, mohamedta@uokofa.edu.iq
[a] **Material Engineering Department, Faculty of Engineering, University of Kufa, Iraq**
[b] **Faculty of Dentistry, University of Kufa, Iraq**

ABSTRACT

The heat treatment is necessary for 2205 duplex stainless steel to remove or dissolve intermetallic phases, removed segregation and to relieve any residual thermal stress in DSS which may be formed during production processes. In the present study, the corrosion resistance of a 2205 DSS in artificial saliva was studied by SEM, XRD, HV test and potentiodynamic measurements. The results indicated that the corrosion resistance mainly effected by ferrite /austenite ratio. The best result was obtained with the treatment at 900°C for 2 min. The austenite phase has corrosion resistance higher than ferrite.

Key word: 2205 Duplex stainless steel, Heat treatment, Artificial saliva, Cyclic potentiodynamic, Orthodontic applications .

تاثير المعاملة الحرارية على تصرف التاكل لسبيكة الفولاذ المقاوم للصدألمزدوج في تطبيقات تقويم الاسنان

علي سبع حمود احمد فرج نور محمد طالب الخفاجي

الخلاصة :-

المعالجة الحرارية ضرورية لل2205 للفولاذ المقاوم للصدأ المزدوج لإزالة أوتذويب أطوار المركبات المعدنية و إزالة الانعزال وكذلك توهين الإجهادات الحرارية المتبقية في الفولاذ المقاوم للصدأ المزدوج والتي تتكون أثناء عمليات الإنتاج. في هذه الدراسة تمت دراسة مقاومة التآكل لل2205 الفولاذ المقاوم للصدأ المزدوج في اللعاب الاصطناعي بواسطة المجهر الاكتروني الماسح، حيود الأشعة السينية، صلادة فيكرز وأختبار التأكل الكهروكيمياوي وتشير النتائج إلى أن مقاومة التآكل تتأثر بصورة رئيسية لوجود أطوار الثانوية (طور سيكما (ونسبة الفرايت / الأوستينايت. تم الحصول على أفضل النتائج مع المعالجة الحراريه عند 900 درجة سيليزية لمدة 2 دقيقة. طور الأستينايت يمتلك مقاومة للتآكل أعلى من الفرايت و طور سيكما له تأثير ضار على سلوك التآكل لل 2205 الفولاذ المقاوم للصدأ المزدوج .

Received : 2017 – 3 - 14
Accepted : 2017 - 4 - 27

INTRODUCTION

Duplex stainless steels (DSS) which consists of two-phase austenite–ferrite microstructures are essential for many applications such as gas refineries, petroleum, and marine media due to their excellent mechanical strength, toughness, hardness and corrosion resistance with relatively low cost (**S. M. Yang et al 2016**) (**N. Ebrahimi ea al 2011**). Chromium (Cr) and molybdenum (Mo) are ferrite stabilizer elements, while nitrogen (N) and nickel (Ni) are primarily enriched in austenite (N. **Sathirachinda ea al 2009**). The duplex stainless steel exhibit complicated phase transformations and precipitation behavior since it contains high alloying elements. Generally, the optimum properties can be obtained with around equal volume fraction of austenite and ferrite without secondary phases such as sigma phase (**N. Ebrahimi ea al 2011**).

The duplex stainless steel has low nickel content compared to 316 austenitic stainless steel as well as higher mechanical strength with acceptable plasticity, the lower nickel content can be considered as an advantage to be used as a biomaterial used in human body. Therefore the DSS is currently used as a biomaterial instead of austenitic stainless (**L. Jinlong et al 2016**).

Many authors studied corrosion behavior of duplex stainless steel in deferent conditions. As concerns the biomedical application, **(A. Kocijan et al 2011**) confirms that the corrosion characteristics of 2205 DSS are better than those of AISI 316L stainless steel, especially under potentiodynamic conditions. This confirms the suitability of 2205 DSS for orthodontic applications in the presence of artificial saliva and with the addition of fluoride ions. **(Souza et al 2017**) presented a study on the influence of ferrite phase content on the electrochemical properties of duplex stainless steels. **(M. Davanageri et al 2015**) studied the influence of heat treatment on microstructure, hardness and wear behavior of super duplex stainless. The aim of this study is use 2205 DSS in the orthodontics applications (wire, bracket and band) as alternative material for 316 to enhanced corrosion resistance. Where the DSS has higher corrosion resistance than and 316 stainless steel and in order to cost-savings due to the lesser Ni amount, Where the 2205 DSS lesser cost than 316. The improvement with respect to orthodontic applications is the decrease in the nickel hypersensitivity effect for patients undergoing orthodontic treatments . Also selection improper heat treatment to improve corrosion resistance of 2205 DSS .

EXPERIMENTAL PROCEDURE

Materials and Heat Treatment

Super duplex stainless steel plates SAF 2205 are employed, the chemical composition of the 2205 duplex stainless steel alloy is shown in Table 1.It agreement with UNS S32760 ASTM A 182/A 182M. Solution treatment was first performed at 115^{0}C for 15 minute (for all samples), in the tube furnace, followed by water quenching in accordance ASTM A182.

This solution treatment is necessary to eliminate secondary phases, to balance the phase fractions and to release any residual stress during production processes. The solubilizes samples were heat treated at 800°C for (2, 4, 8 min), at 850°C (2 min) and at 900°C for 2 min then water quenched .

Light Optical Microscopy (LOM)

The preparation of specimens for microstructural examination were performed according to ASTM standard (E3-01),preparations procedures include many steps such as mounting and the surfaces of the samples including the edges were wet ground using 120, 220, 320, 600, 1000, 1200, 2000 and 2500 grit silicon carbide papers. Then these samples were rinsed in distilled water, then polished with diamond past of 0.9, 0.3 µm to get mirror-like surface for the final step. After polishing the specimens cleaned with ultrasonic devices by ethanol media for 10 min. The electrochemical etching was carried out with a solution containing 40 g of NaOH +100 ml of distilled water, at 2V for 10 second (immersion time) with platinum cathode electrode and the sample act as anode. The optical microscopy can reveal the changes in ferrite and austenite phases and detect the presence of third phases. Zeiss axio Cam MRc5 microscope made in Germany was used in this study and the test performed in the Outo Kumpo Stainless steel Avesta Research Center, Sweden

Scanning Electron Microscopy (SEM)

SEM is one of the common methods for analysis techniques in which a wide range of feature can be observed. SEM is use to identify surface morphology features as well as to better understand the microstructural characteristics associated with the austenite, ferrite and intermetallic phases. As well as the chemical compositions of samples were performed by energy dispersive spectroscopy (EDS). In the present work, the test has been carried out in the laboratory of material in Al-Razi Metallurgy Research Center-Iran by using SEM type (TM = 1000 Hitachi table top Japan).

Vickers Micro-Hardness Test

Hardness test was carried out by a Vickers micro hardness tester Machine (TH715. Beijing Time High Technology Ltd), with an attached microscope, at 400X total magnification according to ASTM E 384 – 99. The test carried out in the Materials Engineering Department- University of Kufa .

X-Ray Diffraction (XRD)

X-ray diffraction used for phases identification (The SHIMADZU LabX XRD-6000, Japan x-ray), with nickel filter and Cu Kα radiation ($\lambda = 1.5406$ A^o). The scanning speed of the diffract meter was adjusted to 6^o per minute with the range of the diffraction angle 2θº was (40º-100º). The test accomplished at University of Baghdad, college of education for pure science)\Ibn Al-Haitham

Electrochemical Corrosion Tests

Two types of corrosion tests have been performed in artificial saliva which composition is presented in Table 2. The first one is potentiodynamic polarization by using three-electrode electrochemical cell, with a platinum counter electrode and a saturated calomel reference electrode (SCE) and working electrode (DSS).The cell contains an electrolyte which simulates the natural saliva, according to (ASTM G5–94 Reapproved 1999 updated 2002), Polarization tests were performed in potentiostat type (Winking M Lab 200). The second cyclic potentiodynamic polarization technique was used to determine the pitting behavior of the 2205 DSS. The cyclic potentiodynamic polarization method gives a reasonable, quick method for qualitatively predicting the propensity of an alloy or metal which suffer of pitting corrosion.

The specimens were prepared into discs with 1cm^2 surface area and 2 mm height. All samples prior to tests were ground with SiC emery paper up to 3000 grit then polished. After polishing, the specimens were cleaned with ethyl alcohol and dried with an air stream. Prior to testing, all specimens were immersed in the electrolytes and the cell was left to stabilize the open circuit potential (OCP). The potential scanning rate was 1mv/s and the scanning rate was (-300 to 200) mV vs. a saturated Calomel electrode.

The corrosion rate measurement is obtained by applying the following equation (**M. Anna and S. O. Janus 2011**)

$$\text{corrosion rate (mpy)} = \frac{0.13 icorr(E.W.)}{A.\rho} \qquad (1)$$

Where:

E. W. = equivalent weight (g/ eq.).

A = area (cm^2).

ρ = density (g/ cm^3).

0.13 = metric and time conversion factor.

I_{corr} = current density (μA / $cm^{2)}$.

RESULTS AND DISCUSSION

Effect of solution treatment on microstructure and phases fraction

The micrograph of the 2205 duplex stainless steel as shown in Fig. 1, the microstructure for untreated specimen contains only ferrite and austenite and no secondary phases were observe. The ferrite appears darker than the austenite on the micrograph. Quantitative analysis of the microstructure using MIP4 student material program gave an area fraction of 50.5% ferrite and 49.5% austenite.

After heat treatment secondary phases may be formed and will subsequently influence the corrosion and mechanical properties of the material in service conditions. The types of secondary phases and its volume fraction depend on many factors such as ageing temperature, and ageing time. The heat treatment temperature and time effect of 2205 duplex stainless steel as shown in Fig. 2, when 2205 DSS treated by temperature less than the solution annealing temperature, the metastable thermodynamic balance was discomposure, result in the material to try for a more stable thermodynamic state through the precipitation of secondary phases. Sigma phase preferentially nucleated at the α/γ or α/α interfaces and grew through the adjacent ferrite due to the ferrite phase is unstable at high temperatures due to the diffusion rates of alloying elements are 100 times faster than diffusion rates values in the austenite and the ferrite is enriched in chromium and molybdenum, which lead to the formation of secondary phases. duplex stainless steel where intermetallic not appeared when 2205 DSS treated at 800°C for 2, 4, 8 min, and 850°C for 2min as shown in Fig. 2a-d, this result has agreement with (**Calliari et al 2011**) Which estimated that sigma phase appears after about 10 min when 2205 DSS aging 850°C.The specimen was treated at 900°C for 2min also contain ferrite and austenite only as shown in Fig. 2e. The effect of the heat treatment on the constituent phase's morphology of specimens was characterized by the SEM. Fig. 3 shows the morphology of 2205 DSS samples before and after treated at different heat treatment conditions. The darker region represents ferrite phase and brighter region represents austenite phase. Fig. 3a shown the as-received sample did not show any secondary precipitates where it contains ferrite and austenite only. Fig. 3b, c, d, e, f illustrated SEM micrograph of the specimens treated at 800°C for 2min, 800°C for 4min 800°C for 8min, 850°C for 2min and 900°C for 2min respectively, it shows that the samples treated at this conditions had not sensitive to intermetallic precipitations where it has ferrite and austenite. On the other hand, the heat treatment has an effect of the ferrite and austenite volume fraction and its grain size. The volume fraction of ferrite phase increased with increasing ageing temperature and the ageing time influenced directly in the in the volumetric concentrations of the ferrite and austenite phases, the volume fraction of austenite phase increased with time this result in good agreement with (**R. Badji et al 2008**). Other effect of heat treatment appeared with increasing ageing temperature was increasing of ferrite grain size.

Phases identification by XRD

Identification of prescience phases for 2205 DSS samples before and after heat treated curried out by X-Ray diffraction technique. Fig. 4 shows diffraction patterns of 2205 DSS sample before treated and samples treated at 800°C for 2, 4 min. The three diffraction patterns shown the peaks corresponding to ferrite and austenite phase only, no evidence was observed for sigma phase this result in agreement with (**G. Farga et al 2009)**. The examination of the DSS samples evidenced the effect of the treatment temperature on the microstructure. Peaks corresponding to ferrite and austenite were clearly observed in the XRD pattern, whereas sigma phase or secondary phases were not detected as shown in Fig. 5 which represent diffraction patterns of samples treated at 800°C for 8min, 850°C for 2min and 900°C for 2 min, which have agreement with optical microscope and scanning electron microscope images, it proved that the two samples contain ferrite and austenite phase, no evidence was observed for sigma phase in the diffraction patterns of two samples.

Effect of aging treatment on distribution of typical elements in the phases

The chemical composition of the phases: ferrite, austenite and secondary phases were determined by energy-dispersive x-ray spectroscopy (EDS) on samples with different aging temperature and times. Table 3 gives the results of an EDS analysis of each phase of the microstructure of the 2205 duplex stainless steel. The chemical composition of each phase does not vary much with the composition of the base alloys. The EDS analysis results were presented in Table3, it is shown that the ferrite phase is rich in chromium and molybdenum with regard nickel while the austenite phase enriches in nickel and content chromium and molybdenum lower than ferrite phase. These results were in good agreement with others authors (**Calliari et al 2006**).

Effect of aging treatment on the micro-hardness

One of important index of mechanical properties, For different conditions treatments, characterizations of the microstructure were evaluated by metallography and hardness testing ,it’s the micro hardness of the aged samples is also studied as a function depend on the aging temperature and time. Vickers micro hardness values of all aged sample were ranging from 234 to 264 HV and depends on aging temperature and time. The aging treatment in the temperature range between 750–950°C for 2, 4, 8 min would not have great influence on the volume fraction of ferrite and austenite. The hardness of the aged specimens is also investigated as a function of aging temperature and time as plotted in Fig. 6. The initial hardness of untreated sample was 251.5 HV for 2205 duplex stainless steel. On the other hand, the amount of secondary precipitates formed during aging process for 2205 DSS alloy was very small which appeared only at 900,850°C for 8 min. Consequently, the hardness of the aged specimen did not change with aging temperature. The hardness values mainly depends on the presence or absence of sigma phase because it is brittle and hard.

Effect of Heat Treatment on Corrosion Behavior of 2205 DSS

The microstructure change which occurred due to heat treatment and secondary phases precipitated play important role in corrosion behavior of DSS alloys. Where the heat treatment effect on corrosion behavior of DSS mainly through changed the ferrite/austenite ratio where the corrosion occurred preferentially in the ferrite phase of duplex stainless steels and the microstructure observation and metallography of 2205 DSS indicated that the volume fraction of austenite phase decreased with the rise of the aging temperature which leading to increase corrosion rate as shows in Fig. 7. The austenite phase better corrosion than ferrite phase for many reasons such as more nickel content than ferrite, generally the Cr is the most effective element in the passive film to improve the resistance of DSS to localized corrosion where the ferrite phase has more Cr. However, the major alloying element in austenite phase is Ni where as in ferrite phase is Cr. Since Cr is more active than Ni it will probably act as anode. The corrosion potential of Cr in duplex stainless steel was lower than the corrosion potential of Ni in active status, ferrite phase was electrochemically more active. Ferrite is relatively rich in Cr and Mo while austenite was rich in Ni and N, also the nickel has many functions added to control phase balance and element partitioning, but also to increase the corrosion resistance (**H.Y. Liou et al 2001**). Depend on data as shown in the Table 3 the nickel content in the austenite was more than 5% and it was more than that in ferrite.

The sample has better microstructure (ferrite/austenite ratio) has higher corrosion resistance. Fig. 7 shown the relationship between aging temperature and corrosion rate at 2 min which indicated that the corrosion rate increase when the microstructure away from the optimum microstructure. The results showed that the best ferrite/austenite ratio for studied specimens obtained after treated the sample at 900°C for 2 min; therefore this sample has the least current density as shown in Table4 and higher corrosion resistance. The sample treated at 850°C for 2 min which has microstructure near to sample at 900°C for 2 min, therefore it has corrosion resistance less than sample at 900°C for 2 min, but more than others specimens. When ageing time increased from 2 to 8 min (at 800°C) the current density reduced from 3.87 to 1.76 $\mu A/cm^2$, this the corrosion rate of Specimen treated for 8 min less than specimen treated for 2 min, due to increasing in austenite phase fraction these result in agreement with other authors **(C.J. Park et al 2004).** The sample treated 800°C, for 4 min has the current density less than sample treated for 2 min and more than sample treated for 8 min .

The Table 4 which describes the electrochemical parameters values obtained from potentiodynamic polarization indicated that the sample treated at 900°C for 2min has best corrosion properties and the sample treated at 800°C for 2min has lowest corrosion properties.

Cyclic Polarization of 2205 DSS in Artificial saliva

The electrochemical behavior of 2205 duplex stainless steel in artificial saliva before and after ageing treatment were analyzed by cyclic potentiodynamic polarization. In cyclic potentiodynamic, polarization curve consist of forward scan as well as back ward scan starting at active open circuit potential. The open circuit potential (E_{corr}) for 2205 DSS in artificial saliva after ageing, was approximate -200 mV. The pitting potential (E_p) is defined as the potential at which the anodic current density increased sharply with respect to back scan and passive current density.The protection potential (E_{prot}) is the noblest potential where pitting and crevice corrosion will not propagate and at which re-passivation occurs or it is the potential at which the reverse scan intersects the forward scan at a value that is less noble than E_p. If E_{prot} is high or more anodic, that is minimal hysteresis, then the metal is said to be very resistant to crevice corrosion.

ΔE ($E_p - E_{prot}$) represents the corrosion resistance of the materials and the smaller the ΔE value is the better the anti-corrosion property. Cyclic Potentiodynamic polarization analyzed the electrochemical behavior of 2205 duplex stainless steel in artificial saliva at 37°C before and after ageing treatment. Fig. 9 illustrates the cyclic potentiodynamic polarization curves of 2205 DSS specimens in artificial saliva solution. It shown that the sample was treated at 900°C for 2 min has best pitting corrosion resistance, where it has the highest break down or pitting potential as shown in Table 5 which illustrates electrochemical parameters of 2205 DSS before and after heat treatment obtained in artificial saliva solution with cyclic polarization, and it has the highest protection or re-passivation potential (-58.3 mV).this mean that the repair of protective film and re-passivation process occurred more readily when it compared with others specimens. The sample has microstructure nearest to microstructure sample treated at 900°C for 2 min, which it treated at 850°C for 2 min has pitting potential (205 mV), this gives evidence that the pitting resistance depends on microstructure. The specimen which has the lowest pitting corrosion resistance, it was treated at 800°C for 2 min which it has pitting potential about (150 mV). The sample which has lower value of ΔE ($E_p - E_{prot}$), if the pitting occurred the propagation happened in a smaller voltage range as in specimen treated at 800°C for 8 min.

Effect of aging treatment on the nickel ion released for 2205 DSS in artificial saliva.

Amounts of nickel ion released from the 2205 duplex stainless steels in artificial saliva at 37 °C versus immersion time was 28 day were shown in Table 6. All tested specimens have Accumulated Ni released with safe limits where less than normal Daily intake 200 – 300 μg / day (**M. Kuhta et al 2008**).

The amounts of nickel released from all samples much less than safe limit and less than less than the mount that released from 316 SS. The amount of Ni released for specimen in Table 6 less than amount of Ni released for 316 SS (**O. Sobol et al 2016**). This has advantage in biocompatibility, thus decreased nickel sensitivity which cause by orthodontic wire. As mention previously the heat treatment effected on microstructure (changed the austenite/ferrite ratio and may precipitated a secondary phases), and this influence on the corrosion resistance of DSS alloys specimens.

The sample was treated at 900°C for 2 which has better microstructure ratio, the last four specimens in Table 6 released nickel ion lower than specimen before heat treatment.

CONCLUSIONS

1- The SAF 2205 is considered to be a promising material as biomaterial in orthodontic wire applications due to the increased corrosion resistance compared to AISI 316L stainless steel. The main improvement with related to biomedical field is relatively low nickel content and the decrease in the nickel hypersensitivity effect for patients undergoing medical treatments. This demonstrates the suitability 2205 DSS for orthodontic applications in artificial saliva.

2- The heat treatment is necessary for 2205 duplex stainless steel to eliminated or dissolve intermetallic phases, removed segregation and to release any residual stresses in product which may be formed during production processes.

3- The chemical composition, aging temperature and aging time and chemical have an important role in secondary phase precipitations and phases balance in the 2205 duplex stainless steel.

4- Ferrite phase was more inclined to corrosion than austenite phase, indicating that ferrite acts as a preferential anode to austenite phase, Polarization measurements make sure this observation, and proved that ferrite may behave as net anode, ferrite fraction increased when increased aging temperature.

Acknowledgment

The authors would like to thank to assist in the practical part by Dr. Raid Abdul Abbas, Research Engineer- High Performance Stainless &Alloys- Avesta Research Center - Outokumpu Stainless AB, Avesta, Sweden and Al-Razi metallurgy research center-Iran.

Fig. 1. The Optical micrographs of as its 2205 DSS sample, the light area represented austenite while the dark area represented ferrite .

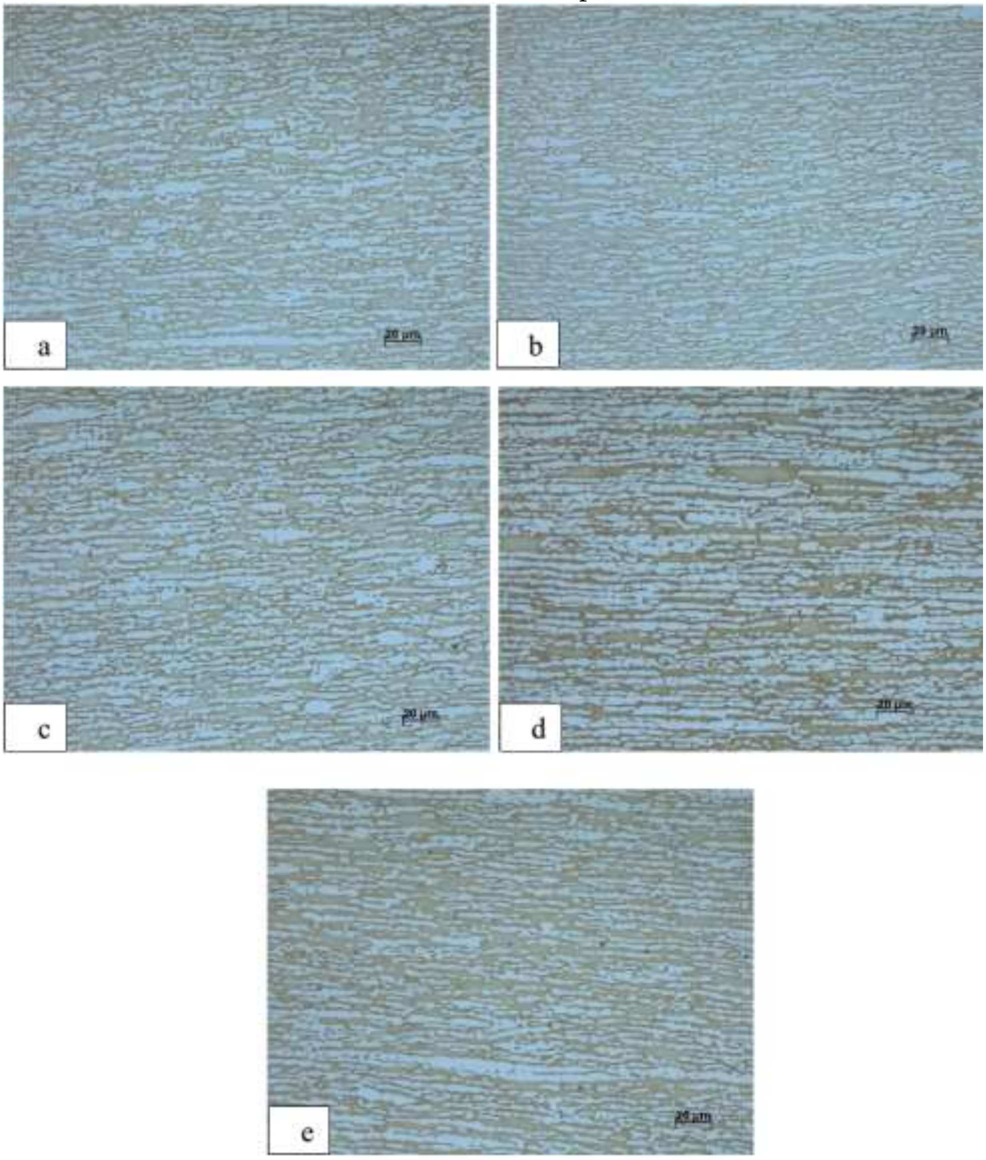

Fig. 2. Optical micrographs of SAF 2205 specimens treated at different conditions, the dark part represents ferrite while the light representing austenite .
(a) 800, °C, 2min (b) 800°C, 4min (c) 800°C, 8min (d) 850°C, 2min (e) 900°C, 2min

.

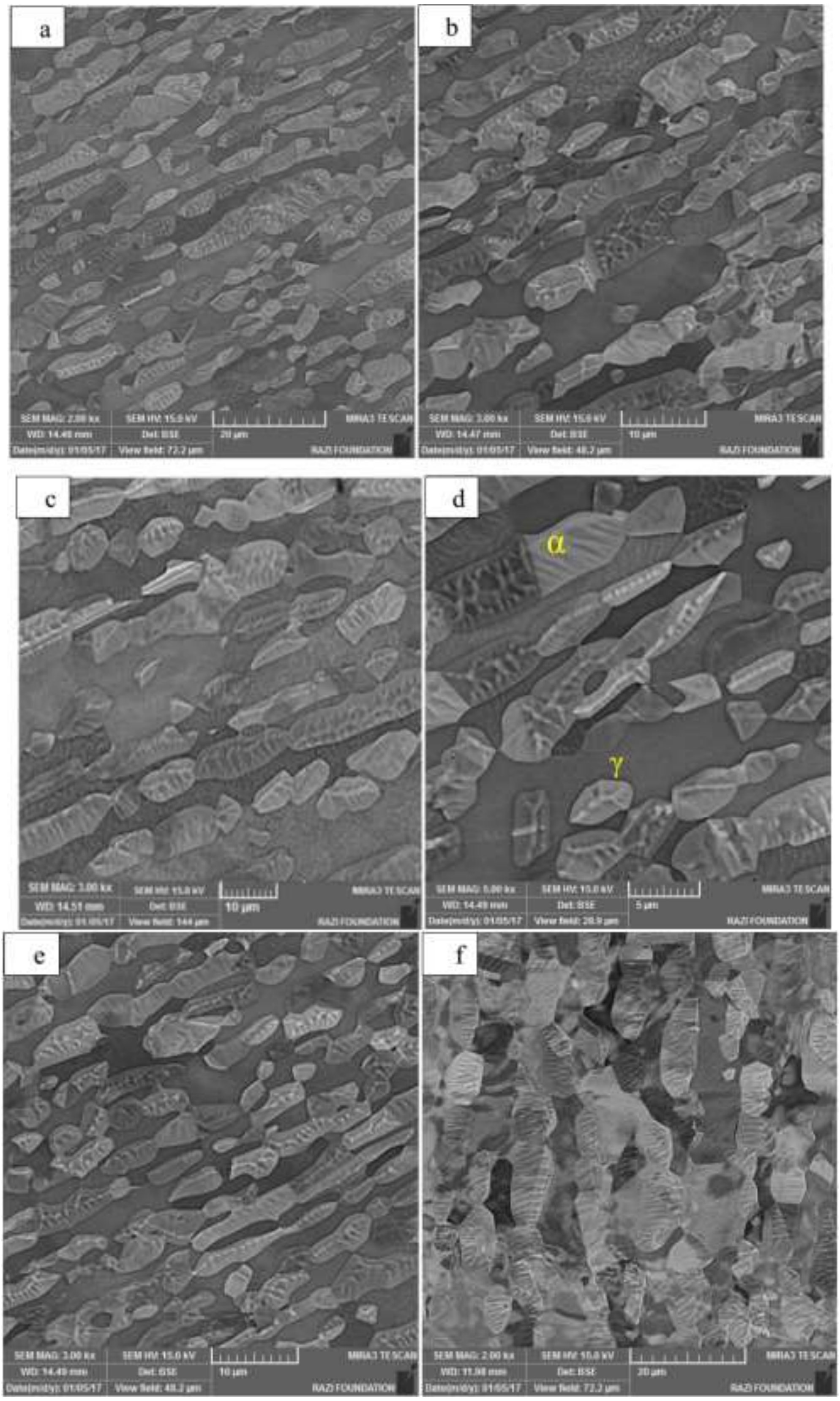

Fig. 3. Morphologies of SAF 2205 specimens characterized by SEM, the dark part represents ferrite while the light representing austenite . **(a)** As its **(b)** at 800°C, 2min **(c)** 800 °C, 4min **(d)** 800°C, 8min **(e)** 850°C, 2min **(f)** 900°C, 2min.

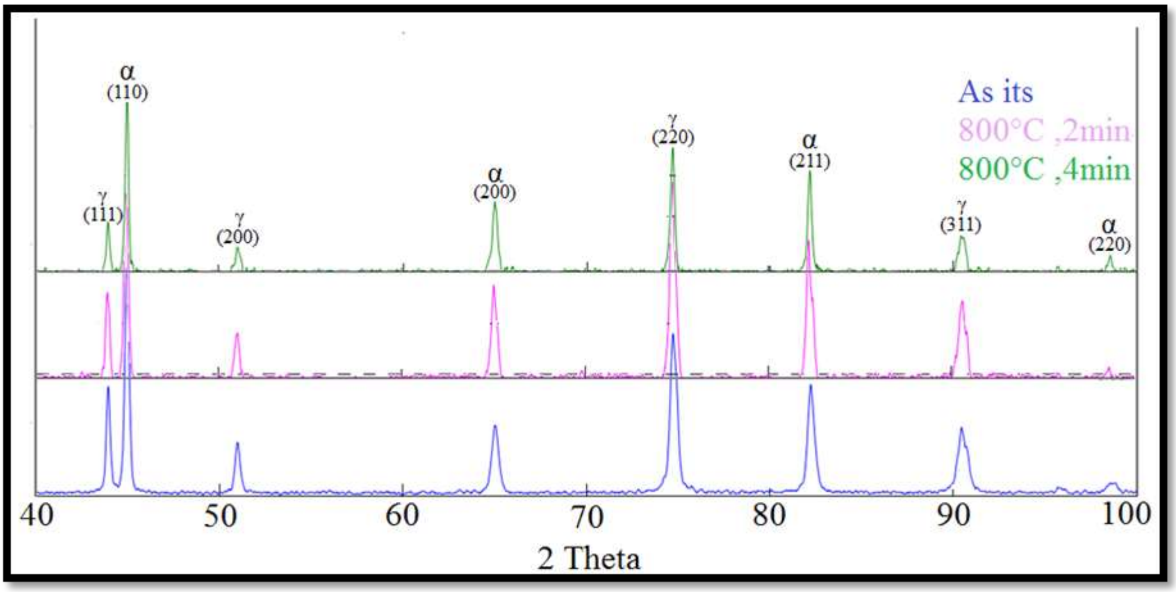

Fig. 4. X-ray diffraction pattern of three specimens of 2205 DSS

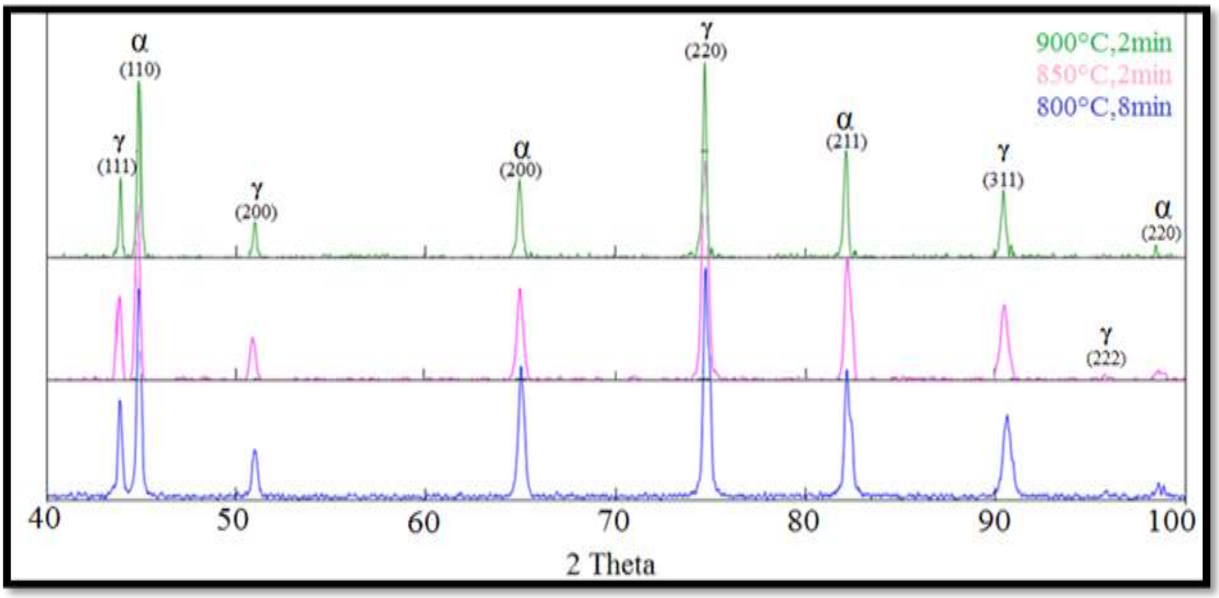

Fig. 5. X-ray diffraction pattern of three specimens of 2205 DSS

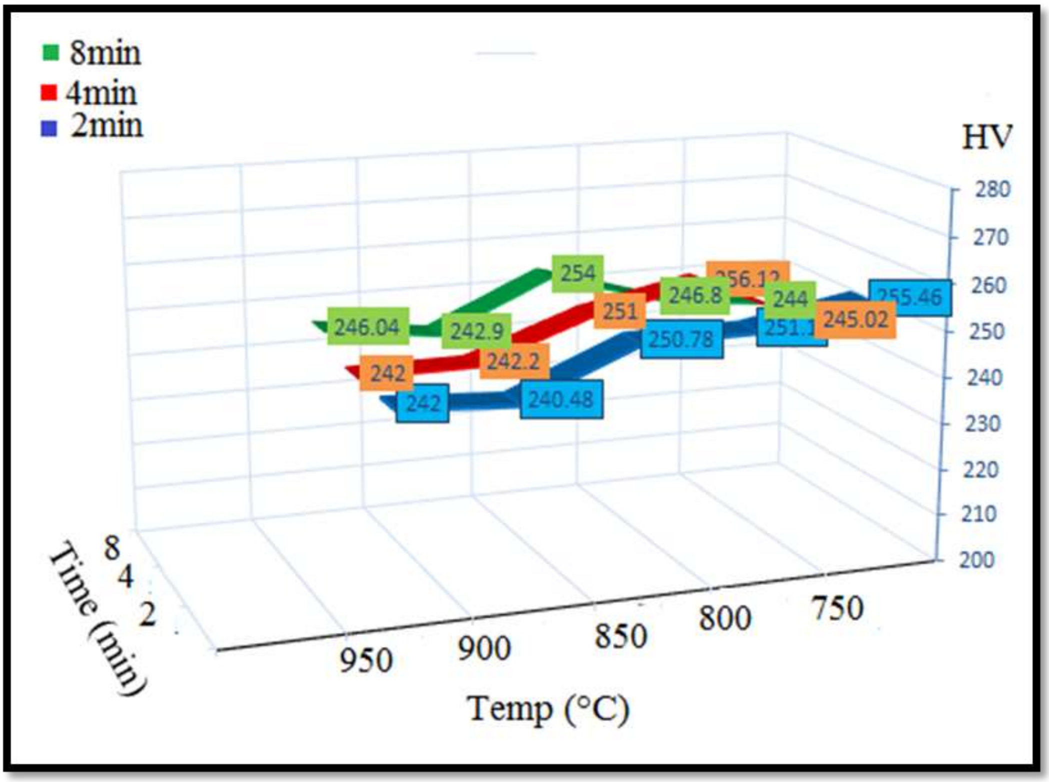

Fig. 6.Variation of micro-hardness values with different ageing temperature for different ageing time.

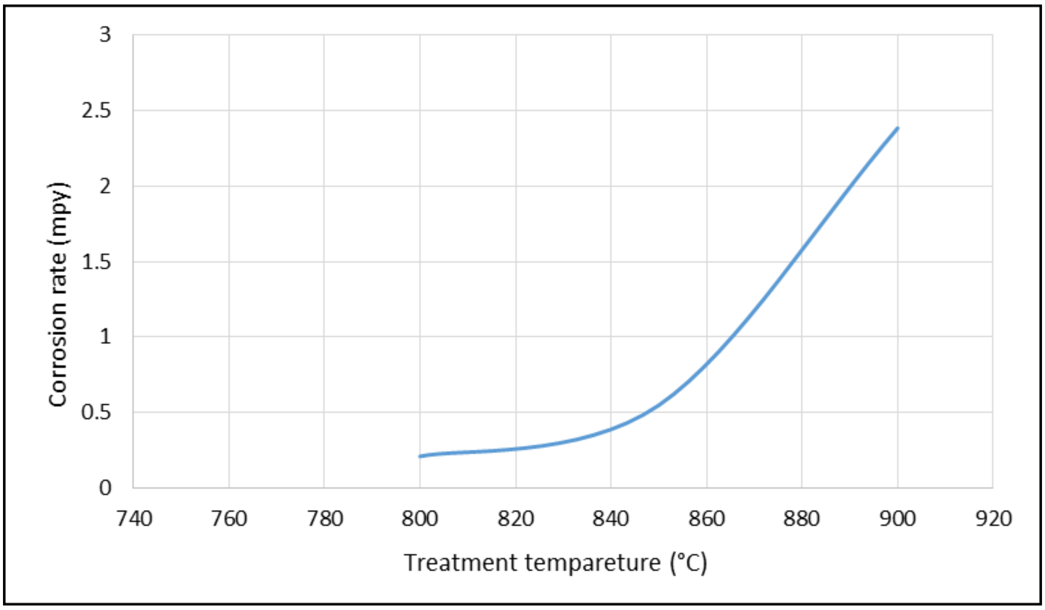

Fig. 7. Relationship between aging temperature and corrosion rate at 2 min.

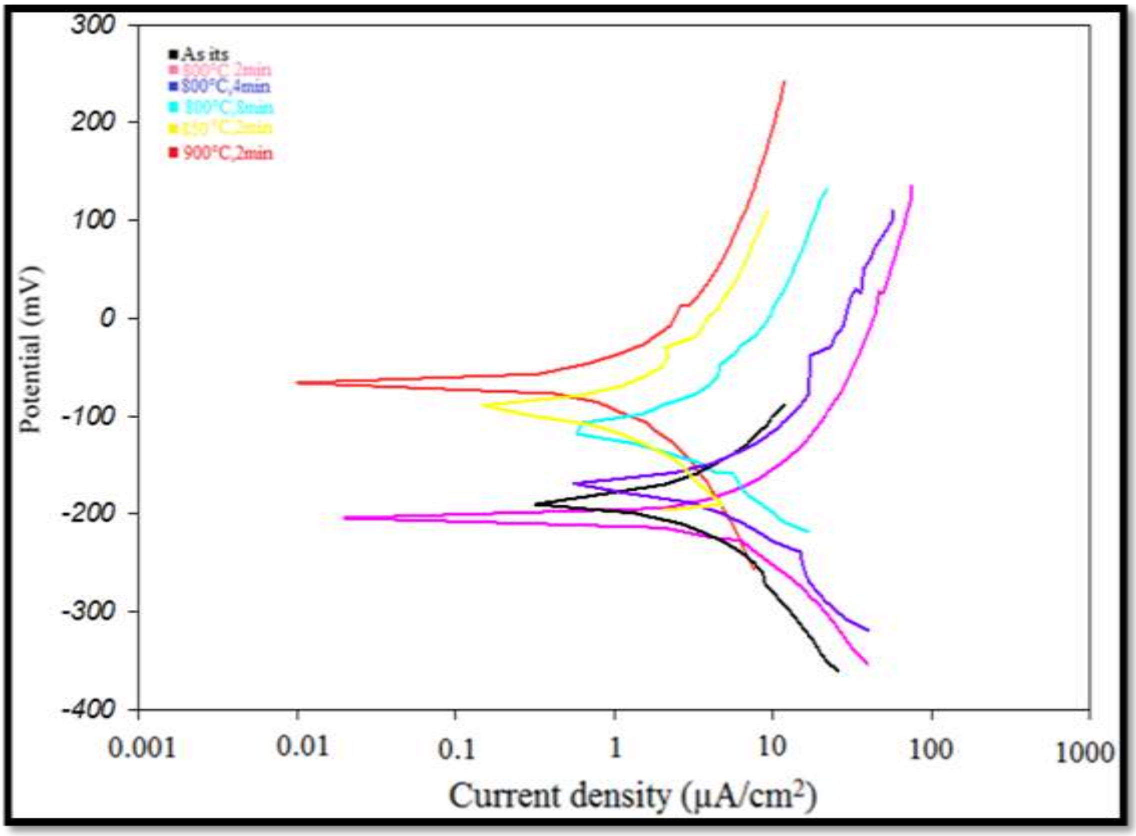

Fig.8. Potentiodynamic polarization curves of 2205 DSS samples in artificial saliva at 37°C.

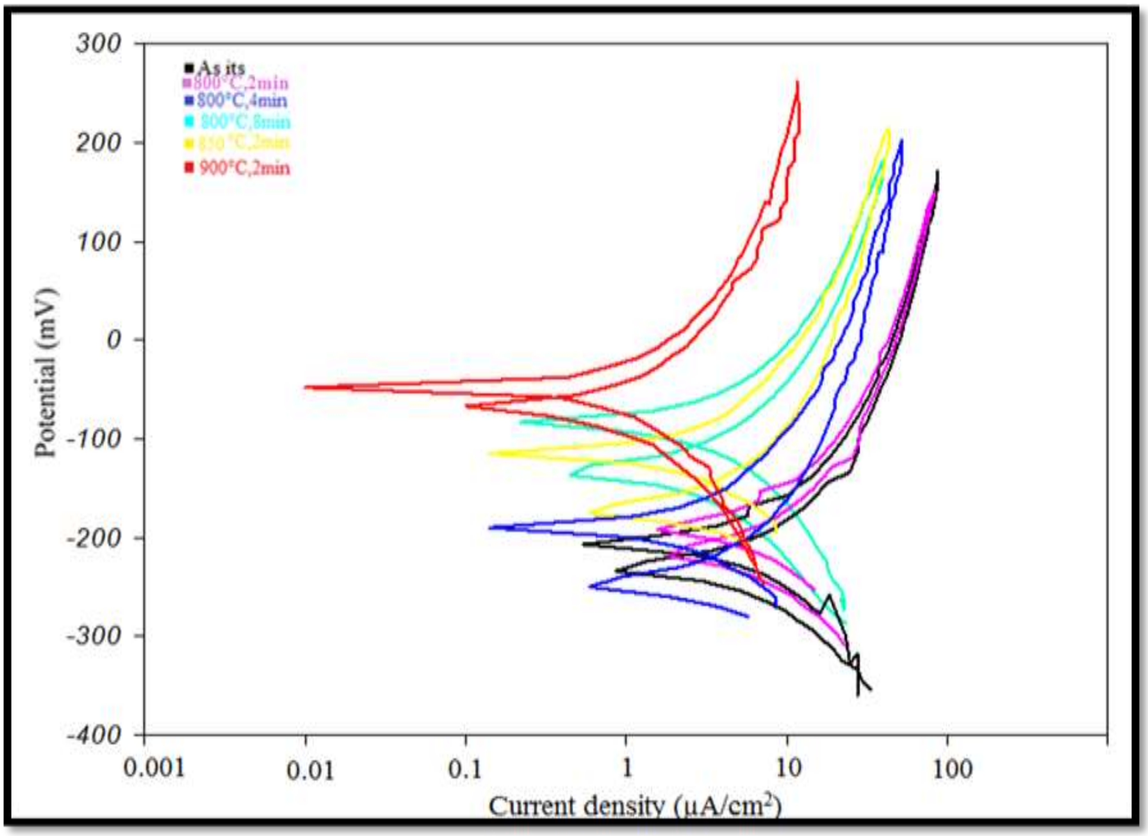

Fig. 9. Cyclic potentiodynamic polarization curves of 2205 DSS specimens in artificial saliva solution

Table 1. Shown the chemical composition analysis of the used 2205DSS alloys .

alloy	ASTM	Cr	Ni	Mo	C	N	Fe
2205	S32205	22.4	5.7	3.1	0.02	0.17	Balance

Table 2. The artificial saliva solution composition (**T. H. Lee et al 2010**)

Compound	Composition (mg/100 mL)
NaCl	40
KCl	40
$Na_2HPO_4H_2O$	69
$Na_2S.9H_2O$	0.5
CaCl2·2H2O	79.5
Urea	100

Table 3 . Chemical composition of various phases obtained by EDS (wt. %)

Treatment Condition (°C, min)	phase	Cr (mean)	Ni (mean)	Mn (mean)	Mo (mean)	Fe (mean)
AS it	ferrite	21.53	3	0.83	5.31	Balance
	austenite	16.98	5.53	0.59	3.12	Balance
800,2	ferrite	21.23	3.03	0.81	5.86	Balance
	austenite	17.4	5.65	0.61	3	Balance
800,4	ferrite	21.61	3.13	0.75	5.65	Balance
	austenite	18.3	5.3	0.64	3.48	Balance
800,8	ferrite	21.46	3.48	0.76	5.54	Balance
	austenite	18.04	5.53	0.6	3.48	Balance
850,2	ferrite	21.07	3.25	0.69	5.55	Balance
	austenite	18.13	5.52	0.65	3.38	Balance
900,2	ferrite	20.77	3.3	0.61	5.23	Balance
	austenite	18.34	5.52	0.49	3.8	Balance

Table 4. Corrosion data obtained from the electrochemical tests at room temperature in artificial saliva.

Treatment conditions (°C), (min)		Current density (μA/cm^2)	Corrosion rate (mpy)
As its		2.12	0.890376
800	2	3.87	1.625356
800	4	2.92	1.226367
800	8	1.76	0.663582
850	2	1.02	0.428388
900	2	0.776	0.325911

Table 5. Electrochemical parameters of 2205 DSS before and after heat treatment obtained artificial saliva solution with cyclic polarization.

Aging temperature (°C)	Aging time(min)	E_{corr} (mV)	E_p (mV)	E_{prot} (mV)	ΔE ($E_p - E_{prot}$) (mV)
As its	-	-207	173	-216.6	389.6
800	2	-195	150	-201	351
800	4	-189	202	-218.7	420.7
800	8	-95	182	-105	287
850	2	-115	205	-145	350
900	2	-48.6	263.8	-59.8	323.6

Table 6. Nickel ion released from the 2205 DSS specimen

Treatment conditions (°C), (min)		Ni ion released(ppm)	Accumulated Ni released rate (μg/cm^2)	Accumulated Ni released (μg)
As its		0.0705	1.0575	2.115
800	2	0.0762	1.143	2.286
800	4	0.0524	0.786	1.572
800	8	0.0677	1.0155	2.031
850	2	0.042	0.63	1.26
900	2	0.0286	0.429	0.858

REFERANCES

S. M. Yang, Y. C. Chen, Y. T. Pan and D. Y. Lin, Effect of silver on microstructure and antibacterial property of 2205 duplex stainless steel, Materials Science and Engineering C. 63. 1 (2016) 376-383.

N. Ebrahimi, M. Momeni, M.H. Moayed, A. Davoodi, Correlation between critical pitting temperature and degree of sensitisationon alloy 2205 duplex stainless steel, Corrosion Science. 53. 2 (2011) 637–644.

N. Sathirachinda, R. Pettersson, J. Pan, Depletion effects at phase boundaries in 2205 duplex stainless steel characterised with SKPFM and TEM/EDS, Corrosion Science. 51. 8 (2009) 1850–1860 .

M. Anna and S. O. Janus, "Biomedical - Engineering, trends, Research and technologies", In tech, Croatia, 2011 .

Calliari, M. Pellizzari, M. Zanellato, E. Ramous, The phase stability in Cr–Ni and Cr–Mn duplex stainless steels , J Mater Sci. 46 (2011) 6919-6920 .

R. Badji, M. Bouabdallah, B. Bacroix, C. Kahloun, K. Bettahar, N. Kherrouba, Effect of solution treatment temperature on the precipitation kinetic of-phase in 2205 duplex stainless steel welds, Materials Science and Engineering A. 496. 1-2 (2008) 447-454.

G. Fargas, M. Anglada and A. Mateo, Effect of the annealing temperature on the mechanical properties, formability and corrosion resistance of hot-rolled duplex stainless steel, Journal of Materials Processing Technology. 209. 4 (2009) 1770-1782 .

Calliari I, Zanesco M, Ramous E, Influence of isothermal aging on secondary phases precipitation and toughness of a duplex stainless steel SAF 2205, Journal of Material Science. 41. 22 (2006) 7643-7649 .

H.Y. Liou, Y.T. Pan, R.I. Hsieh and W. T. Tsai, Effects of alloying elements on the mechanical properties and corrosion behaviors of 2205 duplex stainless steels, Journal of Materials Engineering and Performance. 10. 2 (2001) .231-241

C.J. Park, H.S. Kwon, M.M. Lohrengel, Micro-electrochemical polarization study on 25% Cr duplex stainless steel, Materials Science and Engineering A. 372 1-2 (2004)180-185.

M. Kuhta, D. Pavlin, M. Slaj, S. Varga, M. Lapter and M. Slaj, Type of arch wire and level of acidity: Effects on the release of metal ions from orthodontic appliances, Angle Orthodontic. 79. No 1 (2008) 102-110 .

O. Sobol, G. Holzlechner, G. Nolze, T. Wirth, D. Eliezer,T. Boellinghaus, W. E. Unger, Time-of-flight secondary ion mass spectrometry (ToF-SIMS) imaging of deuterium assisted cracking in a 2205 duplex stainless steel microstructure, Materials Science and Engineering A. 676 (2016) 271-277 .

T. H. Lee, T. K. Huang, S.Y. Lin, L. K. Chen, M. Y. Chou and H. H. Huang. Corrosion resistance of different nickel-titanium arch wires in acidic fluoride-containing artificial saliva. Angle Orthodontist, 2010, 80(3): 547-553.