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* **Corresponding author.**

gne.deep@gmail.com

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Experimental studies on effect of post weld heat treatments on the pitting corrosion and impact toughness of GTA welded martensitic stainless steel joints

Mandeep Singh^{1*}, Dilbag Singh², A S Shahi³

1 Department of Mechanical Engineering, I.K.Gujral Punjab Technical University, Kapurthala

2 Department of Mechanical Engineering, Beant College of Engineering & Technology, Gurdaspur, India

3 Department of Mechanical Engineering, Sant Longowal Institute of Engineering & Technology, Longowal, Sangrur, India

Abstract

Objectives: The present experimental work investigates the effect of post weld heat treatments on the pitting, impact toughness and metallurgical properties of gas tungsten arc welded martensitic stainless steel joints.

Methods/Statistical analysis: Martensitic stainless steel (AISI410 SS) cold rolled plates used as a base materials and welded using GTAW process with two filler materials (ER 304LSS and ER 410 SS for root pass and cover passes respectively). Three heat treatments namely annealing, quenching and plasma nitriding were given to the specimens. After the heat treatments the specimens were subjected to pitting corrosion test, impact toughness test, microhardness testing and microstructural examination. **Findings:** Pitting corrosion results under different heat treatments of the welds showed that the post weld heat treatment induces the significant variations in the pitting resistance. The maximum pitting resistance (minimum mass loss of 0.5108mg) was possessed by the weld with plasma nitriding treatment. The maximum energy absorption capacity of the welds of 62 Joules was obtained in the annealing treatment. The average microhardness values of 474VHN, 372 VHN, 492VHN and 559VHN was obtained in as welded condition, under annealing treatment, under quenching treatment and under plasma nitriding treatment respectively of the welded joints. Based on the micro-structural studies of the welded joint in as received and post weld heat treated conditions, the significant microstructural changes were observed in weld metal zones. **Novelty/Applications:** The present experimental study can beneficially be adopted for welding of martensitic stainless steel (AISI 410 SS) as it suggests the processing conditions to forecast the adequate pitting resistance, impact toughness and microhardness behaviour in similar service conditions.

Keywords: Pitting corrosion; impact toughness; post weld heat treatments; microhardness; microstructure; GTAW

1 Introduction

Martensitic (AISI 410) stainless steels are heat treatable type of steel and contain 11.5% to 13% chromium. The combination of strength, toughness, hardness, corrosion resistance, wear resistance and good weldability makes the alloys attractive for the industrial applications such as steam turbine blades, hydraulic turbine blades, valves, bearings, pressure vessels and cutting tools. The metallurgical performance and mechanical performance of the martensitic stainless steels can be modified by heat treatments. The properties of the welded joints are further depends on the various factors like welding process, welding parameters (heat input), filler material, shielding medium, joint design etc. Different post weld heat treatments (annealing, tempering, quenching etc) effect the metallurgical behaviour and mechanical properties of the welded joints⁽¹⁾.

Furthermore, the pre heating temperature and heat treatment parameters (temperature, soaking period and cooling rate) are also affecting the properties of the joints⁽²⁻⁵⁾. Tempering treatments helps to improve the impact toughness of the welds, and this improvement in the toughness of welds due to the coarsening of lath martensite⁽⁶⁾. The surface properties like hardness, wear resistance and corrosion resistance of the martensitic stainless steel can be modified by using plasma nitriding and nitrocarburising treatments.

During the solidification mechanism of martensitic stainless steel the delta ferrite starts to transform into austenite at around 1300 °C and ends at around 1200 °C in thermodynamically equilibrium conditions. At lower temperature the austenite transforms to martensite. During these transformations the small amount of retained ferrite and retained austenite present in the microstructure between the martensite laths^(7,8). The most common phase in the microstructure of martensitic stainless steel is lath martensite. The microhardness and wear property of the welded joint depends on the amount and type carbides. The amount of metallic carbides will depends on the heat treatment temperature, soaking period and cooling rate⁽⁹⁻¹¹⁾. The distribution of carbides in the matrix also contributes the higher strength and ductility of the weld metal. The cooling rate affects the martensite start temperature which decreases with increasing the cooling rate, greater deformation of prior austenite causes mechanical stabilisation of the austenite and leads to the difficulty of martensite lath propagation into austenite^(12,13). The corrosion-erosion resistance of the martensitic stainless steel can be improved by nitriding treatment, and the wear resistance and corrosion resistance reduces with increasing the testing temperature⁽¹⁴⁾.

Several experimental studies have conducted and reported on the welding of martensitic stainless steel using various welding processes. However, no such studies on the influence of heat treatments on the pitting and impact toughness behaviour of the AISI 410SS welded joints have been reported. So with the aim of to overcome this research gap, the effect of post weld heat treatments (annealing, quenching and Plasma Nitriding) on the pitting and energy absorption behaviour of the gas tungsten arc welded martensitic stainless steel joint was investigated.

2 Materials and Methods

In the present work the martensitic stainless steel (AISI 410SS) was used as a base material (300 mm length, 75mm width and 6mm thick) in the form of rolled plates. The spectroscopy report (chemical composition) of the base plates and filler materials are reported in the Table 1. Gas tungsten arc welding process and industrially pure argon shielding gas was used to weld the base plates. The welding of base plates was completed in four passes (including one root pass, two cover passes and one back cover pass) by ensuring full penetration of filler material in the weld groove with gas tungsten arc welding (GTAW) process with straight polarity (electrode negative and base plates as positive). The welding parameters were used to weld the base plates are presented in Table 2. The filler material (solid wires of diameter 1.6mm) used for the fabrication of the welded joint were ER 304L for root pass and ER 410 for cover passes⁽⁵⁾.

Table 1. Chemical composition (wt. %) of the base material and filler materials

Elements	C	Cr	Ni	Mn	S	Si	Mo	P	Fe
Base Material (AISI 410 SS)	0.01	11.50	0.60	1.27	0.01	0.44	0.20	0.02	Balance
Filler Material (ER 304LSS)	0.02	18.52	9.53	1.39	0.032	1.12	–	0.04	Balance
Filler Material (ER 410 SS)	0.12	12.51	0.55	0.61	0.035	0.51	0.60	0.03	Balance

Table 2. Welding parameters during deposition of weld passes in AISI type 410 stainless steel plates

Weld Pass number	Welding (ampere)	Current	Arc Voltage (volt)	Arc travel (mm/min)	Speed	Heat (J/mm.)	Input	Total Heat (kJ/mm)	Input
Root Pass	110		13	0.8333		1372.80			
Cover pass 1	125		14	0.7692		1820.00		6.326	
Cover pass 2	135		15	0.7018		2308.50			
Back cover pass	130		15	1.8927		824.20			

The edges of the base plates were thoroughly cleaned before starting the welding operation to avoid any type of contamination like rust, oil, dust particles, moisture etc. the edges of the base plates were pre-heated at 140 to 150 °C and inter-pass temperature 240°C to 250°C was maintained. The single-v groove design was used and the geometry of the groove design is shown in Figure 1. After welding operation, the specimens were prepared for evaluation of pitting corrosion test, impact toughness test and metallurgical behaviour of the welded joints by using wire-cut electro discharge machining. Furthermore, different heat treatments ((annealing, quenching and Plasma Nitriding) were given to the welded joints with the aim of to analyses the effect of different heat treatments on the pitting resistance, impact toughness and metallurgical performance of the welds.^(3,6,7). The details of the different heat treatments are presented in the Table 3. For the evaluation of pitting corrosion behaviour of the welded joint in as welded condition (as received) and heat treated conditions, the ferric chloride solution test was performed as per with ASTM G48 standard procedure. The energy absorption behaviour (charpy V-notch impact toughness test) of the welds under different post weld heat treatments was performed as per the ASTM E23 standard procedure.

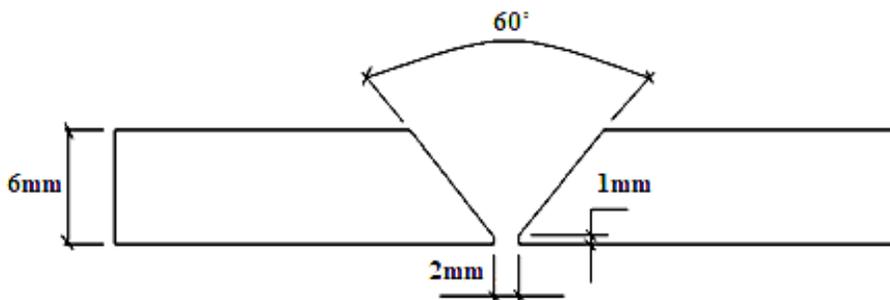


Fig 1. Geometry of the single-V groove design

Table 3. List of post weld heat treatment

S.No.	Post Weld Heat Treatments
PT0	As received/as welded condition
PT1	Annealing (1050 °C for 50 min. followed by slow cooling i.e., furnace cooling)
PT2	Quenching (1050 °C for 50 min. followed by water quenching)
PT3	Plasma Nitriding

3 Results and Discussion

3.1 Pitting Corrosion Resistance of the Welded Joint

In order to determine the pitting behaviour of the weld in as welded condition and different post weld heat treated conditions, a pitting corrosion test was performed on the prepared specimens. As per ASTM G48 standard procedure, the specimens were immersed in the solution of ferric chloride and ionized water for 72 hours⁽¹⁵⁾. The mass loss of the specimens was recorded by using weighing scale (least count of 0.0001 grams) and reported in the Table 4. It was observed that based on the pitting results, the minimum pitting resistance of 1.2501mg (mass loss) was possessed by the PT0 and the maximum pitting resistance was noticed in PT3. A plasma nitriding treatment helps to improve the pitting corrosion resistance of the martensitic stainless

steel welds⁽¹⁴⁾, furthermore very small sized pits were observed in PT3 treated specimens. The photographs of the specimens after pitting corrosion test are presented in Figure 2. Enlarged and merged pits were observed in the PT0 (as received) treated specimens after the pitting corrosion tests, and mostly pits were present in the heat affected zone.

Table 4. Pitting corrosion results of the welds

Specimen Condition	Specimen Name	Initial mass (mg)	After pitting test mass (mg)	Mass loss (mg)
As Welded	PT 0	24.7691	23.519	1.2501
Annealing (1050 °C for 50 min. followed by slow/furnace cooling)	PT 1	21.4224	20.7172	0.7052
Quenching (1050 °C for 50 min. followed by water quenching)	PT 2	22.5972	22.0281	0.5691
Plasma Nitriding	PT 3	24.5428	24.032	0.5108

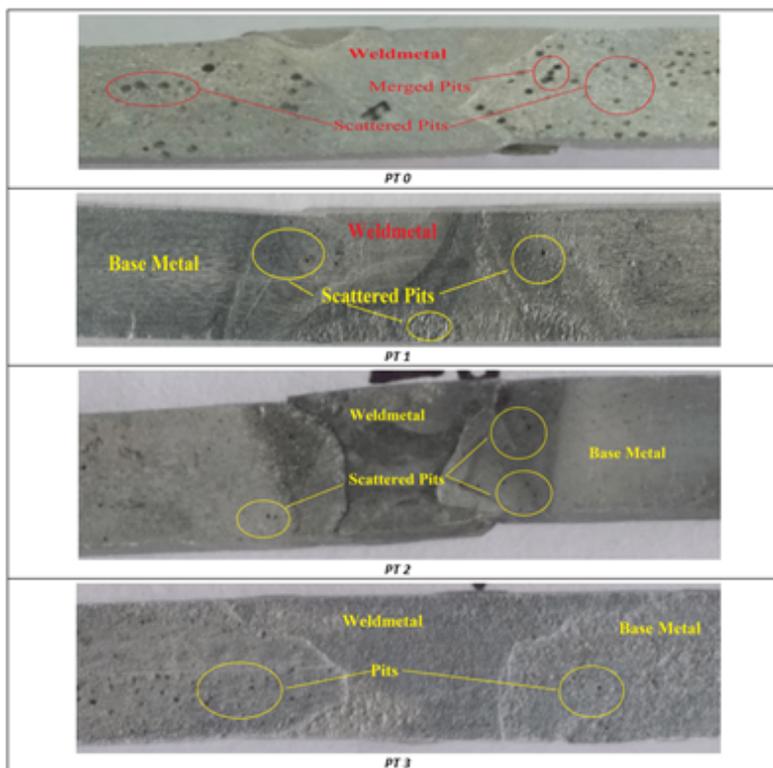


Fig 2. Actual photographs of corrosion specimens after pitting test

3.2 Impact Toughness of Welds

Based on the experimental results charpy V-notch impact test, it was noticed that the maximum toughness in as welded condition/ without any post weld heat treatment of 48 joules. The impact toughness test was performed at room temperature as per the ASTM E23 standard procedure⁽¹⁶⁾. The average toughness (CVN) values of the specimens are mentioned in the Table 5 and plotted in Figure 3. There is significant increment in the impact toughness was observed in the post weld heat treatment of annealing (1050 °C for 50 min. followed by slow cooling i.e., furnace cooling). A drastic loss of CVN value was recorded in quenched specimens i.e, 26 J. The maximum value of impact toughness of 62 J was observed in PT1 treated specimens⁽⁵⁾. The different thermal cycles were experienced by the welds under different heat treatments, this result into microstructural variations occurred across the weld zones. The fractured specimens after charpy v-notch toughness test are presented in Figure 4. It is observed that based on the experimental results of charpy v-notch impact toughness, that the PT1 (annealing) heat treatment is beneficial for improving the toughness of the martensitic stainless steel welded joints.

Table 5. Charpy V-notch impact toughness results of the welds

Specimen Condition	Specimen Name	Impact Toughness (CVN) Value in Joules
As Welded	PT 0	48
Annealing (1050 °C for 50 min. followed by slow/furnace cooling)	PT 1	62
Quenching (1050 °C for 50 min. followed by water quenching)	PT 2	26
Plasma Nitriding	PT 3	50

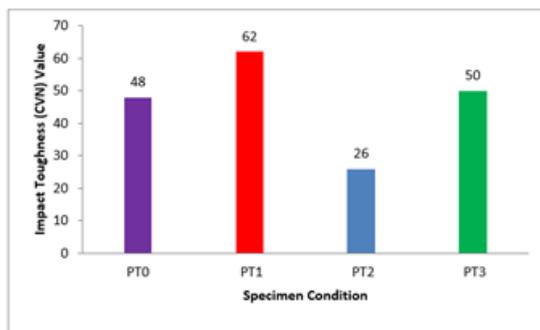


Fig 3. Plot shows the impact toughness (CVN) results of the welds in as received condition and after different post weld heat treatments

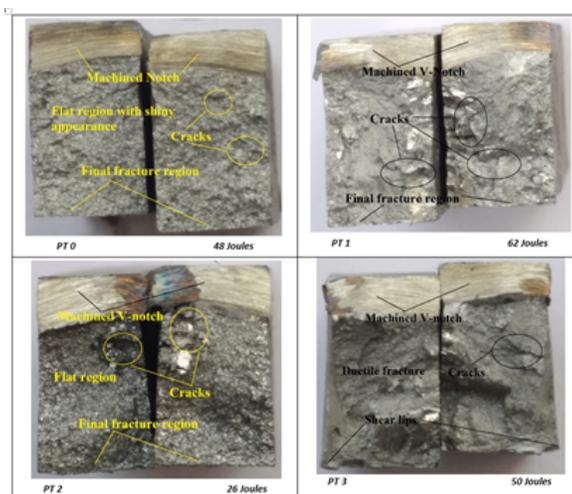


Fig 4. Actual photographs of fractured specimens after Charpy V-notch impact toughness test in as received and post weld heat treated conditions

3.3 Microhardness of the Welded joint

To evaluate the micro-hardness across the different zones of the weldment, a micro-hardness test was performed on DHV-1000 hardness tester at 4.903 N (500gf) load and 15 sec dwell period. The variation of micro-hardness of the welded joint in as received and different post weld heat treated conditions is shown in **Figure 5**. The average hardness of 524 VHN was recorded in the as received condition. The post weld heat treatments are also affects the microhardness of the welded joint. The maximum hardness (~581VHN) was obtained in the nitrided treatment condition and this increase in the hardness is due to the formation of the metallic carbides (Cr_2N and Cr_7C_3). The softening effect was observed in the annealed specimen. Due to the fine grained microstructure and heat dissipation characteristics, the average microhardness of 568VHN was observed in the quenched specimen.

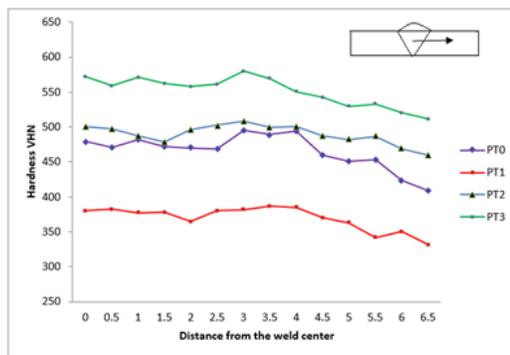


Fig 5. Microhardness plot of weld joint in as received condition and heat treated conditions across the weld centreline

3.4 Metallurgical Behaviour

The specimens were machined out from the welded plate and polished up to 2500 grit sized emery papers for microstructural examination of joint. After polishing process, manual etching was done by using etchant of hydrochloric acid (5cc), picric acid (1gram) ethanol (100cc) and few drops of 3% H₂O₂ (5,17). The photomicrographs of the weld metal are presented in Figure 6. It was observed that based on the microstructural examinations, the heat treatments affects the microstructure of the welded joint. Coarse microstructure was observed in the annealing treated specimens due to the slow cooling rate and fine microstructure in the quenched specimens due to the relatively faster cooling rate. The grains of weld zone corresponding to PT 2 (quenching treatment) specimen is relatively small dendrites with small inter-dendritic spacing as compared with PT1 (annealing treatment) specimen. The fine microstructure of the specimen PT2 treatment is due to the faster cooling rate of the weld joint (5,6).

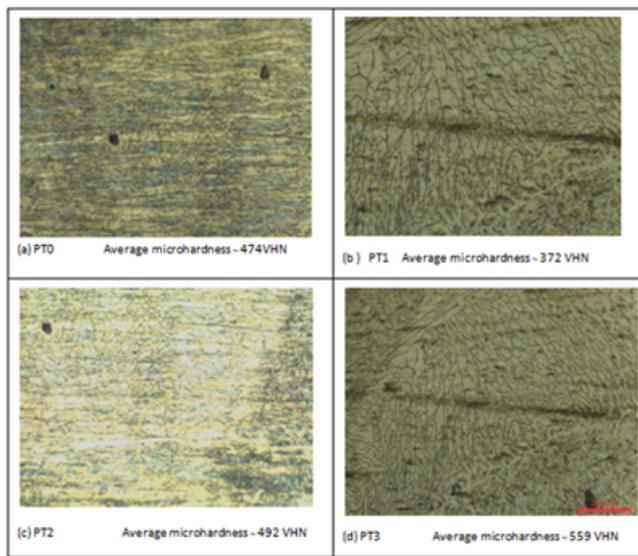


Fig 6. Photomicrograph of Weld Metal of martensitic stainless steel welded Joint in As Welded and Post Weld Heat Treated Conditions (a) as received condition (b) annealing treatment (c) quenching treatment and (d) plasma nitriding condition

4 Conclusion

On the basis of present experimental work, the following conclusions can be drawn

- Pitting resistance of the welded joint is significantly affected by the post weld heat treatments. The maximum pitting resistance is possessed by the plasma nitrided welds.

- Post weld heat treatments have the significant effect on the impact toughness behaviour of the joints. Based on the results, the maximum impact toughness (CVN value of 62 joules) was achieved in annealing heat treatment.
- Micro-structural studies of the welded joint in as received and post weld heat treated conditions, show that significant microstructural changes were observed in weld metal zones.
- The microhardness variations were also observed in the welds. These microhardness variations are due to the microstructural changes.

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References

- 1) Abioye TE, Omotehinse IS, Oladele IO, Olugbade TO, Ogedengbe TI. Effects of post-weld heat treatments on the microstructure, mechanical and corrosion properties of gas metal arc welded 304 stainless steel. *World Journal of Engineering*. 2020;17(1):87–96. Available from: <https://dx.doi.org/10.1108/wje-11-2019-0323>.
- 2) Espitia LA, Varela L, Pinedo CE, Tschiptschin AP. Cavitation erosion resistance of low temperature plasma nitrided martensitic stainless steel. *Wear*. 2013;301(1-2):449–456. Available from: <https://dx.doi.org/10.1016/j.wear.2012.12.029>.
- 3) tao Xi Y, xin Liu D, Han D. Improvement of corrosion and wear resistances of AISI 420 martensitic stainless steel using plasma nitriding at low temperature. *Surface and Coatings Technology*. 2008;202(12):2577–2583. Available from: <https://dx.doi.org/10.1016/j.surfcoat.2007.09.036>.
- 4) Kumar S, Chaudhari GP, Nath SK, Basu B. Effect of Preheat Temperature on Weldability of Martensitic Stainless Steel. *Materials and Manufacturing Processes*. 2012;27:1382–1386. Available from: <https://dx.doi.org/10.1080/10426914.2012.700150>.
- 5) Singh M, Shahi AS, Singh D. Effect of weld groove volume on the mechanical and metallurgical performance of GTA welded martensitic stainless steel (AISI 410 SS) joints. *Materials Today: Proceedings*. 2020;28:1580–1587. Available from: <https://dx.doi.org/10.1016/j.matpr.2020.04.844>.
- 6) Rajasekhar A, Reddy GM, Mohandas T, Murti VSR. Influence of post-weld heat treatments on microstructure and mechanical properties of AISI 431 martensitic stainless steel friction welds. *Materials Science and Technology*. 2008;24(2):201–212. Available from: <https://dx.doi.org/10.1179/174328407x179773>.
- 7) Ebrahimi GR, Keshmiri H, Momeni A. Effect of heat treatment variables on microstructure and mechanical properties of 15Cr–4Ni–0.08C martensitic stainless steel. *Ironmaking & Steelmaking*. 2011;38(2):123–128. Available from: <https://dx.doi.org/10.1179/030192310x12816231892468>.
- 8) Li CX, Bell T. A comparative study of low temperature plasma nitriding, carburising and nitrocarburising of AISI 410 martensitic stainless steel. *Materials Science and Technology*. 2007;23(3):355–361. Available from: <https://dx.doi.org/10.1179/174328407x161204>.
- 9) Lin Y, Lin CC, Tsai TH, Lai HJ. Microstructure and Mechanical Properties of 0.63C-12.7Cr Martensitic Stainless Steel during Various Tempering Treatments. *Materials and Manufacturing Processes*. 2010;25(4):246–248. Available from: <https://dx.doi.org/10.1080/10426910903426307>.
- 10) Wen P, Zhipengcai, Zhenhuafeng G. Microstructure and mechanical properties of hot wire laser clad layers for repairing precipitation hardening martensitic stainless steel. *Optics & Laser Technology*. 2015;75:207–213. Available from: <http://dx.doi.org/10.1016/j.optlastec.2015.07.014>.
- 11) Wang P, Lu SP, Xiao NM, Li DZ, Li YY. Effect of delta ferrite on impact properties of low carbon 13Cr-4Ni martensitic stainless steel. *Materials Science and Engineering A*. 2010;527:3210–3216. Available from: [10.1016/j.msea.2010.01.085](https://doi.org/10.1016/j.msea.2010.01.085).
- 12) Ma XP, Wang LJ, Qin B, Liu CM, Subramanian SV. Effect of N on microstructure and mechanical properties of 16Cr5Ni1Mo martensitic stainless steel. *Materials & Design*. 2012;34:74–81. Available from: <https://dx.doi.org/10.1016/j.matdes.2011.07.064>.
- 13) Bilmes PD, Llorente CL, Méndez CM, Gervasi CA. Microstructure, heat treatment and pitting corrosion of 13CrNiMo plate and weld metals. *Corrosion Science*. 2009;51(4):876–881. Available from: <https://dx.doi.org/10.1016/j.corsci.2009.01.018>.
- 14) Mesa DH, Toro A, Sinatora A, Tschiptschin AP. The effect of testing temperature on corrosion–erosion resistance of martensitic stainless steels. *Wear*. 2003;255(1-6):139–145. Available from: [https://dx.doi.org/10.1016/s0043-1648\(03\)00096-6](https://dx.doi.org/10.1016/s0043-1648(03)00096-6).
- 15) 17.ASTM G48 Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys. .
- 16) ASTM International E23-07. Standard test method for notch impact testing of metallic material. .
- 17) ASTM International E407-07. Standard practices for microetching metal and alloy. .