Electrochemical studies and corrosion resistance of activated Tungsten inert gas AISI SS316L weldments

S Manivannan¹, J Vairamuthu², P Velmurugan³, N Janaki Manohar⁴, C Ramesh Kannan⁵ and B Stalin⁶

¹Department of Mechanical Engineering, Karpagam Academy of Higher Education, Coimbatore-21, Tamil Nadu, India.
²Department of Mechanical Engineering, Sethu Institute of Technology, Pulloor- 626 115, Kariapatti, Tamil Nadu, India.
³Department of Mechanical Engineering, School of Mechanical and Automotive Engineering, College of Engineering and Technology, Dilla University, Dilla, Ethiopia.
⁴Department of Mechanical Engineering, Sri Venkateswaraa College of Technology, Sripurumudur, Tamil Nadu 602105
⁵Department of Mechanical Engineering, PET Engineering College, Tirunelveli, Tamil Nadu, India.
⁶Department of Mechanical Engineering, Anna University, Regional Campus Madurai, Madurai - 625 019, Tamil Nadu, India.

* Corresponding author: manivannan.meta@gmail.com

Abstract. Welding is the most convenient fabrication process with tremendous development in past few decades. The noteworthy technique is Activated flux TIG welding method (also known as A-TIG welding) that was well-equipped a little while back, which enhances productivity and quality of weld joints by better depth of penetration. In this research work, the electrochemical studies are performed to investigate the corrosion resistance of excellent depth of penetration A-TIG welded 316L stainless steel (SS316L) sample at room temperature. At dilute aqueous ambience, Potentiodynamic studies reveal that the SS316L welding joints have an apathetic attitude with certain range. Electrochemical Impedance calculations illustrate the breakdown occurs due to corrosion in alkaline circumstances.

1. Introduction
Due to the excellent corrosion resistance, strength, electrical conductivities and thermal conductivities, Austenitic Stainless steel were acknowledged as a sophisticated stainless steel and it is extensively used in industrial applications viz. nuclear reactors, heat exchangers etc. [1-5], It is superior in general corrosion resistance, corrosion by seawater, Inter-granular corrosion (IGC), capable thermal properties, good in fabrication and better weld-ability [6-9]. SS316L is rich in chrome-nickel, since the chromium is magnificent corrosion resistance. During deformation, it is identified that the SS316L has high hardening rate and it is associated with “stacking fault energy (SFE)” in which the crystal structures are closely packed. In the past few decades, there have been vigorous development in metal joining techniques viz. laser and electron beam welding, hybrid welding, MIG welding, TIG welding, etc. [10-15], Because of better welding interface, TIG welding is used to join stainless steels. Even though, the weld joint of TIG welding has high potential problems [18]. TIG welding process is...
limited up to 3mm thickness at single pass welding and this leads to lower productivity. Further, the joining of thick wall sections and heavy pipes is performed by multi pass welding procedure. In order to strive the penetration of the base metals, excessive welding current will be used and the weld interface is outspread which is directly proportional to lesser penetration. Also, there will be some unnecessary additional cost obtained for the edge preparation of the base metals and excess filler metal for the multi pass procedure.

Numerous studies have been undertaken since 1995 in the arc soldering process to improve the penetration of base metal. One of the innovated processes is TIG welding process with the Activating Flux technique because of its modest price and simple in operation. Paton Electric Welding Institute (1960) explains that Activated TIG (A-TIG) welding has greater penetration by adding a thin amount of activated flux to base metals. A-TIG requires the base metal to be welded using a single pass welding process, with a thickness of 8 mm to 10 mm. In fact, in contrast with conventional TIG welding joints, the soldering joint of the A-TIG welding process exceeded. Many methods for improving penetration in the activated TIG welding phase have been proposed by numerous writers. D.S. Howse et al., (2002) investigates about the arc constriction by active fluxes that flow of the welding current is defined to the center of the arc and thus the depth of penetration on the base metal occurs [16]. Heiple et al., (1982) states that surface tension gradient is reversed by the addition of Oxygen (O₂) on the molten weld metal which produces an inbound fluid flow [17].

![Figure 1. Schematic representation of TIG welding & A-TIG Welding process](image)

This statement reversed the Marangoni effect of convection that the heat flows towards the origin of the weld pool and hence the depth of penetration is excellent between the base metals [24-26]. Further, the investigation is performed by J.J Lowke et al., (2004) that the flux reacts as an electric insulator and the better penetration takes place between the base metals [19]. Fig. 1 displayed a schematic comparison between TIG welding process and A-TIG welding process. In this present research, the authors have investigated the electrochemical properties viz. intergranular attack, corrosion by cavities / holes, formation of crack growth for the SS316L A-TIG welded samples [20-22].

2. Experimental Investigation

2.1. Materials and Methods

Austenitic Stainless Steel has a good manufacturing quality of all stainless steels. 316L austenitic stainless steel welding by Activated Flux Tungsten Inert Gas welding process is part of this research [25]. The sample size is 75 mm in length, 50 mm in width and 10 mm in thickness. From Table 1, the chemical structure has demonstrated that the base metal is medium chromium molybdenum steel with good resistance to corrosion.
Table 1. Material properties of the bronze metal matrix

| Element | C  | Mn  | Si  | Cr | Ni  | Mo  | P  | S  | N  | Fe  |
|---------|----|-----|-----|----|-----|-----|----|----|----|-----|
| Amount (Wt. %) | 0.032 | 1.86 | 0.73 | 17.22 | 12.78 | 2.4 | 0.043 | 0.033 | 0.12 | Balance |

Previously, the SS316L samples are prepared for the A-TIG welding process. The surface of the plates is coated with 600 grit durable compact abrasive layer scale 230 mm x 280 mm. The impurities present on the base metal surface are washed using (CH3)2CO, left fully free. After cleansing process, the samples are coated with activated flux powders viz. Silicon-di-oxide, titanium-di-oxide, Calcium oxide and Chromium (III) oxide that is mixed by adding (CH3)2CO. After coating, the acetone easily evaporated at the room temperature and the flux powder clings to the surface of the base metal.

2.2. Machine selection

Activated Flux TIG welding is performed on the base metal SS316L by the digitally controlled robotic system MAGICWAVE 3000. The specification of the machine is shown in Table 2. It is evident from the requirements that welding is performed for low-alloy steel, high-alloy steel, aluminium alloys and other non-ferrous metals.

Table 2. Specification of fully automated MAGICWAVE 3000

| Sl.No | Specifications            | Values                      |
|-------|---------------------------|----------------------------|
| 1     | Current                   | 250A @ 100% Duty Cycle (AC)| 300A @ 100% Duty Cycle (DC)|
| 2     | Power Source              | AC power                   | DC power                   |
| 3     | Open Circuit Voltage      | 89 Volts                   |
| 4     | Electrode Diameter        | 1.0 mm - 3.2 mm            |
| 5     | Machine Dimensions        | 560 mm X 250 mm X 435 mm   |
| 6     | Weight                    | 28.1 kg                    |

2.3. Preparation of samples for corrosion

The weld interface is sliced using power hacksaw and the samples are deburred using the abrasive sheet. The base metal also prepared for investigation in order to correlate the corrosion behavior with the A-TIG welded samples. The metal surface has been prepared by using SiC 1200 (P-4000) abrasive grit emery paper and cleaned by distilled water, acetone ((CH3)2CO) and left dry at room temperature.

2.4. Electrochemical Studies

Corrosion resistance is investigated by the use of potential polarizing curves (PdP) and Electrochemical Impedance Spectroscopy (EIS) at an ambient temperature of 28°C. The studies have been performed by using PARSTAT 4000A with Polarization prediction software. Platinum and saturated calomel electrode (SCE) surface areas of 25 mm² were used as an electrode of reference. On the surface area, the study has been performed for 2 cm² for each and every time. At an interval of 1000 mV-1.500 mV the polarization curves were measured at a rate of Scan if mV/s. A sample A-TIG welded at Open-Circuit Potential (OCP) for one hour has been retained with electrochemical impedances. [30-31].

2.5. Surface Morphological Analysis using SEM-EDS

Hitachi S-4800 cold cathode field scan electron microscope (FE-SEM) is used to observe surface morphology. Thermo NORAN NSS power dispersion X-ray (EDS) paired with the FE-SEM gives a state-of-the-art imaging device of around 1 nm in resolution at 15kV of beam energy. The element distribution can be characterized using EDS analysis. Yttrium Aluminium Garnet (YAG) backscattered electron (BSE) detector which is available along with FE-SEM is used to capture contrast-enhanced images of multi-phase materials [32-34].
2.6. Optical Microscope
The observation of grain structures of base metals, weld interface and Heat Affected Zone (HAZ) is
performed by advanced industrial type microscope. It also used to measure the average grain diameter
of base metal and weld interface using linear interception method [35].

3. Results and Discussion

3.1. Morphological Studies with EDS
The microstructure is observed using optical and electron microscope with the average size of
dendritic multi-phase of ~100 micron. The analysis of YAG-BSE and EDS of the welded sample is
shown in Fig 2 and Fig 3. Fig 2 shows the EDS analysis of best A-TIG welded sample which means
there will minimum pitting corrosion occurs on the base metal. Fig 3 shows the EDS analysis of the
worst welded sample which means that more corrosion occurs on the welded zone and heat affected
zone.

![Figure 2. SEM and EDS analysis of the best metal at dendritic multi-phase of ~100 micron](image1)

![Figure 3. SEM and EDS analysis of the best metal at dendritic multi-phase of ~50 micron](image2)
Figure 4. EDS analysis of best A-TIG welded sample at a) Base metal b) HAZ c) Fusion zone

Fig 4 (a) shows that the EDS analysis performed at the base metal. In the base metal, the weight and atom percentage of ferrous are identified as 69.21 and 64.41 respectively. Due to partial weight percentage and atom percentage of metal is ferrous composition; the welded sample is subject to corrode. But the chromium weight and atom percentage are 14.13 and 14.13 respectively. Basically, chromium acts as corrosive resistance agent on the base metal. Fig 4 (b) shows the EDS analysis performed at the HAZ. The weight percentage of ferrous and chromium are identified as 51.64 and 5.20 respectively. The atom percentage of ferrous and chromium are identified as 39.04 and 3.14 respectively. Compared to the base metal, HAZ weight and atom percentage of chromium is low. Hence, pitting corrosion takes place severely on the HAZ [36].
Figure 5. Obvious elemental distribution of best A-TIG welded sample

Fig 4 (c) shows the EDS analysis performed at the fusion zone. The atom percentage and weight percentage of ferrous composition is identified as 47.54 and 27.37 respectively. The weight percentage and atom percentage of Chromium is identified as 6.78 and 4.19 respectively. Compared with the base metal, the fusion zone weight percentage and atom percentage of chromium is minimum and compared with the HAZ, the weight and atom percentage of chromium is maximum. Hence, the HAZ is severely corroded compared with base metal and fusion zone.
Figure 6. EDS analysis of worst A-TIG welded sample at: a) Base metal  b) HAZ  c) Fusion zone

EDS image mapping of the individual element’s segregation into obvious phases of the best A-TIG welded sample is shown in Fig. 5. Fig. 6 shows that the EDS analysis of poor welded sample at the HAZ. Fig. 6 (a) shows that the EDS analysis performed on the base metal of maximum corroded sample. The weight percentage and atom percentage of ferrous composition at base metal are identified as 68.74 and 62.28 respectively and chromium weight and atom percentage are identified as 18.08 and 17.59 respectively. Fig. 6 (b) shows the EDS analysis performed on the HAZ. The weight percentage and atom percentage of chromium composition present in HAZ are identified as 16.40 and 9.89 respectively. Compared with the base metal, chromium composition present in HAZ is minimum.
Hence, this results severe corrosion takes place on HAZ compared to the base metal. Fig. 6 (c) shows the EDS analysis of fusion zone which the weight and atom percentage of chromium is identified as 10.43 and 5.73 respectively. Compared to base metal and HAZ, the weight percentage and atom percentage of chromium is minimum at the fusion zone. Fig. 7 shows that EDS image mapping of the individual elemental segregation into obvious phases of the worst A-TIG welded sample.

3.2. Optical Microscopic Studies

From the Fig. 8, the microstructural image contains the fusion zone (FZ), Heat affected zone (HAZ) and the base metal zone (BM) of the metal which produces optimum Depth, Width and Aspect ratio. Due to excess amount of heat produced during the weld, HAZ is formed nearby fusion zone. The grain size of the base metal is high compared with the fusion zone. According to hall-pitch statement, the refinement of grain size produces optimum welding strength and the hardness level of the particular zone is high compared with the base metal. This results in a greater resistance than the base metals to the fusion environment.
3.3. Potentio-dynamic polarization studies
The dynamic polarization is being performed for the base metal 316 stainless steel at the room temperature of 28°C. Polarization is scanned at the rates from 0.01 mVs⁻¹ to 50 mVs⁻¹ and the graph is plotted was shown in Fig. 9. The result has been taken from three different spots viz. Base metal, Weld interface and Fusion zone. The typical anodic electrode polarization behavior of SS 316 in a sodium chloride (NaCl) solution consisting of active dissolution, passivity and sudden increment in the density of current due to pitting on the base metal. The pitting is stable due to this sudden increment of density of current. The welded samples are also tested at maximum scan rate, failed to show stable pitting [37-40]. This happens because of chromium oxide present on the welded sample. The HAZ is the highest corrosion region in contrast to the base metal region and fusion zone of the A-TIG study through polarization curves of AISI SS 316 L. The level of pitting at the HAZ is too poor compared to the FZ and BM [41-42].

3.4. Electro-chemical Impedance Spectra
The confirmations of protective film formation on the metal surface, AC (electro-chemical impedance spectrum) spectra have been employed. The resistance of charge transfer (Rt) increases when a
protective film forms on the metal surface; the capacitance value (Cdl) decreases with a double level [43-47]. Parameters of the AC impedance include load transmission resistance (Rt) and double layer capacitance (CdL) from Nyquist plots of base metal (B), fusion zone (F) and the affected area (D), as shown in Fig. 10. From EIS curves, the surfaces states that there was a severe corrosion occurs on the heat affected zone compared with the base metal and fusion zone. Base metal has better corrosive resistance and HAZ has poor corrosive resistance. The real impedance component (Z') accelerates to the maximum degree in the heat zone with variations of the values at the first stage of corrosion. Therefore, relative to the base metal and welding environment, the heat influencing environment’s corrosion intensity is low.

![Figure 10. Electrochemical Impedance Spectra (Nyquist plot) of AISI SS316L.](image)

4. Conclusions
TIG welding samples has penetration on the ferrous alloys especially stainless steel, hence Activated – TIG welding is the special outcome in the area of research. The SEM images confirm the intermetallic compound present at the welding interface without flaws and porosity. An energy Dispersive spectroscopy result, chromium level attains its own peak level and it acts a corrosive resistance for the base metal and weld interface. The better and poor pitting corrosion sample is differentiated by the measurement of chromium composition present on the base metal, fusion zone and HAZ. Comparison has performed with the help of image mapping, that HAZ affects more by corrosion compared with the base metal and fusion zone. Polarization plots confirm that severe pitting occurs on the HAZ compared with the BM and FZ. The Nyquist plot once again confirms that corrosion resistance is lower at the HAZ compared with BM and FZ.

5. References
[1] Pritima D, Stalin B, Vairamuthu J, Mallesham P, Srinivasa Rao M, Marichamy S 2021 Analysis of Parameters on Bend Force in Nickel-Coated Mild Steel Sheets Through Contour Plot. In: Arockiarajan A., Duraiselvam M., Raju R. (eds) Advances in Industrial Automation and Smart Manufacturing. Lecture Notes in Mechanical Engineering. Springer, Singapore, pp. 647-652. https://doi.org/10.1007/978-981-15-4739-3_55
[2] Senthil Kumar P S, Marichamy S, Sivakandhan C, Stalin B, Dhinakaran V, Satyanarayana I 2021 Evaluation of Material Properties and Abrasive Resistance of Tantalum Carbide-
Based Hardox Steel for Construction Purpose. In: Arockiarajan A., Duraiselvam M., Raju R. (eds) Advances in Industrial Automation and Smart Manufacturing. Lecture Notes in Mechanical Engineering. Springer, Singapore, pp. 69-76. https://doi.org/10.1007/978-981-15-4739-3_6

[3] Pritima D, Padmanabhan P, Marichamy S, Sivakandhan C, Stalin B, Dhinakaran V 2021 Material Characterization and Parametric Effect on Nickel-Coated Mild Steel Sheets by Electroplating Process. In: Arockiarajan A., Duraiselvam M., Raju R. (eds) Advances in Industrial Automation and Smart Manufacturing. Lecture Notes in Mechanical Engineering. Springer, Singapore, pp. 465-471. https://doi.org/10.1007/978-981-15-4739-3_40

[4] Geethamani R, Jaganathan S, Prem Anand S, Sheeba Rani S, Stalin B 2020 Heat capacity improvement in the electric furnace through amendment of the electric circuit on melting of hardox steel Mater. Today: Proc. https://doi.org/10.1016/j.matpr.2020.08.364

[5] Rajaparthiban J, Saravanavel S, Ravichandran M, Vijayakumar K, Stalin B 2020 Investigation on effect of machining parameters using TGRA approach for AISI 316 steel Materials Today: Proceedings, Vol.24, pp.1282–1291. DOI: 10.1016/j.matpr.2020.04.443.

[6] C. Ramesh Kannan, B. Stalin, M. Ravichandran and K. Sathiyha Moorthi, “Performance Analysis of SS304 Steel Hat Stringer on the Chassis Frame”, In: S. Hiremath, N. Shanmugam, B. Bapu (eds) Advances in Manufacturing Technology, Lecture Notes in Mechanical Engineering, Springer, Singapore, 2019, pp.289-296. DOI: 10.1007/978-981-13-6374-0_34

[7] S.Bagavathy, P. Ramesh Kumar, P.Anantha Christu Raj, B.Stalin (2020), Frequency measurement through electric network analyzer for ultrasonic machining of steel, Mater. Today: Proc., https://doi.org/10.1016/j.matpr.2020.08.629

[8] S.Sheeba Rani, V.Kamatchi Sundari, P.Subha Hency Jose, S.Sivaranjani, B.Stalin, D.Pritima (2020), Enrichment of material subtraction rate on Eglin steel using electrical discharge machining process through modification of electrical circuits, Mater. Today: Proc., https://doi.org/10.1016/j.matpr.2020.07.670

[9] C. Ramesh Kannan, T. Srirenga Karthi, P. Padmanabhan and B.Stalin (2017), “Noise Analysis of Titanium Carbide Insert in Manufacturing of BS817M40 Steel” Advances in Natural and Applied Sciences, Vol.11, no.4, pp.612-619.

[10] M.Swapna Sai, V.Dhinakaran, K.P.Manoj Kumar, V.Rajkumar, B.Stalin, T.Sathish (2020), “A Systematic Review of effect of different welding process on mechanical properties of grade 5 titanium alloy”, Materials Today: Proceedings, Vol.21, pp.948–953. DOI: 10.1016/j.matpr.2019.08.079.

[11] V.Dhinakaran, M.Varsha Shree, T.Jagadeesha, P.M. Bupathi Ram, T. Sathish, B.Stalin (2020), “A review on the recent developments in modeling heat and material transfer characteristics during welding”, Materials Today: Proceedings, Vol.21, pp.908–911. DOI: 10.1016/j.matpr.2019.08.079.

[12] R.Senthil Kumar, V.Elango, K.Giridharan, V.M.Jothiprakash, B.Stalin (2020), Optimization and enhancement of friction stir welding strength on high yield strength deformed steel, Mater. Today: Proc., https://doi.org/10.1016/j.matpr.2020.09.149

[13] A.Radhiika, G.Thenmozhi, M.Balakarthisayan, B.Stalin (2020), Enhancement of welding strength through electric current and resistance on ERSW process using chromium steel, Mater. Today: Proc., https://doi.org/10.1016/j.matpr.2020.08.363

[14] M.Balasubramanian, B.Stalin, S.Marichamy, K.Anandan, Ram Subbiah (2020), Assessment of weld joint strengths on dissimilar alloys of Inconel 625 and aluminium 7068 using FSW process, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.08.315

[15] M.Vetrivel Sezhian, R.Ramadoss, K.Giridharan, G.Chakravarthi, B.Stalin, Comparative study of friction stir welding process and its variables, Mater. Today: Proc., https://doi.org/10.1016/j.matpr.2020.08.394

[16] Howse, D. S., and W. Lucas. "Investigation into arc constriction by active fluxes for tungsten
inert gas welding." *Science and Technology of Welding and Joining* 5, no. 3 (2000): 189-193.

[17] Heiple, C. R., and J. R. Roper. "Effect of selenium on GTAW fusion zone geometry." *Welding journal* 60, no. 8 (1981): 143.

[18] Jayakrishnan, S., and P. Chakravarty. "Flux bounded tungsten inert gas welding for enhanced weld performance—A review." Journal of Manufacturing Processes 28 (2017): 116-130.

[19] Lowke, J. J., M. Tanaka, and M. Ushio. "Mechanisms giving increased weld depth due to a flux." *Journal of physics D: applied physics* 38, no. 18 (2005): 3438.

[20] Savitskii, M. M. "The mechanism of the effects of electrically-negative elements on the penetrating power of an arc with a tungsten cathode." Avt. Svarka 9 (1980): 17-22.

[21] Ahmadi, E., and A. R. Ebrahimi. "Welding of 316L austenitic stainless steel with activated tungsten inert gas process." *Journal of materials engineering and performance* 24, no. 2 (2015): 1065-1071.

[22] Brinkman, Charles R., Vinod K. Sikka, and Roy T. King. "Mechanical properties of liquid-metal fast breeder reactor primary piping materials." *Nuclear Technology* 33, no. 1 (1977): 76-95.

[23] Lobanov, Leonid, Pavel Mikheev, Georgiy Prokopenko, Vitaliy Knyst, Yurii Kudryavtsev, Jakob Kleiman, and Bogdan Mordyuk. "Method for processing welded metal work joints by high-frequency hammering." U.S. Patent Application 10/480,478, filed December 9, 2004.

[24] Xu, Y. L., Z. B. Dong, Y. H. Wei, and C. L. Yang. "Marangoni convection and weld shape variation in A-TIG welding process." *Theoretical and applied fracture mechanics* 48, no. 2 (2007): 178-186.

[25] Yan, Jun, Ming Gao, and Xiaoyan Zeng. "Study on microstructure and mechanical properties of 304 stainless steel joints by TIG, laser and laser-TIG hybrid welding." *Optics and Lasers in Engineering* 48, no. 4 (2010): 512-517.

[26] Chidambaram, R.K. and Palani, P., 2017. Modelling and Analysis of Tool Wear on a Cryogenically Treated CNMG120408SMRH13A Insert in the Turning of AISI4340 Steel Using Response Surface Methodology. *Transactions of FAMENA*, 41(1), pp.63-80.

[27] Munoz, A. Cabello, Guillaume Rückert, Bertrand Huneau, Xavier Sauvage, and Surendar Marya. "Comparison of TIG welded and friction stir welded Al–4.5 Mg–0.26 Sc alloy." *Journal of materials processing technology* 197, no. 1-3 (2008): 337-343.

[28] Fan, Ding, Ruihua Zhang, Yufen Gu, and Masao Ushio. "Effect of Flux on A-TIG Welding of Mild Steels (Physics, Processes, Instruments & Measurements)." *Transactions of JWRI* 30, no. 1 (2001): 35-40.

[29] Quigley, M. B. C., P. H. Richards, D. T. Swift-Hook, and A. E. F. Gick. "Heat flow to the workpiece from a TIG welding arc." *Journal of Physics D: Applied Physics* 6, no. 18 (1973): 2250.

[30] Reclaru, L., R. Lerf, P-Y. Eschler, and J-M. Meyer. "Corrosion behavior of a welded stainless-steel orthopedic implant." *Biomaterials* 22, no. 3 (2001): 269-279.

[31] Khandelwal, Himanshu, Gurbhinder Singh, Khelendra Agrawal, Satya Prakash, and R. D. Agarwal. "Characterization of hydroxyapatite coating by pulse laser deposition technique on stainless steel 316 L by varying laser energy." *Applied Surface Science* 265 (2013): 30-35.

[32] Harraz, M., N. El-Mahallawy, K. Abd Elghany, M. Schleser, H. Palkowski, and Anke Klingner. "Characterization of 3D Printed Stainless Steel SS316L Powders Joined by TIG-, Plasma-and Laser Welding." *Journal of Engineering Science and Military Technologies* 1, no. 2 (2017): 91-95.

[33] Jetly, Saurabh, and V. K. Singla. "To study the Process Parameters Involved in Tungsten Inert Gas Welding of Austenitic Stainless Steel Alloys SS-310 and SS-316." PhD diss., 2014.

[34] Ramesh Kannan.C, Venkatesh and Milon Selvam Dennison, "The outcome of Turning Factors on the machining Characteristics While Turning 655M13 Steel Alloy using
TiAlN Coated Carbide Insert”, International Journal of Engineering and Advanced Technology, Vol 9, ISSUE 3, (Feb. 2020), ISSN: 2249 - 8958, pp.1251 -1260.

[35] Munoz, A. Cabello, Guillaume Rückert, Bertrand Huneau, Xavier Sauvage, and Surendar Marya. "Comparison of TIG welded and friction stir welded Al–4.5 Mg–0.26 Sc alloy." Journal of materials processing technology 197, no. 1-3 (2008): 337-343.

[36] Kikuchi, K., Y. Kurata, S. Saito, M. Futakawa, T. Sasa, H. Oigawa, E. Wakai, and K. Miura. "Corrosion–erosion test of SS316 in flowing Pb–Bi." Journal of nuclear materials 318 (2003): 348-354.

[37] Stalin B, Sudha G T, Kailasananthan C and Ravichandran M 2020 Mater. Today Commun. 25 101655 https://doi.org/10.1016/j.mtcomm.2020.101655

[38] Raja S, Ravichandran M, Stalin B, Anandakrishnan V 2020 "A Review on Tribological, Mechanical, Corrosion and Wear Characteristics of Stir Cast AA6061 Composites", Materials Today: Proceedings 22 2614.

[39] Sudha G T, Stalin B and Ravichandran M 2019 Mater. Res. Express 6 096520 https://doi.org/10.1088/2053-1591/ab2cef

[40] Stalin B, Ravichandran M, Arivukkarasan S, Mohanavel V 2018 “Weight Loss Corrosion Studies of Aluminium-LM4 Reinforced With Alumina Silicate (Al2O3:SiO2) Particulates Composites in Sodium Chloride (NaCl) Solution”, International Journal of Mechanical and Production Engineering Research and Development, Special Issue, June 2018, pp.329-336.

[41] Prathap.J, Ramesh Kannan.C and Pamanabhan.P, “Experimental investigation of tool wear in turning of Inconel718 Material using RSM”, International Journal of Advance Engineering and Research Development, Volume 2, Issue 9, September (2016), ISSN: 2348-8360, pp. 37-44.

[42] Lee, Hong-Joo, Duk-Won Kang, and Young Ju Lee. "An electrochemical study of stainless steels and a nickel alloy in a decontamination agent using the potentiodynamic method." Korean Journal of Chemical Engineering 21, no. 4 (2004): 895-900.

[43] Mansfeld, Florian. "Electrochemical impedance spectroscopy (EIS) as a new tool for investigating methods of corrosion protection." Electrochimica Acta 35, no. 10 (1990): 1533-1544.

[44] Al-Muhanna, K. "Corrosion behavior of different stainless steel alloys exposed to flowing fresh seawater by electrochemical impedance spectroscopy (EIS)." Desalination and Water Treatment 29, no. 1-3 (2011): 227-235.

[45] Venkata T, Muneeswaran T, Manjula M, Stalin B, Vairamuthu J 2019 “Synergy between sodium molybdate and binary inhibitor (BHI+Zn2+) on corrosion inhibition of mild steel in aqueous medium containing 60 ppm Cl− ion”, Materials Research Express, Vol.6, no.11, 1165g6. DOI:10.1088/2053-1591/ab5233.

[46] P.S. Senthil Kumar, S. Marichamy, B. Stalin, M. Ravichandran, K. Vinothbabu (2019), “Corrosion and Wear Properties on Synthesized Silicon Carbon Nanotubes”, International Journal of Recent Technology and Engineering (IJRTE), Vol. 8, no.1S2, pp.28-32.

[47] P.Perumal, K. Ramanathan, L. Ganesan, B. Subramainan, V.Ganesh and B. Stalin (2019), “Investigation of TiN coating uniformity and its corrosion behaviour using image process”, Materials Research Express, Vol.6, no.4, pp.1-10, 046411. DOI: 10.1088/2053-1591/aafae9.