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Optimal Evaluation & Characterization of Inconal-625 Through Taguchi Technique

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***Abstract*—In this paper we focused on the design of experiment for the characterization planning for Inconel-625 super alloy. As far as the diversity of environmental factors are concerned, we performed heat treatment and corroding of the sample pieces for five different settings. Ion-irradiation on various fluence was performed for the bare, heat treated and corrodes samples. Combination of different parameters and different settings make multiple permutation and combination for the proper characterization of super alloy. This paper focused on the taguchi technique, which optimizes the numbers of trial for Ion-irradiation. Therefore, we performed the characterization with optimum numbers of irradiated samples. For the characterization of the treated and bare samples Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray Analysis (EDAX), X-ray powder diffraction (XRD) and wear tests are performed.**

***Index Terms*—Nitreding, ion irradiation. Inconel-625, SEM, EDAX.**

I. Introduction

There is always a need of super alloy in the fields of aeronautical, aerospace, and marine applications. Inconel625 has good mechanical properties, weldability, and resistance to high temperature corrosion, which makes it a super alloy to perform for such specific needs. As far as concerned about the Inconel-625 ability to perform under some extreme environmental conditions, Inconel-635 can use to protect the sophisticated sensors and electric systems form ion irradiation in the fields of aeronautical application. For the optimize use of the super alloy we need the proper characterization of the alloy in various condition to that we can predict the right amount of thickness to be used for the application as a protecting shield for the sophisticated sensors and electric systems. Nickel-chromium base super-alloys especially Inconel-625 are well-known for their excellent performance at elevated temperatures like outstanding surface stability, high mechanical strength and resistance to corrosion, oxidation and thermal creep. Inconel 625 is a high strength, corrosion resistant superalloy widely used in the chemical industry for its resistance to a variety of aqueous corrodents.

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The composition of the Inconel 625 majorly followed by 65.8% Ni, 20.75% Cr, 8.27% Nb, 1.04% Fe, and 0.216% Ti. By this we can understand that the alloy has high nickel and chromium percentage which provide it hardness and strength too.

II. Problem Identification

The Key issue for technical development in the field of automobile, textile, plastic, foundry, forging tools –defense sector and fusion technology for simultaneous satisfying for the requirement of high material performance. It is necessary to modify surface properties of steel components. Plasma nitriding is a very advance technology for surface modification. The performance of nitrided component and aforesaid advantages are encouraging to work with this new technology. Inconel 625(Nickle Base Alloy) has high temperature resistance property and commonly used for high temp. Applications such as Nuclear Power Plant, Aircraft gas turbine points. Therefore, a right treatment of surface modification is required through ion irradiation process, here we finalized the nitriding through plasma medium. In this process the high fluence low pressure nitrogen ions are provided for the surface treatment of the Inconel 625. This approach of low-pressure plasma nitriding has been chosen based on the research data available of the past researchers of the same field. To identify the right treatment strategy and settings, we required the detailed investigation of the dynamic factors effect on Inconal 625. For this we conducted various experiment trials for the sample preparation before to go for plasma nitriding. Each and every method of sample preparation is totally different from the other treatment so that we can get identification of the dynamic factor effect on the surface for the plasma pretreatment. If any sample provides good results will treat as the identified item for the surface treatment method identification. For the sample preparation we have lot of variables and their levels to it was really difficult to design an experiment for the same.

III. Sample Preparations

Three types of samples are being prepared to conduct experiments (nitriding process) for Inconel 625 are as below:

I. Cutting &polished sample without after/further treatment (Bare Samples)
II. Cutting & Polished with Corrosion in various environments. (Corrode Samples)
III. Cutting & Polished with Heat Treatment at various Parametric Settings. (Heat Treated Samples)

In the Fig. 1 we can see the corrode samples of Inconel 625, the corroding process can clearly shown. Here small piece of 20 x 20 mm sample dipped in various chemicals for the three different setting timings i.e., 72 hrs., 140 hrs. 240 hrs. The six different chemicals used are H_2SO_4, KOH, NaOH, HNO_3, HCl, and Chromic Acid. The number of possible combinations here are 18.

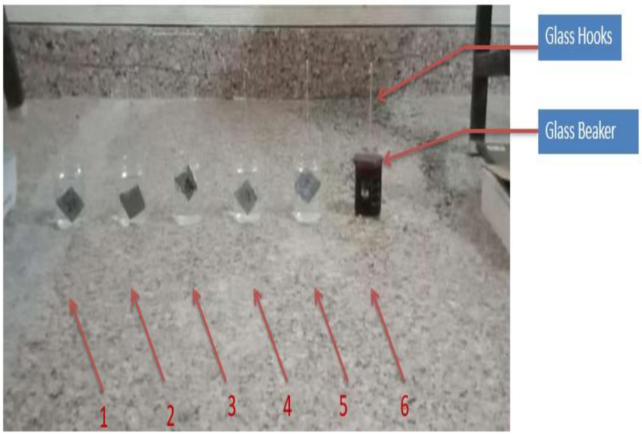

Fig 1: Corrosion Process with various environments (Contact hr. range: 72 hrs., 140hrs, 240 hrs.). (Chemical used here: H_2SO_4, KOH, NaOH, HNO_3, HCl, Chromic Acid)

As far as the annealing is concerned the furthermore samples are required to perform the full experimental investigation for the Inconel 625. In this series we can see if only 2 types of samples in annealing are used, this will increase the sample preparation requirement double. In the practical approach we required annealing for 5 different settings, nitriding for time based three different settings and the nitriding temperature for four different settings. For this whole system experiment we required 2160 samples as well as sample preparation time and other consumables to perform the experiment for full factorial design. This can clearly understand that required huge cost, time, and labor. This is not as fit for the economies of scale as well as much attractive and optimized design of experiments approach. To overcome this, we moved towards optimizing the system settings. With the revised and optimize settings of the relevant parameters. If we go with full factorial design, this again required 256, still not feasible, time taking, and required huge cost.

Table1: Five factor variables with corresponding levels (without Optimized)

S. No	Factor	Levels
1	Corroding	6
2	Heat treatment	6
3	Annealing	5
4	Nitriding Time	3
5	Nitriding Temperature	4

Full Factorial Multilevel Design for sample preparation without optimized parametric settings (MiniTab):

Multilevel Factorial Design

WORKSHEET 1

Multilevel Factorial Design

Design Summary

Factors:	5	Replicates:	1
Base runs:	2160	Total runs:	2160
Base blocks:	1	Total blocks:	1

Number of levels: 6, 6, 5, 3, 4

Table2: Five factor variables with corresponding levels (Optimized):

S. No	Factor	Levels
1	Corroding	4
2	Heat treatment	4
3	Annealing	2
4	Nitriding Time	2
5	Nitriding Temperature	4

Full Factorial Multilevel Design for sample preparation with optimized parametric settings (Mini Tab):

Multilevel Factorial Design

WORKSHEET 2

Multilevel Factorial Design

Design Summary

Factors:	5	Replicates:	1
Base runs:	256	Total runs:	256
Base blocks:	1	Total blocks:	1

IV. APPLICATION OF TAGUCHI FOR EXPERIMENT DESIGN:

The optimized parametric settings as mentioned in the table no. 2 are used to design the experimental runs through taguchi technique. Here we perform this through the help of software package Mini Tab. The taguchi approach suggested the use of L16 array for the optimum run of the experiment, this has only 16 different parametric runs detailed as below.

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Taguchi Design for sample preparation with optimized parametric settings (Mini Tab):

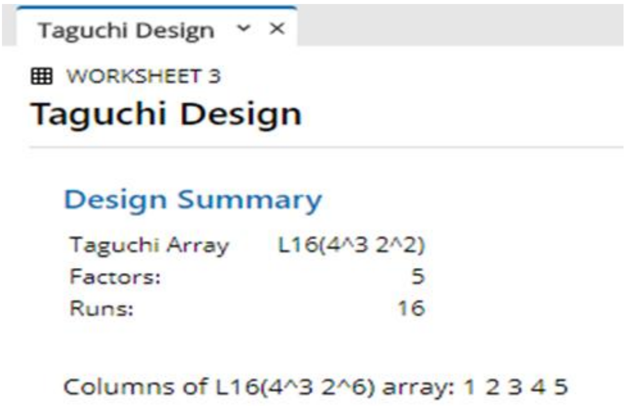

Table 3: Parameters & Levels

Parameters/ Level	I (1)	II (2)	III (3)	IV (4)
Corroding	72 hrs.	120 hrs.	240 hrs.	360 hrs.
Heat Treatment	700^0 C	750^0 C	800^0 C	850^0 C
Nitriding Temp	450^0 C	500^0 C	550^0 C	600^0 C
Nitriding Time	12 hrs.	24 hrs.	NA	NA
Annealing Time	8 hrs.	12 hrs.	NA	NA

The dynamic effecting factors/parameters are varied as per Table 4 for generating sets of experiments. The levels for all the parameters are coded i.e. I, II, III and IV.

Table 4: Taguchi (L16) based parametric settings for five variables:

Parameters	F1	F2	F3	F4	F5	MRR (gm/min)
Run 1	1	1	1	1	1	0.016500
Run 2	1	2	2	1	1	0.018590
Run 3	1	3	3	2	2	0.019267
Run 4	1	4	4	2	2	0.018242
Run 5	2	1	2	2	2	0.017450
Run 6	2	2	1	2	2	0.021240
Run 7	2	3	4	1	1	0.021444
Run 8	2	4	3	1	1	0.020958
Run 9	3	1	3	1	2	0.022590
Run 10	3	2	4	1	2	0.024950
Run 11	3	3	1	2	1	0.021548
Run 12	3	4	2	2	1	0.023687
Run 13	4	1	4	2	1	0.030092
Run 14	4	2	3	2	1	0.028789
Run 15	4	3	2	1	2	0.019879
Run 16	4	4	1	1	2	0.021065

Above is the response observations of the plasma treated samples, as par the parametric settings of L16 array. The main effect chart has been plotted for the same. This cart provides us a platform to predicting the significance of parameters on response. Fig. 2shows the interactions of the various parameters with each other with reference to the observational factor.

Fig 2: Main Effect Plot for MRR

Fig. 3: Ion Irradiation facility, high fluence Ion Beam Facility at Nano Technology Centre, Allahabad

Above is the Ion Irradiation facility, high fluence Ion Beam Facility at Nano Technology Centre, Allahabad. Here we conducted the irradiation of the samples with the ions of helium and nitrogen. With the SAM profile results shows the nitrogen ion are Havier and could not be able to penetrate the surface of the Inconel 625 alloy as helium can. The ion treated samples were also compared with the bare samples for the better understanding of the behavior of the material. Similarly, at the ahmdabad facility, we conducted the plasma nitriding process for the treated and bare samples. Similarly, the characterization like Scanning Electron Microscopy (SAM), Energy Dispersive X-Ray Analysis (EDAX), X-ray powder diffraction (XRD), machining test were performed for the topographic investigation. The results of the plasma nitriding and the high fluence nitriding were also compared. Below is one of the SAM images of the treated (corroded) sample.

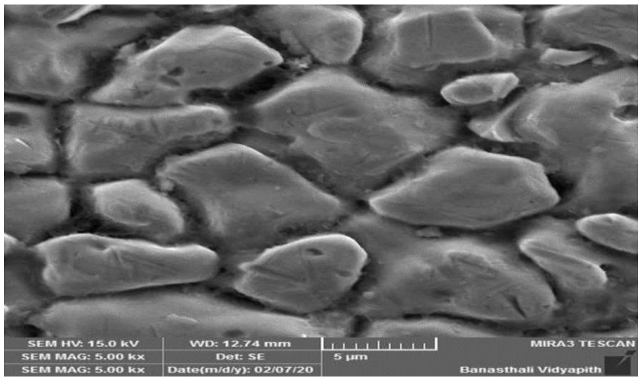

Fig 4: SEM Results: magnification 5 µm

V. Conclusion

The present study focusses on the topographic investigation and characterization of the Inconel 625 supper alloy. Here we have taken various influencing dynamic factors and surface effecting variable simultaneously for the study. The interaction study of those variable is very needed for the better understanding of the Inconel behavior with the actual conditions of the environment. The characterization has been followed for the ion treated samples, but to get the actual environmental condition, different surface treatment methods were used. But it was too difficult to handle the data in the form of full factorial combination of all parametric settings. Therefore, optimization and Taguchi analysis is being used to handle data. Using Taguchi technique, only 16 experiments were required at different settings to get identification of the Inconel 625 characterization. Furthermore, the Scanning Electron Microscopy (SAM), Energy Dispersive X-Ray Analysis (EDAX), X-ray powder diffraction (XRD), machining test were performed for the topographic investigation.

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References

[1] J. A. Gonzalez, J. Mireles, S. W. Stafford, M. A. Perez, C. A. Terrazas, and R. B. Wicker, "Characterization of Inconel 625 fabricated using powder-bed-based additive manufacturing technologies," Journal of Materials Processing Technology, vol. 264, pp. 200–210, 2019.

[2] T. E. Abioye, D. G. McCartney, and A. T. Clare, "Laser cladding of Inconel 625 wire for corrosion protection," Journal of Materials Processing Technology, vol. 217, pp. 232–240, 2015.

[3] G. U. Jeong, C. K. Jin, H. Y. Seo, and C. G. Kang, "Experimental investigation on the deformation behavior of Inconel 625 superalloy at high temperatures," Metals, vol. 9, no. 7, p. 720, 2019.

[4] D. Verdi, M. A. Garrido, C. J. Múnez, and P. Poza, "Microscale evaluation of laser cladded Inconel 625 exposed at high temperature in air," Materials & Design, vol. 114, pp. 326–338, 2017.

[5] P. D. Enrique, E. Marzbanrad, Y. Mahmoodkhani, Z. Jiao, E. Toyserkani, and N. Y. Zhou, "Surface modification of binder-jet additive manufactured Inconel 625 via electrospark deposition," Surface & Coatings Technology, vol. 362, pp. 141– 149, 2019.

[6] A. Mostafaei, P. Rodriguez de Vecchis, I. Nettleship, and M. Chmielus, "Effect of powder size distribution on densification and microstructural evolution of binder-jet 3Dprinted alloy 625," Materials & Design, vol. 162, pp. 375– 383, 2019.

[7] A. Cui, V. Uhlenwinkel, A. Schulz, and H. W. Zoch, "Austenitic stainless steel powders with increased nitrogen content for laser additive manufacturing," Metals, vol. 10, no. 1, p. 61, 2020.

[8] Y. B. Lai, W. J. Liu, Y. Kong, F. Y. Wang, and Y. H. Zhao, "Influencing factors of residual stress of Ti-6.5Al-1Mo-1V2Zr alloy by laser rapid forming process," Rare Metal Materials and Engineering, vol. 42, pp. 1526–1530, 2013.

[9] F. Wang, W. Liu, Y. Zhao, Y. Lai, and W. Han, "Subarea simulation and distributed computing of direct laser fabrication," International Journal of Advanced Manufacturing Technology, vol. 71, no. 1-4, pp. 667–673, 2014.

[10] Y. Liu, C. Liu, W. Liu et al., "Optimization of parameters in laser powder deposition AlSi10Mg alloy using Taguchi method," Optics & Laser Technology, vol. 111, pp. 470–480, 2019.

[11] T. Yang, T. Liu, W. Liao et al., "The influence of process parameters on vertical surface roughness of the AlSi10Mg parts fabricated by selective laser melting,"Journal of Materials Processing Technology, vol. 266, pp. 26–36, 2019.

[12] B. Liu, B. Q. Li, and Z. Li, "Selective laser remelting of an additive layer manufacturing process on AlSi10Mg," Results in Physics, vol. 12, pp. 982–988, 2019.

[13] T. Yu, L. Yang, Y. Zhao, J. Sun, and B. Li, "Experimental research and multi-response multi-parameter optimization of laser cladding Fe313," Optics & Laser Technology, vol. 108, pp. 321–332, 2018.

[14] T. Bhardwaj, M. Shukla, C. P. Paul, and K. S. Bindra, "Direct Energy Deposition - Laser Additive Manufacturing of Titanium-Molybdenum alloy: Parametric studies, microstructure and mechanical properties," Journal of Alloys and Compounds, vol. 787, pp. 1238–1248, 2019.

[15] Y. Li and D. Gu, "Parametric analysis of thermal behavior during selective laser melting additive manufacturing of aluminum alloy powder," Materials & Design, vol. 63, pp. 856–867, 2014.

[16] H. Hu, X. Ding, and L. Wang, "Numerical analysis of heat transfer during multi-layer selective laser melting of AlSi10Mg," Optik, vol. 127, no. 20, pp. 8883–8891, 2016.

[17] P. Conti, F. Cianetti, and P. Pilerci, "Parametric finite elements model of SLM additive manufacturing process," Procedia Structural Integrity, vol. 8, pp. 410–421, 2018.

[18] C. Pleass and S. Jothi, "Influence of powder characteristics and additive manufacturing process parameters on the microstructure and mechanical behavior of Inconel 625 fabricated by selective laser melting," Additive Manufacturing, vol. 24, pp. 419–431, 2018.

[19] W. H. Yang and Y. S. Tarng, "Design optimization of cutting parameters for turning operations based on the Taguchi method," Journal of Materials Processing Technology, vol. 84, no. 1-3, pp. 122–129, 1998.

[20] Y. B. Lai, B. H. Zhang, J. B. Zhao, W. J. Liu, and Y. H. Zhao, "Calculation and experimental verification of optimal overlapping ratio in laser metal direct manufacturing," Transactions of the China Welding Institution, vol. 37, pp. 79–82+132-133, 2016.

[21] A. Balaram Naik and A. Chennakeshava Reddy, "Optimization of tensile strength in TIG welding using the Taguchi method and analysis of variance (ANOVA)," Thermal Science and Engineering Progress, vol. 8, pp. 327–339, 2018.

[22] A. H. Bademlioglu, A. S. Canbolat, N. Yamankaradeniz, and O. Kaynakli, "Investigation of parameters affecting Organic Rankine Cycle efficiency by using Taguchi and ANOVA methods," Applied Thermal Engineering, vol. 145, pp. 221– 228, 2018.

[23] K. Viswanath Allamraju, "Voltage optimization of piezoelectric circular transducer by Taguchi and ANOVA approches," Materials Today: Proceedings, vol. 5, no. 2, pp. 5322 –5327, 2018.

[24] Y. Dongxia, L. Xiaoyan, H. Dingyong, N. Zuoren, and H. Hui, "Optimization of weld bead geometry in laser welding with filler wire process using Taguchi's approach," Optics and Laser Technology, vol. 44, no. 7, pp. 2020 –2025, 2012.