TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 1186 - 1192

Substrate by High Velocity Oxy-fuel (HVOF) Method

Raden Dadan Ramdan
Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology, Bandung, Indonesia.
Budi Prawara
Center of Electronics and Telecommunication Research, LIPI Indonesia, Bandung, Indonesia.
Irma Pratiwi
Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology, Bandung, Indonesia.
Syauqi Ramadhan
Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology, Bandung, Indonesia.
BambangWidyanto
Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology, Bandung, Indonesia.
RochimSuratman
Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology, Bandung, Indonesia.

Article Info
Volume 83
Page Number: 1186 - 1192
Publication Issue:
May - June 2020

Article History
***Article Received**: 11August 2019*
***Revised**: 18November 2019*
***Accepted**: 23January 2020*
***Publication**: 10 May2020*

Abstract:

Abradable coatings are widely used for specific application, such as break pad application. The background of the present research is due to the early failure of the break pad coating in motor cycle product. The approach of the present research is by developing abradable coating material on steel substrate by high velocity oxy-fuel (method). Two variable parameters are optimized in the present research, surface preparation and heat treatment before the coating process. For the case of surface preparation, three different surface preparations were performed including blasting, etching and combination between blasting and etching. On the otherhand, three different heating temperatures were performed before the coating, heating at temperature of 50oC, 100oC and 150o. It was observed sample treated with combination of blasting and etching before the coating produced roughest surface as well as thickest coating. This sample also show highest hardness as compared with others. For the case of heating temperature, it was observed optimum temperature obtain at temperature of 100oC which significant increasing of hardness as well as coating thickness obtained. From SEM observation after wear test, abrasive wear mechanism was observed after on all samples.

Keywords: *abradable material, HVOF coating, break pad, steel substrate.*

I. INTRODUCTION

In the present time, application of material in all aspects of human life has been well-developed. One of the mechanical properties which is needed in the industrial sector is wear resistance[1,2,3]. One example of wear-resistant material application in industry is brake linings and also Chromium coating on shafts that against friction loads. Research on material that can meet the criteria of good wear resistance continues to be developed starting from the type of powder material, the spraying process, the characteristic of the coating material and the relationship of the overall parameters [4].

One unique material in wear resistance applications is abradable coating. One application of this material is in gas turbine engine for reducing the gap between rotating and stationary parts [4]. Abradable coating is a type of coating which using materials that has a tendency to experience wear phenomena when rubbing against other materials. There are several types of abradable coatings that are commonly used; porous coatings and solid coatings [5].

One of coating method with good results but have not yet been widely used in application of abradable coating is high velocity oxygen fuel (HVOF). The HVOF method is a good method for the spraying process of iron based coating [6]. Thermal and kinetic energy being used to melt the powder to become a deposit on the coated surface in HVOF process. There are two types of HVOF; Detonation gun system and Continuous combustion system. The difference between them lies in the fuel that being used and the cooling system [7].

Based on the above reasons, the main objective of this research is to find a material with good wear

May – June 2020
ISSN: 0193-4120 Page No. 1186 - 1192

resistance properties and apply coating methods using the High Spray Velocity Oxygen Fuel (HVOF). The research parameters are focused on the surface treatment parameters to investigate the type of interlocking that will occur in a variety of applied surface treatments. In addition, pre-heat parameter was also investigated to understand the effect of pre-heat on the coating-substrate interlocking mechanism. It is found that different surface treatments will produce different surface roughness values and will affect the sticking ability of the powder. In addition, pre-heat will affect the ability of the powder to stick on the substrate as well.

II. EXPERIMENTAL DESIGN

A. Materials

The substrate material which is used in this study is ST-37 steel. The powder materials which are used in this study consist of binders, abrasive materials, reinforcing materials, friction modifiers, and fillers whose composition can be seen in Table 1.

Table 1. Powder Composition

No	Powder Composition	Materials	Percentage (%)	Mass (g)
1	Binder	Kaolinite	25	740
2	Abrasive Material	Silica	20	600
3	Reinforcing	Aluminium	11	330
4	Friction Modifier	Carbon	10	300
5	Filler	Barium Sulphate	10	300
6		Vermiculite	8	240
7		Magnetite	8	240
8		Potassium Hydroxide	8	240
	Total			2990

All the powders are mixed using blending machine for 8 hours then being sieved by 200 Mesh sieving machine to ensure the powder size is in accordance with the specification of HVOF method. Furthermore, the powders are heated to 80ºC by oven to ensure that the powders are not moist therefore will not interfere the spraying process.

ST-37 specimens were cut to 9 specimens by dimensions of length x width x thickness are 50 x 50 x 3 mm, with the design parameter according to Table 2.

Table 2. Experimental Design for Each Parameter

No.	Pre-Heat Variation(°C)	Variation 1 Code	Surface Treatment	Variation 2 Code	Specimen Code
1	50	50	*Etching*	E	50E
2	50	50	*Blasting*	B	50B
3	50	50	*Blasting + Etching*	EB	50EB
4	100	100	*Etching*	E	100E
5	100	100	*Blasting*	B	100B
6	100	100	*Blasting + Etching*	EB	100EB
7	150	150	*Etching*	E	150E
8	150	150	*Blasting*	B	150B
9	150	150	*Blasting + Etching*	EB	150EB

B. Methods

Each specimen was cut in half by size of 50 x 40 x 3 mm and 50 x 10 x 3 mm. Therefore, specimen width of 40 mm is prepared for wear testing refer to specifications of the pin on disk wear test, while smaller specimens are used for other tests such as Metallography and Hardness Test. After cutting, each side of specimens are proceeded to Chamfering process. Chamfering process is done on every corner of the surface which will be sprayed with HVOF to prevent residual stresses at the surface angle. After Chamfering, both small and large specimens are combined by tack welding.

Grinding are done by Grinding Machine starting from grit 60, 100, 240 to all specimens therefore the surfaces have been free from any residual or rust and ready for surface treatment. In this experiment, surface roughness was measured as well to obtain the roughness value (Ra) for each specimen of Blasting, Etching, Etching Blasting, and Control. This measurement is needed to observe the contribution of surface treatment to the increase in surface roughness of the substrate which will be coated.

After all the powder and specimen preparation process being done, each specimen will be sprayed using Thermal Spray High Velocity Oxygen Fuel (HVOF) method with the parameters in Table 3.

Table 3. HVOF Parameter

No.	Parameter	Value

1.	Pressure	6,2 Bar
2.	O_2 Partial Pressure	8 Bar
3.	N_2 Partial Pressure	5 Bar
4.	Propane Pressure	5,5 Bar
5.	O_2 Flow rate	271 Litre/min
6.	N_2 Flow rate	8 Litre /min
7.	Propane Flow rate	62,4 Litre/min
8.	powder feeder rotational velocity	5 rpm
9.	Torch	130 mm
10.	Spray distance	200 mm
11.	Spray Angle	90º
12.	Powder size	200-280 Mesh (0,053-0,074 mm)
13.	Pre-heating Variation	50°C, 100°C, 150°C

Characterizations and Tests

Visual examination was carried out by taking picture of the specimen surface that has been sprayed with coating material, then the picture being analyzed to find the defects that occur during HVOF process. In addition, the final thickness of the specimen was also measured using micrometer screw gauge at 5 different points at each of the nine specimens to determine the thickness of the coating. SEM characterization is carried out to see the wear mechanism that occurs while EDS is carried out to obtain the chemical composition of coated surface. Wear resistance test is carried out based on ASTM G99 to obtain the wear coefficient value and also the wear rate of each specimen. pin on disk testing was carried out according to the parameters in Table 4.

Table 4 Pin on Disk Parameter

Parameter	Value
Force	9,8 N
Rotational velocity	33 rpm
Temperature	25 ºC
Pin Material	High Speed Tool Steel SKH 9 (64 HRC[8])
Time	5 minutes (300 s)
Cycle	3 cycles

Surface roughness measurement after coating was carried out as well to determine the coating surface roughness value (Ra). Vickers Hardness Test was conducted to compare the coating hardness of one treatment to another. Metallographic examination was carried out to measure coating thickness and observe the mechanical interlocking that occurred as well as defects that appeared in micro scale.

III. Results and Discussions

Visual observations were conducted on the surface of the specimen that had been given a Surface Treatment to see any indication of defects on the surface of the specimen. The visual data results are shown in Figure 1.

Through visual observations it can be seen that the surface with Etching treatment on the three specimens (50E, 100E, and 150E) are not perfect. This can be seen from the results of Etching specimen which gives unevenly reflection on the surface of the specimen. This uneven result is an indication that the surface of the oxide formed on the surface of the specimen is uneven therefore it can be said that the surface of the specimen is uneven. The quality of the etching results will have an impact on the next process.

The results of the blasting treatment showed that the specimen that meets the maximum ISO 8501-1 Sa standards [9] up to Sa 3 is only 150B specimen. While the 50B (d) and 100B (e) specimens only meet the Sa 2.5 standard, with an indication of stains on the surface of the specimen resulting from the blasting surface treatment therefore these stains will certainly affect the bonding of the powder on the specimen surface. From the results of Blasting + Etching treatment, it can be seen that the surface is uneven for 50EB (g) and 100EB (h) specimens, but for 150EB (i) specimen the result is quite good.

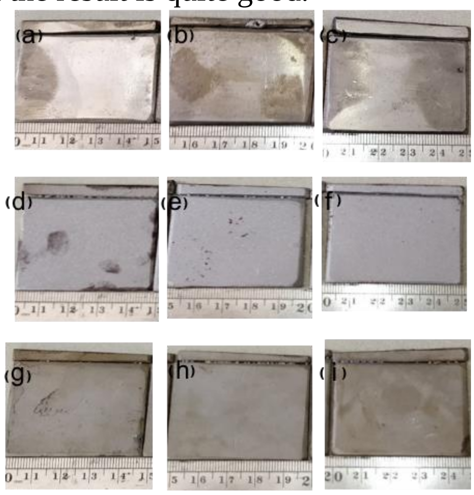

Figure 1. Visual observation of specimens after surface treatment (a) 50E; (b) 100E; (c) 150E; (d) 50B; (e) 100B; (f) 150B; (g) 50EB; (h) 100EB; (i) 150EB

Visual observation results on specimens after the

HVOF process can be seen in the Figure 2. In the first spray group which was given pre-heat at a temperature of 50 ºC (Figure 2. a, b, c) show good coating results without any defects for 50B and 50EB specimens. However, for the 50E specimen, there are two defects found, namely the Insufficient Adhesion of Powder and Shades and Gloss Variation. Insufficient Adhesion of Powder defect can occur because the bonding of powder to the substrate is not good enough. This defect can also occur as a result of uneven surface therefore there are areas on the surface of the specimens which are not affected by surface treatment prior to coating.

In the second spray group which is at 100ºC preheat (Figure 2. d, e, f) 100E, 100B, and 100EB specimens show the same coating defect in the form of orange peel. Orange peel defects can occur due to two factors; high degree variation of powder size and also different cooling rates between spray areas.

The third spray group which was given 150°C pre-heat (Figure 2. g, h, i) show the 150EB specimen with a very perfect surface without any defects. While in the 150E and 150B specimens there are defects in the form of Shades and Gloss Variation. This defect occurs due to uneven coating thickness.

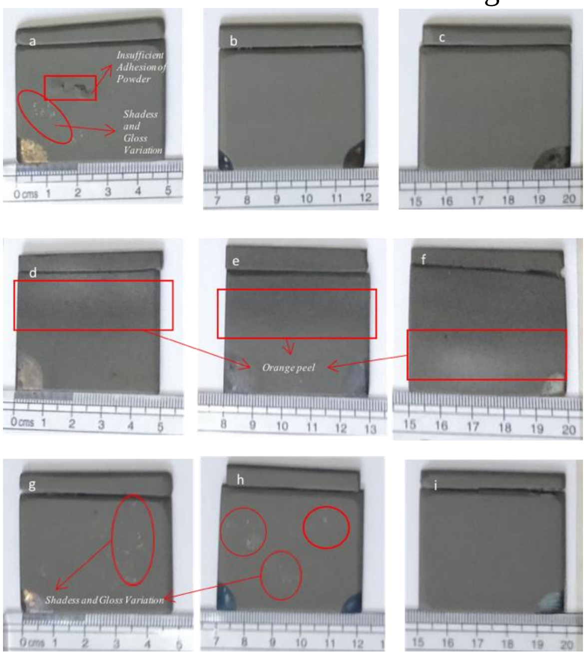

Figure 2. Visual observation of specimens after HVOF Process a) 50E; b) 50E; c) 50EB; d) 100E; e) 100B; f) 100EB; g) 150E; h) 150B; i) 150EB

The large number of defects found in etching treatment specimens is due to the low surface roughness value in the etching specimens therefore the ability of the powder to make a mechanical bonding to the substrate is low. This theory is supported by the results of surface roughness (Ra) of 0.714 µm in etching specimen compared to the high surface roughness in blasting and blasting + etching specimens which the value of surface roughness is3,004 µm and 3,816 µm (figure 3).

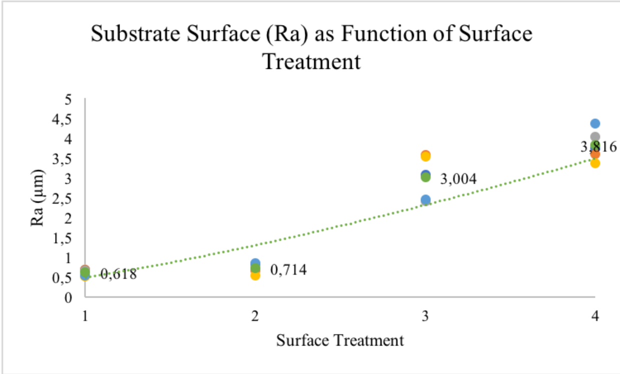

Figure 3. Substrate Surface Roughness (Ra) as Function of Surface Treatment

The low roughness value for specimens with etching treatment only has also been confirmed through metallographic observations shown in figure 4. At the surface of the etching specimen, the substrate surface seems flat and relatively homogeneous and relatively same compared to the surface of the substrate without treatment. In the blasting surface treatment specimen, the surface of the substrate is wavy and not homogeneous. Whereas blasting + etching treatment results in a bumpy and relatively homogeneous surface.

Figure 4. Metallographic Examination of Specimen with various treatment; a) 50E, b) 100E, c) 150E, d) 50B, e) 100B, f) 150B, g) 50EB, h) 100EB, i) 150EB

From the micrometer screw gauge thickness data of the coating (figure 5 and 6), it can be seen that the

TEST Engineering & Management
May – June 2020
ISSN: 0193-4120 Page No. 1186 - 1192

thickness value will increase for each surface treatment starting from etching, blasting, and blasting etching. This is in line with the roughness value which continues to increase as well for the surface treatment. The thickness continues to increase due to the better bonding ability of the powder to the substrate surface along with an increase in surface roughness value. The effect of surface treatment is more significant than the effect of pre heat on coating thickness, it can be seen from the increase in thickness due to surface treatment for each condition of the same pre heat is higher than the increase in thickness due to variations in pre heat temperature for each surface treatment condition.

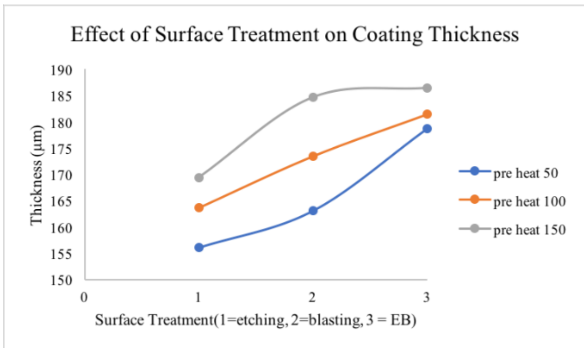

Figure 5. Effect of surface treatment on coating thickness

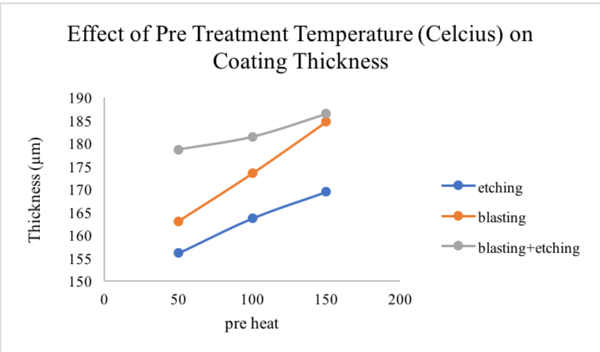

Figure 6. Effect of temperature of pre-treatment on coating thickness

Microvickers hardness data in figure 7 and figure 8 shows an increasing trend every time the pre-heat temperature increases. Likewise, the changes in surface treatment, the value of hardness increases in line with the value of surface roughness which increases as well. The specimen with blasting etching surface treatment always has the highest hardness for each pre-heat variation. The microvickers hardness value increases along with the thickness which also increases. For metallographic observations, high hardness values were obtained in specimens with blasting etching surface treatment because porosity was formed less than blasting and the more porosity were found in surface of etching treatment. Effect of surface treatment is more significant than the effect of pre-heat on the hardness of the coating results, since the increase in hardness due to surface treatment for each condition of the same pre heat is higher than the increase in hardness due to variations in pre heat temperature for each surface treatment condition.

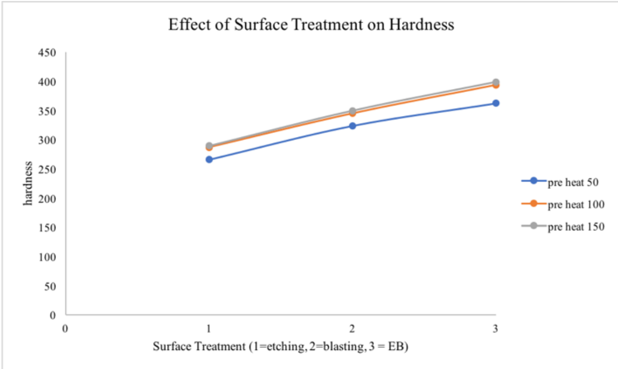

Figure 7. Effect of surface treatment on hardness

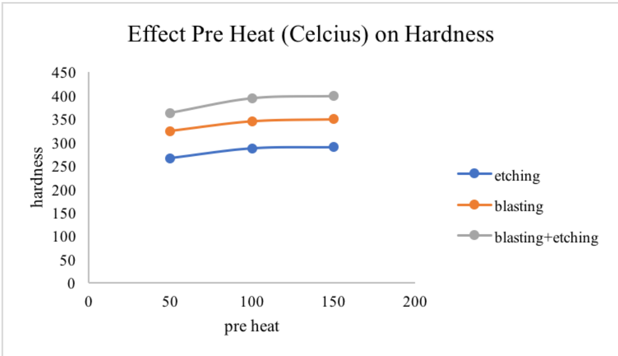

Figure 8. Effect of pre-heat on hardness

Pin on Disk Test is carried out to obtain the wear characteristics of the coating material that has been produced. From the results of wear testing with the mass loss method which we can see in figure 9, generally the rate of mass reduction gets smaller along with higher roughness value. Generally, specimens with blasting etching surface treatment always have less mass reduction for each pre-heat variation. It can be said that surface roughness has an impact on the rate of mass reduction or wear rate. The greater the surface roughness value, the smaller the wear rate that occurs.

May – June 2020
ISSN: 0193-4120 Page No. 1186 - 1192

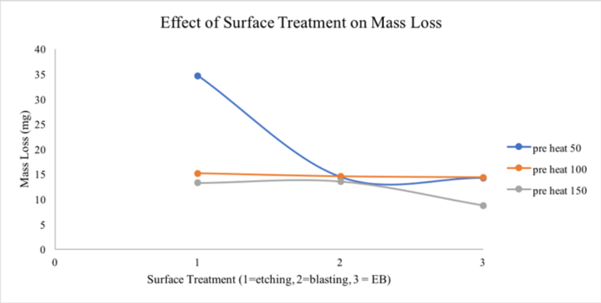

Figure 9. Effect of surface treatment on mass loss

Theabradable HVOF results can also be examined by SEM and EDS which are shown Figure 10 and Table 5. The EDS result shows the elements contained in the specimen. From the EDS results in Table 5, it is known that there are elements which are indeed constituent elements of the powder mixture for the abradable material. The results of SEM show that in the area of wear there was a detachment of coating particles and the presence of test scratch. This phenomenon indicates that the wear occurred through abrasive mechanism. From the overall EDS results it can be concluded that there is no adhesive wear mechanism. From the EDS results it can also be concluded that the elements that are easily detached are Ca, K, Ba, and Mg which have function as fillers in the design. In addition, it can be concluded that the wear that occurs is peel off mechanism rather than layer by layer because the rate of mass reduction in first cycle is always dominant compared to second and third cycle. Reduction in second or third cycle is only about 10% of the reduction in first cycle.

Figure 10. SEM observation of 150°C blasting specimen after wear test

Table 5. Chemical Composition of 150°C blasting specimen

EDS	Composition (%)								
	O	Ni	Cr	Al	Fe	Si	C	K	Ba
A	6.44	43.37	33.39	4.18	1.63	0.50	10.49	-	-
B	-	68.34	22.90	2.17	2.98	3.61	-	-	-
C	7.98	44.02	34.72	2.08	11.05	0.16	-	-	-

IV. CONCLUSION

Surface treatment will affect the thickness, hardness and the characteristics of abradableHVOF coating as well. The thickness value of the material increases according along with increasing of surface roughness. The hardness value also increases along with the increasing of roughness. The rate of mass reduction will decrease along with increasing in the roughness value. Variation of pre-heat parameters will affect the thickness, hardness, and wear characteristics of theabradable HVOF coating. The thickness value of the material increases along with the increasing of pre-heat temperature. In addition, the hardness value also increases along with the increasing of thickness. Generally, the rate of mass reduction will decrease according to the increase in pre-heat temperature.

REFERENCES

[1] David R.H and Michael F. Ashby, "Engineering Materials I: An Introduction of Properties, Applications, and Design", 2019, pp 469-484.
[2] T.F.J. Quinn, "The Role of Wear in The Failure of Common Tribosystem" *Wear*, Vol. 100, 1-3, pp 399-436.
[3] MJ Neale and M Gee, "Industrial Wear Problems" *A Guide to Wear Problems and Testing for Industry*, 2001, pp 3-31.
[4] R. E. Johnston, "Mechanical characterisation of AlSi-hBN, NiCrAl-Bentonite, and NiCrAl-Bentonite-hBN freestanding abradable coatings" *Surface and Coatings Technology*, vol. 205, 201, pp 3268–3273G.
[5] www.chinapowdercoating.com/abradable-coating/
[6] S. Vignesh, K. Shanmugam, V. Balasubramanian, & K. Sridhar, "Identifying the optimal HVOF spray parameters to attain minimum porosity and maximum hardness in iron based amorphous metallic coatings" *Defence Technology*, Vol. 13, 2017 101–110.
[7] S. Amin, H. Panchal, & A. Professor "A Review on Thermal Spray Coating Processes" *International Journal of Current Trends in Engineering & Research Scientific Journal Impact Factor*, Vol. 2, 2016, pp 556–563.
[8] High Speed Tool Steel SKH 9 hardness number, available at: http://www.Otaisteel.com

May – June 2020
ISSN: 0193-4120 Page No. 1186 - 1192

[9] ISO 8501-1 Sa standards, available at: http://www.adhesive.org

AUTHORS PROFILE

Dr. Eng. RadenDadanRamdan ST,is Assistant Professor at Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology (ITB). He completed doctoral degree in Kobe University. Besides being active as lecturer, he gets involved in many projects from Industries as well related to failure analysis investigation, atomic scale simulation in materials, and development of alternative materials. He is active in publishing journal related to atomic scale simulation in materials, biomaterials, and surface treatment. In 2018, He was chosen as Chairperson of International Conference on Design and Application of Engineering Materials (IC-DAEM).

Dr. Eng. Budi Prawarais a Senior member in Research Center of Electronics and Telecommunications at The Indonesian Institute of Sciences (LIPI). He completed doctoral degree in University of The Ryukyus, Japan. His research field is in thermal spray coating technology.

Irma Pratiwi ST, is a research assistant at Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology (ITB). She is a graduate of Bandung Institute of Technology in Materials Engineering Major. She studied the effect of CO_2 and acetic acid in API 5L X65 steel corrosion at NaCl environment for her undergraduate final project. She recently takes master degree program in Materials Engineering Major at ITB and her research focus is about RCA (Rotating Cage Autoclave) modification for corrosion testing.

Syauqi RamadhanST, is a graduate of Bandung Institute of Technology in Materials Science and Engineering Department. He studied about abradable coating materials. He is active in HimpunanMahasiswaTeknik Material as Head of Human Resources Ministry and Vice Leader of Advocacy Division in KabinetMahasiswa ITB. His research interest is in thermal spray coating technology.

Dr. Ir. BambangWidyantoM.Sc,is Associate Professor at Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology (ITB). He completed doctoral degree in Universite De Technologie Compiegne, France. His research field is in Corrosion. Besides being active as lecturer, he gets involved as well in many industrial projects related to corrosion. He is member of Indonesian Corrosion Association (president since 1995) and The National Association Corrosion Engineers (associate).

Prof. Dr. Ir. RochimSuratman, is Professor at Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology (ITB). He completed doctoral degree in KatholiekeUniversiteit Leuven, Belgium. His research field is in Heat Treatment, Composite materials, Welding, and Casting Technology. Besides being active as lecturer, he gets involved as well in many industrial projects related failure analysis and welding technology. He received four Indonesian patents related to research in composite materials.