THE POTENTIAL OF EVAPORATION BOATS WASTE AS A CRUCIBLE MATERIAL FOR CASTING: A REVIEW

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ABSTRACT: Industry in Indonesia continues to experience development in line with advances in science and technology, and this is because the industrial sector makes the most significant contribution to the national economy. However, industrial operations that are getting bigger can produce various kinds of waste, one of which is waste from the processing of plastic metallization applications and modern vacuum coating on food packaging, namely evaporation boats. The result of this waste is substantial because, in its application, evaporation boats will always be used as long as plastic food packaging continues to be produced around the world, so it is necessary to have handling for environmental sustainability in the future. Evaporation boat waste is waste that cannot be decomposed but can withstand heat and be used as a refractory material, especially as a primary material for making crucibles.

KEY WORDS: Evaporation Boats Waste, Refractory, Crucible

1. INTRODUCTION

The development of the manufacturing industry in Indonesia is considered relatively rapid and in line with advances in science and technology. This development is inseparable from the demands in this globalization era to continue to make changes and progress. Another demand is realizing environmentally sound development through effective and efficient waste management [1]. Various types of waste are generated in the metallurgical manufacturing industry sector, one of which is waste left over from the application of plastic metallization and modern vacuum coating, namely evaporation boats [2].

Evaporation boats are materials used for coating aluminum in decorative applications, plastics, glass, and food packaging in vacuum chambers [3]. In the metallization process, aluminum plastic is heated using evaporation boats to the melting point of a vacuum so that the atoms and molecules will evaporate and stick to the surface, then cooled rapidly so that it crystallizes and forms a thin layer on food packaging products [4]. The purpose of having an aluminum metal coating on food packaging is to eliminate contamination by bacteria and microorganisms. However, in its operation, the industry engaged in plastic metallization always produces a lot of evaporation and boat waste. Currently, the amount of waste generated from this industrial activity is enormous because in its use, the material for evaporation boats is used in large quantities and has a relatively short service life, so in the future, there must be a solution for processing and utilizing the waste.

The material life of the evaporation boats for plastic metallization is only 15 hours, after which it is necessary to replace new evaporation boats to maintain the effectiveness of the plastic metallization process [5] [6]. Therefore, the amount of waste evaporation boats produce

is considerable due to their continuous use and in a short time. However, the efficient handling of waste disposal has yet to be known. Whereas the evaporation boat material inside contains Boron Nitride (BN) and Titanium Diboride (TiB_2), which have very good electrically conductive and thermal conductivity properties with high-temperature applications and resistance to chemicals and heat [7]. Material evaporation boats also have the advantage of being a refractory material [8].

Refractory material can maintain its strength and shape at high temperatures, is very heat resistant, and has good thermal conductivity [9]. The superior of Boron Nitride, which has good heat resistance, needs to be used as a refractory material applied to high temperatures, such as crucibles for metal smelting [10].

A crucible is a container for melting non-ferrous materials in the shape of a crucible resembling a pot where the top diameter is larger than the bottom diameter [11]. Crucibles also purify materials and their alloys at high temperatures [12]. The requirements for a good quality crucible are that it is inert or does not react chemically with the melted material and is heat resistant so that it can last a long time in use. However, the current problem with the quality of crucible products on the market is that they must be fixed. The metal casting industry experiences many problems because the price of crucibles available in the market is costly, difficult to obtain, and only lasts for a short time, so further development is needed in crucible materials [13].

Evaporation boat waste has excellent potential for future quality waste utilization and treatment. Its availability in large quantities and its advantages as a refractory material must be used widely. Besides reducing environmental impacts due to waste pollution, evaporation boats can also solve the problem of crucible products, which still need further development to obtain higher quality crucible products. This article provides a literature review centered on examining the characteristics of waste generated from evaporation boats and its impact on the mechanical and physical attributes of the crucible material employed in metal casting processes.

2. REFRACTORY MATERIALS FOR MAKING CRUCIBLES

In non-ferrous smelting activities such as aluminum, copper, brass, gold, silver, and palladium, it is necessary to use quality crucible products. The choice of base material in the manufacture of crucibles must be appropriate to avoid contamination of the melt during smelting [14]. Table 1 shows the following refractory materials to high temperatures:

Table 1: Refractory Materials for High-Temperature Applications

Refractory Materials	**Melting Point (C^o)**	**Thermal Conductivity ($Wm^{-1}K^{-1}$)**	**Reference**
Graphite	3600	140	[15]
BN	2200	1300	[16]
TiB_2	3225	120	[17]
AIN	2200	248	[18]
SiO_2	1200	1.2-1.4	[19]
Al_2O_3	2072	30	[20]
CaO	2572	30	[21]
MgO	2852	45-60	[22]
SiC	1200	45	[23]

The procedure for selecting crucible materials that have the potential to melt metals must consider several important aspects, namely the strength of the material from the interaction between the crucible and thermodynamics, such as melting temperature, softening, wettability, and resistance to thermal shock. [24]. The procedure for choosing the crucible material must be considered because if it does not, it will cause failure of the crucible.

Fig. 1. Crucible failure [25]

Failures in crucible products can be in the form of cracks and deformations. Cracks cause liquid metal leakage, while deformation is caused because the crucible material cannot withstand high temperatures during smelting. Failure in the crucible is unavoidable due to the continuous use of the crucible in smelting [26]. Therefore, the crucible products must have high purity and density, fine grain, good thermal conductivity, thermal shock and oxidation resistance, excellent stability, and low porosity to increase the crucible's service life [27].

3. CHARACTERISTICS OF EVAPORATION BOAT WASTE

Evaporation boat waste contains compound elements, namely between BN and TiB_2. One of the advantages of evaporation boats is that they do not change much even though they have been used and become waste. The properties of the material evaporation boats on the market are usually used in the plastic metallization process.

Table 2: Properties of Material Evaporation Boats [7]

Property	units	Value
Density	(g/cm^3)	> 2.75
Porosity	(%)	<3
Brinell Hardness	HB 2.5/40	45
Flexural Strength	MPa	70
Young's Modulus	GPa	55
Fracture Toughness	MPa $\sqrt{m}$	1.8
Thermal conductivity at 20° C	W/mK	80
Resistivity at 1600° C	Rail (10-6 Ωcm)	1300-4800

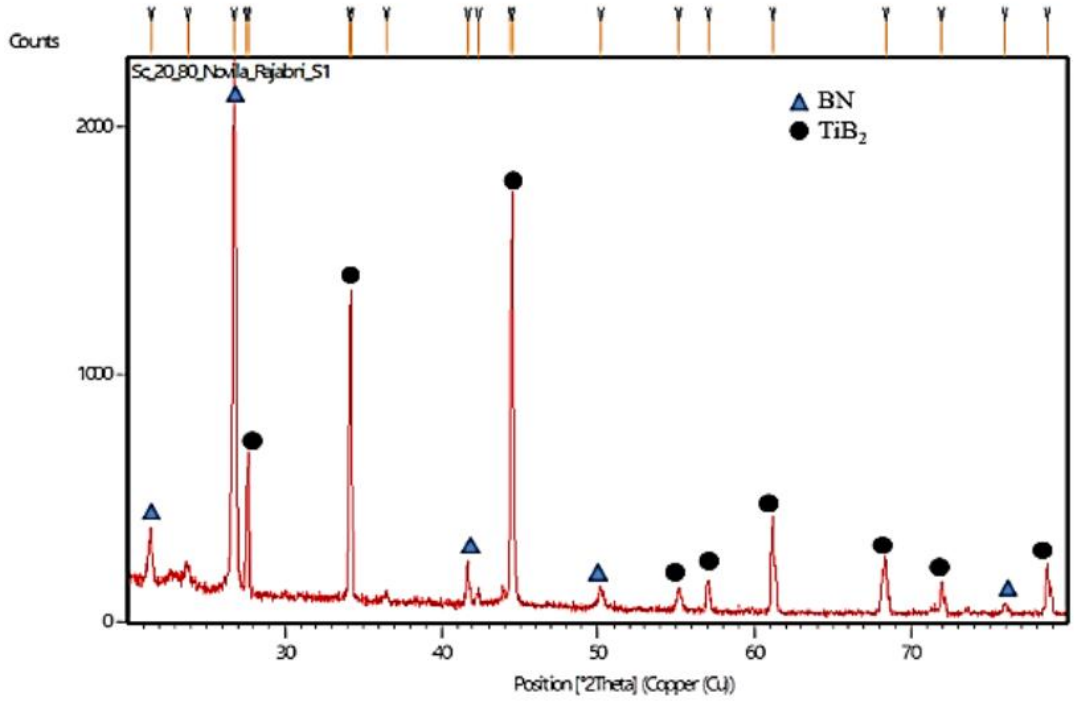

Fig. 2. XRD Results from Evaporation Boats Waste [28]

The results of XRD tests on evaporation boat waste have been carried out, and they show that there are high crystallinity peaks in the BN and TiB_2 compounds. The combination of compounds between the two makes evaporation boat waste have the properties of high thermal conductivity and melting point. Hence, evaporation boat waste is suitable for refractory materials [28].

Boron Nitride (BN) and Titanium Diboride (TiB_2) contained in the material of evaporation boats were studied for many applications as aluminum evaporation and deposition vessels, which produce good electrical conductors [29]. However, the service life of evaporation boats is limited due to the interaction of the metal with ceramic materials in the evaporation vessel, which cannot be used continuously. Therefore, there is a lot of waste, and even though the waste material in evaporation boats has many advantages, it needs to be utilized.

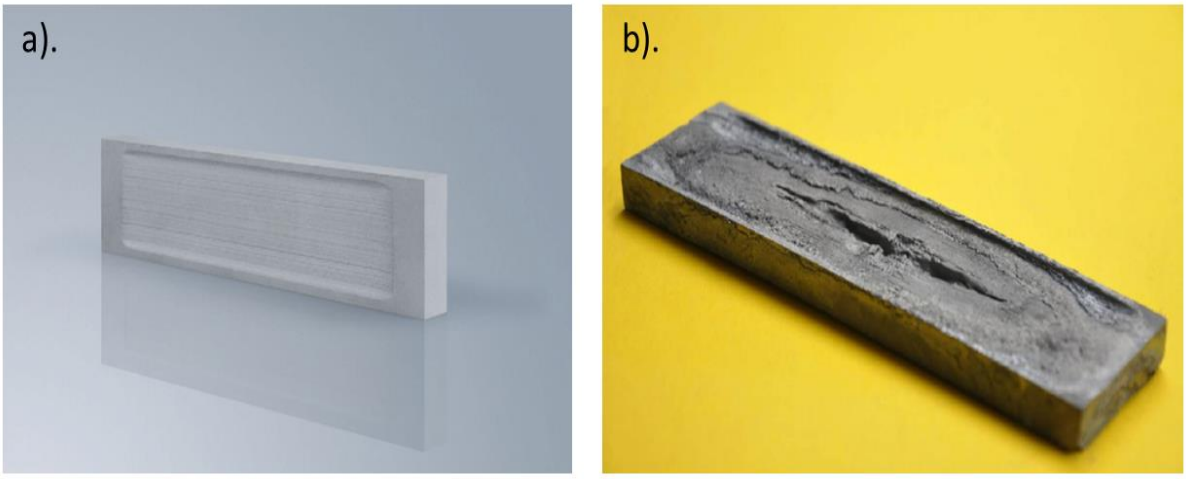

Fig. 3. a). New Material Evaporation Boats, b). Evaporation Boats Waste [29]

4. EFFECT OF EVAPORATION BOATS ON CRUCIBLE PROPERTIES

Research on the manufacture of crucibles has been carried out a lot. Usually, materials such as graphite, kaolin, and refractory cement are used to make crucibles that contain refractory materials. Several research studies focusing on the manufacture of crucibles made from evaporation boat waste have also been carried out. Table 3. Shows a collection of research on the manufacture of crucibles from evaporation boat waste.

Table 3: Research in the Investigation of Crucible Manufacturing

References	Research Focus	Results
[30]	Made an invention related to the method for making metal smelting crucibles from evaporation boat waste and has been patented with patent number IDS000004495 regarding the best composition of crucible materials, namely evaporation boat waste (50%), graphite materials (25%), and kaolin materials (25%). In addition, the crucible material is given thermal shock treatment to determine the impact resistance value of the crucible.	The method for making crucibles using the best and patented composition has an impact resistance value based on ASTM D256 of 0.01772659 J/mm^2. In addition, based on the analysis of the thermal shock treatment carried out on the crucible, it is concluded that the higher the temperature of the thermal shock treatment, the lower the impact resistance value.
[31]	We are analyzing the effect of thermal shock and the best composition percentage of metal smelting crucibles made from evaporation boat waste on macrostructure and impact resistance. Impact testing is used to determine the level of resistance of the crucible from impact, while the macrostructure is used to determine the shape of the fracture from the impact testing carried out.	Variations in thermal shock and crucible material composition influence the crucible's impact resistance. The impact resistance value for each composition variation shows a decreasing value with increased thermal shock. The fracture results from all specimens have brittle properties and can provide high light reflectivity.
[32]	It was important to know the effect of thermal shock and the best composition of refractory materials, namely alumina, rice husk ash, and kaolin materials, on the value of impact resistance and macrostructure. Adding alumina material to the refractory material can increase the mechanical strength.	The higher the refractory material's thermal shock (ΔT) temperature, the lower the impact strength. Since the cooling of the material occurs suddenly and the material's structure becomes imperfect, it is also evident that the fracture has a flat surface and reflects a shiny shine—the higher the temperature of the thermal shock, the darker the color of the impact fracture.
[33]	Analyze the manufacture of crucible materials that utilize rice husk ash mixed with other refractories such as graphite and kaolin. Rice husk ash is utilized as a crucible base material because it contains refractory materials; besides, rice husk ash in Indonesia is still limited to animal feed. The analysis was conducted to determine the compound phase of rice husk ash and the thermal shock treatment of impact resistance and macrostructure.	The compound phases in the rice husk ash material from the XRD test were 98.8% SiO_2, 100% Carbon, and 100% $Si_2O_5(OH)_4$. Based on the results of the analysis of thermal shock, heating or cooling quickly can cause a failure of the strength of the material due to damage to the atomic structure due to heat shock and high heat exceeding the strength of the material.

[34]	Conduct experimental analysis on the effect of mixing time on the hardness of Vickers crucible materials made from evaporation boat waste, kaolin, and refractory cement. Mixing materials is necessary so that the process of mixing crucible materials becomes more homogeneous and prevents the failure of the crucibles.	The results of the analysis from his research are that the longer the mixing time, the more homogeneous the mixture of crucible materials will be, and the more homogeneous the crucible, the greater the hardness, which is because the particles of the crucible are getting solid and the hardness can increase. Meanwhile, the micro-crucible structure of mixing the ingredients for a long time will produce a homogeneous phase because the particles are evenly distributed.
[35]	Investigate the effect of drying control on the crucible green body material on compressive strength, impact resistance, and macrostructure made from evaporation boat waste, graphite, and kaolin. Drying control is important for crucibles because if the water content in the crucible is too high, it will cause cracks during the combustion process.	The controlled drying process will cause the crucible material to increase its mechanical properties with the length of drying time. Mechanical stresses in ceramic materials during drying can occur because water shrinkage can cause cracks if the drying conditions are not carefully controlled, so the compressive strength and impact values of the crucible decrease.
[36]	Experimental study of the effect of extrusion time on evaporation boats waste materials, graphite, and castable cement as crucible materials in extruder machines on density, porosity, and impact strength. Extrusion is used for crucible materials in the presence of friction which is then channeled by a screw to produce material that conforms to the shape of the mold hole.	The analysis shows that the longer the extrusion time, the higher the density value, while the shorter the extrusion time, the higher the porosity value. The crucible's mechanical properties are increased using a longer extrusion time.
[37]	In his research, he analyzed the effect of compaction pressure on the density, porosity, and microstructure of crucibles made from evaporation boat waste, kaolin, castable, and rice husk ash. The compacting pressure on the crucible is a significant parameter in reducing the water content in the crucible formed prior to the combustion process so that it does not crack.	The results show that the higher the compaction pressure on the crucible made from evaporation boats, kaolin, castable, and rice husk ash, the mechanical properties and density will increase, and the porosity of the crucible is found to be higher with reduced crucible compaction pressure. The white phase of high compaction pressure is produced because the particles can unite tightly.
[38]	Conduct a study on the effect of temperature in the sintering process on density, porosity, and bending strength of refractory linings based on evaporation boat waste. Refractory materials include evaporation boat waste, refractory cement, and silica sand. The sintering temperature is important to control because it determines the uniform grain growth rate in crucible firing.	The resulting analysis shows that the higher the sintering temperature, the more density and mechanical properties, such as bending, will increase. Still, the sintering temperature must also be adjusted to the level of the melting point of the material used, whereas the lower the sintering temperature, the porosity will increase. The mechanical

		properties of the crucible will decrease.
[39]	Investigate and analyze the effect of firing temperature parameters on density, porosity, impact resistance, and the macrostructure of crucible materials made from refractory materials such as graphite, kaolin, and castable cement. The firing temperature is considered very important to control in the combustion process for making crucibles because the firing temperature will determine the maturity level of the crucible; too high a temperature will cause damage to the material because it does not match the melting point of the material, so this parameter is important to control.	The results are that the higher the firing temperature will produce mechanical properties such as higher impact strength; the porosity is also observed to increase with increasing temperature, and the porosity decreases; this is because high temperatures will make the particles of the material stick together more tightly and densely so that the grain boundaries get smaller and stick together tightly.
[40]	Researching the effect of holding time parameters on density, porosity, and Vickers hardness in crucible materials made from evaporation boats waste with a mixture of kaolin and graphite materials. The holding time parameter can also affect the crucible yield because the combustion process requires holding time to produce the perfect crucible material maturity level.	Based on the tests' results, the longer the holding time used, the stronger the crucible material will be. The hardness and density values increase with a long holding time, while porosity decreases with decreasing firing holding time; the process of burning crucible material will become more perfect due to the holding time at the combustion temperature used.
[41]	Analyze the effect of the green body heating rate on the mechanical and physical properties of crucible materials such as compressive strength, hardness, and microstructure made from evaporation boats waste with a mixture of kaolin, graphite, and fire-resistant cement. The heating rate parameter is also necessary because it determines the time needed for the firing process. Control of this parameter needs to be used so that the crucible material does not experience thermal shock due to the heating rate that is too fast.	It is known that the slower the heating rate used, the better the mechanical properties and physical properties of crucible material. The compressive strength and hardness Vickers values are known to increase along with the slow rate. In contrast, the microstructure and fast heating rate are known to be increasingly inhomogeneous and uneven. There is not enough time for the particle's crucible materials to coalesce during combustion.

5. FUTURE STUDY

Evaporation boat waste has a significant potential for the utilization and management of waste in the future. Besides reducing the environmental impact due to the increasing and piling up waste pollution, evaporation boat waste can also be used to increase added value in industries engaged in plastic metalizing. Opportunities for commercializing this crucible product are still extensive, and there are excellent prospects for the future due to the high demand for crucibles for the smelting industry for various types of metal in Indonesia.

The use of evaporation boat waste is not only used as a material in the manufacture of crucibles, but in the future, it can be used again widely in other component manufacturing applications that require very high heat resistance, such as refractory linings, furnace waiting

linings, and in other applications as a substitute material. Refractories, which, if bought in the market, are very expensive.

6. CONCLUSION

The results of studies from various literature that have been conducted concluded that many crucible materials use refractory materials that can withstand high temperatures. Evaporation boat waste generated from the plastic metallization industry is colossal due to its continuous use and unknown waste handling. Evaporation boat waste is a material containing BN and TiB_2 compounds. It has properties as a refractory material and has the potential to be used as a material for making crucibles for metal smelting. Evaporation boat waste can be used as a substitute for refractory materials to make crucibles for smelting non-ferrous materials, which are very expensive.

REFERENCES

[1] P. Prajapati *et al.*, "Critical review on technological advancements for effective waste management of municipal solid waste — Updates and way forward: Advancements in Municipal Solid Waste Management," *J. Environ. Technol. Innov.*, vol. 23, p. 101749, 2021, doi: 10.1016/j.eti.2021.101749.

[2] J. Eichler, K. Uibel, and C. Lesniak, "Boron Nitride (BN) and Boron Nitride Composites for Applications under Extreme Conditions," *J. Int. Ceram.*, vol. 65, pp. 61–69, 2010, doi: 10.4028/www.scientific.net/ast.65.61.

[3] A. Mukhopadhyay, G. B. Raju, B. Basu, and A. K. Suri, "Correlation between phase evolution, mechanical properties and instrumented indentation response of TiB2-based ceramics," *J. Eur. Ceram. Soc.*, vol. 29, no. 3, pp. 505–516, 2009, doi: 10.1016/j.jeurceramsoc.2008.06.030.

[4] Rusiyanto *et al.*, "Bab VIII. Pengaruh Komposisi Bahan Terhadap Mechanical Properties Pada Crucible Untuk Peleburan Aluminium," in *Book Chapter Kimia Jilid 1*, Inovasi Kimia, 2022, pp. 197–221. doi: DOI: https://doi.org/10.15294/ik.v1i1.80.

[5] J. A. Bayus, *Environmental Life Cycle Comparison of Aluminum-based High Barrier Flexible Packaging Laminates*. 2015.

[6] H. He *et al.*, "Applied properties and life cycle assessment of flexible packaging lamination processes: a comparative study," *Int. J. Life Cycle Assess.*, vol. 26, no. 3, pp. 561–574, 2021, doi: 10.1007/s11367-021-01883-4.

[7] PT. 3M Indonesia, "3M ™ Evaporation Boats 4.0," *3M Sci. Appl. to life*, pp. 1–2, 2015.

[8] S. Bernard and P. Miele, "Polymer-derived boron nitride: A review on the chemistry, shaping and ceramic conversion of borazine derivatives," *J. Mater.*, vol. 7, no. 11, pp. 7436–7459, 2014, doi: 10.3390/ma7117436.

[9] L. Backman, J. Gild, J. Luo, and E. J. Opila, "Part I: Theoretical predictions of preferential oxidation in refractory high entropy materials," *J. Acta Mater.*, vol. 197, pp. 20–27, 2020, doi: 10.1016/j.actamat.2020.07.003.

[10] Rusiyanto *et al.*, "Pengaruh Durasi Pencampuran Terhadap Mechanical Properties Crucible Peleburan Aluminium," *Inov. Kim.*, no. 1, pp. 39–64, 2022, doi: 10.15294/ik.v1i1.61.

[11] A. Leman, T. Tiwan, and M. Mujiyono, "Tungku Krusibel dengan Economizer untuk Praktik Pengecoran di Jurusan Pendidikan Teknik Mesin FT UNY," *J. Din. Vokasional Tek. Mesin*, vol. 2, no. 1, p. 21, 2017, doi: 10.21831/dinamika.v2i1.13496.

[12] M. Palacz *et al.*, "Experimental Analysis of the Aluminium Melting Process in Industrial Cold Crucible Furnaces," *Met. Mater. Int.*, vol. 26, no. 5, pp. 695–707, 2020, doi: 10.1007/s12540-019-00368-2.

[13] D. L. Zariatin, I. Ismail, and M. Jaya, "Studi Eksperimental Efisiensi Peleburan Aluminium pada Tungku Crucible Furnaces," *JTERA (Jurnal Teknol. Rekayasa)*, vol. 4, no. 2, p. 209, 2019, doi: 10.31544/jtera.v4.i2.2019.209-218.

[14] X. yong Gao, L. Zhang, X. hui Qu, X. wei Chen, and Y. feng Luan, "Effect of interaction of refractories with Ni-based superalloy on inclusions during vacuum induction melting," *Int. J. Miner. Metall. Mater.*, vol. 27, no. 11, pp. 1551–1559, 2020, doi: 10.1007/s12613-020-2098-9.
[15] A. Hoseinpur and J. Safarian, "Mechanisms of graphite crucible degradation in contact with Si–Al melts at high temperatures and vacuum conditions," *Vacuum*, vol. 171, p. 108993, 2019, doi: 10.1016/j.vacuum.2019.108993.
[16] S. N. Perevislov, "Structure, Properties, and Applications of Graphite-Like Hexagonal Boron Nitride," *Refract. Ind. Ceram.*, vol. 60, no. 3, pp. 291–295, 2019, doi: 10.1007/s11148-019-00355-5.
[17] B. R. Golla, T. Bhandari, A. Mukhopadhyay, and B. Basu, "Ultra-High Temperature Ceramics: Materials for Extreme Environment Applications," in *The American Ceramic Society*, John Wiley & Sons, Inc., 2014, pp. 316–361. doi: https://doi.org/10.1002/9781118700853.ch13.
[18] M. Qin *et al.*, "Powder injection molding of complex-shaped aluminium nitride ceramic with high thermal conductivity," *J. Eur. Ceram. Soc.*, vol. 39, no. 4, pp. 952–956, 2019, doi: 10.1016/j.jeurceramsoc.2018.11.037.
[19] N.-T. Nguyen, *Fabrication technologies*, Second Edi. Elsevier Inc, 2012. doi: 10.1016/b978-1-4377-3520-8.00004-8.
[20] D. Whitney, *Ceramic Cutting Tools*, vol. 2, no. 1993. Elsevier Ltd, 2014. doi: 10.1016/B978-0-08-096527-7.00037-4.
[21] Y. Xu *et al.*, "Characteristics and performance of CaO-based high temperature CO2 sorbents derived from a sol-gel process with different supports," *RSC Adv.*, vol. 6, no. 83, pp. 79285–79296, 2016, doi: 10.1039/c6ra15785h.
[22] K. S. Sridhar Raja, S. Ganesan, and J. Senthil Kumar, "Performance and emission characteristics of biodiesel from black pepper oil," *Int. J. Ambient Energy*, vol. 40, no. 5, pp. 463–466, 2019, doi: 10.1080/01430750.2017.1410227.
[23] R. Ji, Y. Liu, Y. Zhang, B. Cai, X. Li, and C. Zheng, "Effect of machining parameters on surface integrity of silicon carbide ceramic using end electric discharge milling and mechanical grinding hybrid machining," *J. Mech. Sci. Technol.*, vol. 27, no. 1, pp. 177–183, 2013, doi: 10.1007/s12206-012-1215-8.
[24] S. Fashu *et al.*, "A review on crucibles for induction melting of titanium alloys," *Mater. Des.*, vol. 186, p. 108295, 2020, doi: 10.1016/j.matdes.2019.108295.
[25] J. Bayley, D. Crossley, and M. Ponting, *Metals and Metalworking: A research framework for archaeometallurgy*, vol. 6, no. 6. 2008.
[26] Y. Hendronursito, K. Isnugroho, and D. C. Birawidha, "Analysis of crucible performance for aluminum scrap casting at small and medium enterprises (SMEs) foundry," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 478, no. 1, 2019, doi: 10.1088/1757-899X/478/1/012005.
[27] H. Chen, H. Xiang, F. Z. Dai, J. Liu, and Y. Zhou, "Porous high entropy (Zr0.2Hf0.2Ti0.2Nb0.2Ta0.2)B2: A novel strategy towards making ultrahigh temperature ceramics thermal insulating," *J. Mater. Sci. Technol.*, vol. 35, no. 10, pp. 2404–2408, 2019, doi: 10.1016/j.jmst.2019.05.059.
[28] N. R. Fajri, R. Rusiyanto, R. D. Widodo, W. Sumbodo, and D. F. Fitriyana, "Pengaruh Thermal Shock dan Komposisi Evaporation Boats, Semen Tahan Api, dan Pasir Silika terhadap Kekuatan Impact dan Foto Makro Lining Refractory," *J. Rekayasa Mesin*, vol. 12, no. 1, p. 11, 2021, doi: 10.21776/ub.jrm.2021.012.01.2.
[29] M. Herrmann, J. Räthel, S. Höhn, J. Eichler, and A. Michaelis, "Interaction of titanium diboride/boron nitride evaporation boats with aluminium," *J. Eur. Ceram. Soc.*, vol. 31, no. 13, pp. 2401–2406, 2011, doi: 10.1016/j.jeurceramsoc.2011.04.035.
[30] Rusiyanto *et al.*, "Metode Pembuatan Crucible Peleburan Logam Berbahan Limbah Evaporation Boats," IDS000004495, 2021
[31] S. I. Nurrohmah, Rusiyanto, R. D. Widodo, and W. Sumbodo, "Pengaruh Thermal Shock dan Komposisi Grafit, Kaolin (Clay) Terhadap Struktur Makro dan Ketahanan Impak Kowi Berbahan Dasar Limbah Evaporation Boats.," *J. Rekayasa Mesin*, vol. 11, no. 2, pp. 287–295, 2020.
[32] A. L. Sari and R. Rusiyanto, "Pengaruh Thermal Shock Resistence dan Komposisi Bahan Refraktori Terhadap Kekuatan Impact dan Struktur Makro," *J. Din. Vokasional Tek. Mesin*, vol.

4, no. 2, pp. 105–110, 2019, doi: 10.21831/dinamika.v4i2.27392.
[33] D. R. Sari, Rusiyanto, R. D. Widodo, and Pramono, "Pengaruh thermal shock resistance terhadap makro struktur dan ketahanan impact kowi pelebur (crusible) berbahan komposit abu sekam padi/grafit/kaolin," *J. Kompetensi Tek.*, vol. 9, no. 1, pp. 53–59, 2017.
[34] S. Triyanto, Rusiyanto, R. D. Widodo, S. Anis, and D. F. Fitriyana, "Pengaruh Waktu Pencampuran Terhadap Kekerasan Vickers Material Crucible Berbahan Limbah Evaporation Boats, Kaolin, dan Semen Tahan Api," *J. Rekayasa Mesin*, no. July, pp. 325–330, 2021.
[35] Rusiyanto, M. Irfan, R. D. Widodo, Sunyoto, and D. F. Fitriyana, "Effect Of Drying Time On Cimpressive Strength, Impact Strength And Macro Structure Of Crucible Materials Made From Evaporation Boats Waste, Graphite And Kaolin," *Int. Conf. Sci. Technol.*, vol. 030001, no. March, 2023, doi: https://doi.org/10.1063/5.0124101.
[36] G. T. Akbar, Rusiyanto, Sunyoto, Kriswanto, and N. F. Hendrix, "Pengaruh Waktu Ekstrusi Bahan Evaporation Boats, Grafit Dan Semen Castable Pada Mesin Ekstruder Terhadap Densitas, Porositas Dan Kekuatan Impak," *J. Inov. Mesin*, vol. 4, no. 2, pp. 49–55, 2022, doi: https://journal.unnes.ac.id/sju/index.php/jim Pengaruh.
[37] P. H. Krismanto, Rusiyanto, R. D. Widodo, Kriswanto, and H. N. Firmansyah, "Pengaruh Tekanan Terhadap Densitas, Pororsitas dan Struktur Mikro Kowi (Crusible) Berbahan Evaporation Boat, Kaolin, Castbale, dan Abu Sekam Padi," *J. Inov. Mesin*, vol. 2, no. 2, pp. 11–18, 2020.
[38] L. Erliyanti and H. Sunyoto, "Pengaruh Temperatur Sintering Terhadap Densitas, Porositas, dan Kekuatan Bending Lining Refractory Berbasis Limbah Evaporation Boats," *J. Kompetensi Tek.*, vol. 12, no. 1, pp. 25–30, 2020.
[39] A. Latif, Rusiyanto, Sunyoto, Kriswanto, and D. F. Fitriyana, "Effect of Firing Temperature on Density, Porosity, Impact Strength, and Macro Structure of Crucible Materials Made from Graphite, Kaolin, and Castable Cement," *Int. J. Mech. Eng. Technol. Appl.*, vol. 3, no. 2, pp. 93–99, 2022.
[40] W. M. Hidayat, Rusiyanto, R. D. Widodo, W. Sumbodo, and D. F. Fitriyana, "Effect of Firing Holding Time on Density, Porosity, and Hardness, Crucible Materials Based on Evaporation Boats," *Int. J. Mech. Eng. Technol. Appl.*, vol. 3, no. 2, pp. 79–84, 2022.
[41] M. N. A. Habiby, R. Rusiyanto, R. D. Widodo, and W. Sumbodo, "Pengaruh Laju Pemanasan Green Body Terhadap Sifat Mekanis dan Fisis Material Crucible Berbahan Limbah Evaporation Boats," *J. Rekayasa Energi Manufaktur*, vol. 7, no. 1, pp. 20–26, 2022, doi: http://doi.org/10.21070/r.e.m.v7i1.1639.