ICMIEE22-117

MICROSTRUCTURAL STUDY OF SME MANUFACTURED MARINE PROPELLER

Ismail Hossain Sian[1], *Abdullah Al Noman*[1], *Billal Bin Amin*[1], *M. Azizur Rahman*[1], *Md. Shahnewaz Bhuiyan*[1*]
[1] Department of Mechanical & Production Engineering, Ahsanullah University of Science & Technology, Tejgaon, Dhaka-1208, BANGLADESH

ABSTRACT
Engineering based SME is considered as the nerve of Bangladesh economy by simultaneously creating jobs, poverty alleviation and strengthening foreign currency reserve by reducing dependence on imported products for local industries. But this promising industry is now facing roadblocks mainly due to poor quality under service loading. Though many new and advanced manufacturing techniques are now available, but conventional sand casting is the most widely used manufacturing technique by the spare parts manufacturer in Bangladesh. It is well established that mechanical properties (strength, toughness) of a material are determined by its microstructure. Till to date, the microstructure characterization of engineering based SME products have not been subject to much scrutiny. Therefore, in this paper an attempt has been made to systematically investigate the microstructure of SME manufactured marine propeller using Optical microscope and Scanning Electron Microscope equipped with Energy Dispersive Spectroscopy. Locally made marine propeller one supplied by ACBD company and one purchased from the local market were used for this study. It was found that the microstructure of both materials mainly consists of pores, needle shaped particles, and Chinese script like features embedded on the aluminum matrix. Based on EDS results it may be concluded that the needle shaped particle is mainly composed of Si and Al. The average pore size in local material is about 1.5 times larger than that of ACBD material. Today it is well established that the so called conventional particle fracture mechanism for ductile fracture operates only after the maximum load applied in the alloys where as the presence of pores may exhibit premature growth soon after the beginning of plastic deformation. Therefore, it may be inferred that ACBD material will have superior quality compared to that of local material.

Keywords: SME, Al-Si Alloy, Microstructure, Composition, Porosity.

1. Introduction
Small and Medium Enterprises (SMEs) can be considered as the nerve of Bangladesh economic development. This section contributes as a solution to the country's socio-economic growth in terms of providing opportunities for employment, alleviating poverty, and facilitating GDP growth. The SME sector in Bangladesh is made up of about 7.9 million enterprises and contributes approximately 25% of the country's gross domestic product (GDP) [1-4]. According to the International Cooperation Organization for Small and Medium Enterprises in Asia (ICOSA), SME sector in Bangladesh accounts for 35.49% of the total employment [5]. Unfortunately, after year 2000, SME sector began to lose their business to an influx of imported components. In fact, SME sector is mainly dealt by people who are called "engineering artisan", a vast pool of labor force coming from an adverse socioeconomic condition with no formal education but had commendable skills in producing and repairing many manufacturing parts. Many SMEs start with weak technological capability and their products are unable to achieve quality certification. For example, an SEM workshop in Bhaluka manufacture crankshaft for buses and trucks. Sales were good as the price of the product was much lower than that of an imported one but the product was not tough and long lasting and broke within six months. It has been identified that inferior quality raw material was used to produce those crankshafts and resulted low quality products [6]. It is worth mentioning that in the past a number of studies have been conducted mainly addressing (i) the role of SME in the economy of Bangladesh [6-8], (ii) identification of problems and challenges facing SMEs in Bangladesh [2, 10-11]. Though several authors reported that the use of poor quality raw material can be considered main roadblocks in producing quality and reliable products, but till date no research work has been carried out to understand the quality, mechanical property under service load, safety and reliability of the SME manufactured products. Note that most of the spare parts manufacturer used conventional sand casting method to fabricate parts where scraps from the ship breaking industry is used as raw materials [12-14]. Historically, secondary alloy is considered of inferior quality to primary alloy due to inclusion and lack of compositional control [15]. Therefore, strong and focused study needs to be performed in order to improve the quality of the product.

Generally, the microstructural observation is considered as one of the primary methods in evaluating the effect of composition, production technique, deformation processes of a product under service condition. Thus, in order to optimize the performance of SME products in service, the microstructure and their influence in the mechanical properties must be well characterized.

Therefore, in this study, two dimensional microstructural features of SME manufactured marine propeller is evaluated using a combination of optical microscopy and scanning electron microscopy (SEM).

2. Experimental Procedure
Locally made marine propellers with unknown chemical composition were used in the present study. One propeller is manufactured by Artisan Craft (BD) Limited through sand casting process. Hereinafter, the material is

* Corresponding author. Tel.: +88-01795571619
E-mail addresses: newaz.mpe@aust.edu (M. S. Bhuiyan)

referred to as ACBD material. The other propeller was purchased from the local market and hereinafter the as-cast material is referred to as local material. Note that both propellers were made using sand casting from completely recycled scrap material with unknown chemical composition as well as sand casting processing techniques. Specimens at location of 0.2R, 0.4R, 0.6R and 0.8R (R indicates the propeller radius) respectively were extracted and polished using 600,800,100 and 1200 grit emery papers. The specimens were then polished with 2.5 µm and 0.5 µm diamond paste. The finely polished specimens were then etched using Kroll's reagent [92ml distilled water, 6ml HNO_3, 2ml HCl]. The etched samples were then observed under Optical microscope (using a Motic AE 2000 microscope) and scanning electron microscope (TESCAN VEGA 3). Compositional analysis was carried out using EDS.

3. Results

3.1 Microstructure observation

Fig. 1 shows the microstructure of both ACBD material and local material under optical microscope. Both samples clearly show the existence of pores and acicular particles embedded in the aluminum matrix.

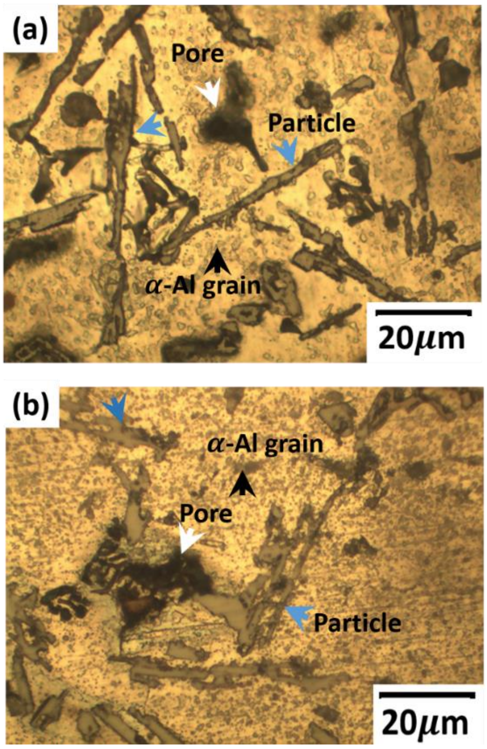


Fig. 1 Optical micrograph of samples showing the microstructure observed: (a) ACBD material, (b) Local material.

3.2 SEM analysis

Fig. 2 and Fig. 3 shows the microstructure of ACBD material and local material, respectively, under SEM. Careful observation revealed the existence needle shaped particles (shown by blue arrow) and Chinese script like features (shown by black arrow) is embedded in Al matrix (shown by white arrow).

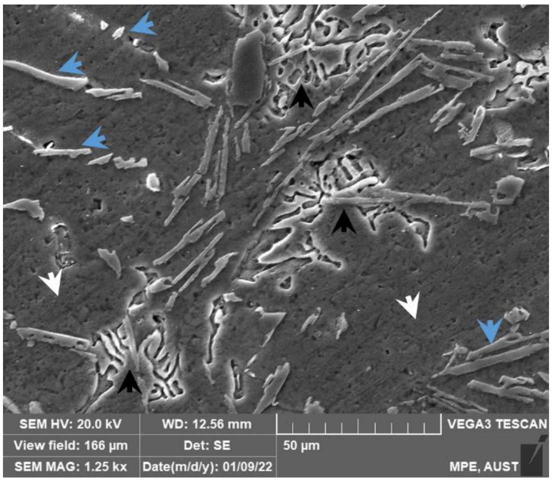


Fig. 2 SEM micrograph of ACBD material showing: (i) acicular particles (blue arrow), (ii) Chinese script like morphology (black arrow), (iii) matrix (white arrow).

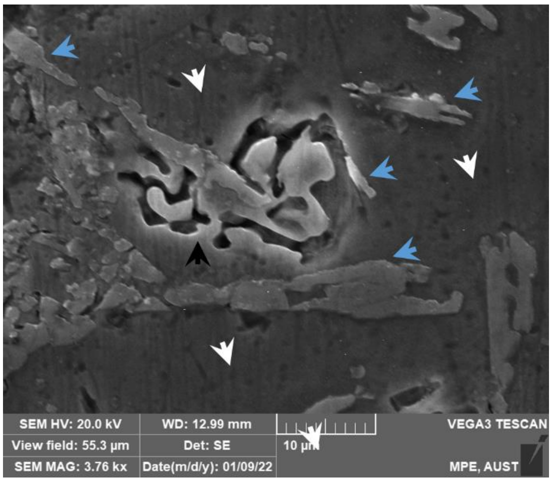


Fig. 3 SEM micrograph of local material showing: (i) acicular particles (blue arrow), (ii) Chinese script like morphology (black arrow), (iii) matrix (white arrow).

3.3 Porosity analysis

SEM micrograph of both samples clearly showed the presence of pores of different size (Fig. 4). In the present study, the SEM images were used for quantitative analysis of pores. For this purpose, ImageJ version 1.53g was used for analyzing the images. The pore area measurement process involved two steps: (i) First, the SEM images were calibrated using the scale bar at the bottom of the image, (ii) then the boundary of the pore is carefully selected using line segment. The measurement (pore area, circularity, roundness, solidity) was then analyzed using the "measurement" tool built in ImageJ and is tabulated in Table-1. It can be seen that though the minimum pore area for both material is almost same, however, the maximum pore area and the average pore area differs greatly. The maximum pore area in local material is about 3.4 time larger than that of ACBD material, whereas the average pore area in local material is about 1.5 times higher than that of ACBD material.

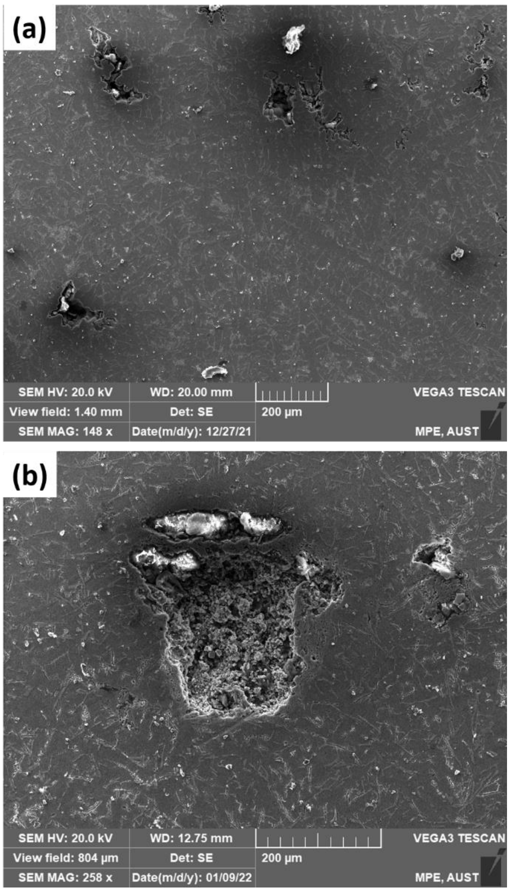


Fig. 4 SEM micrograph of samples showing the presence of pores of different size observed: (a) ACBD material, and (b) Local material.

Fig. 5 shows the frequency distribution of measured pore area for both materials. It can be seen that pore area distribution for both material is heavily skewed to the left. Majority of the pore area is less than 32000 μm^2.

Table 1: Results of 2D image analysis of pores

Parameter	Material	
	ACBD material	**Local material**
Maximum area (μm^2)	33277	114467.97
Minimum area (μm^2)	22.32	24.42
Average area(μm^2)	4975	4230.65
Average circularity	0.474	0.61
Average solidity	0.77	0.84

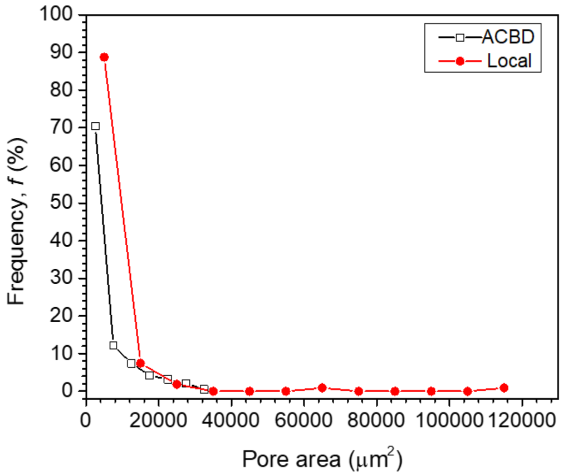


Fig. 5 Variation of pore area in ABCB and local material.

3.4 Particle analysis

As observed in Fig. 3 that the microstructure of both the studied material consists of needle shaped particle and Chinese script like features. In this section, the morphology (i.e. particle area, circularity, roundness etc.) needle shaped particles has been analyzed from SEM images using Image J version 1.53g software. For particle analysis, the calibrated SEM images were first converted to 8-bit images and then 8-bit images were converted into binary images using conventional thresholding in ImageJ. The area of particles was then calculated. A detailed step-by-step procedure to acquire particle data using ImageJ is provided elsewhere [16-17]. The result is shown in Table-2. It can be seen that local material has larger particles compared to that of ACBD materials. The average particle area in ACBD material is about 40.51μm^2 whereas particle area of local material is about 48.83 μm^2. Though the minimum particle area for both material is almost same, however, the maximum particle area in local material is about 1.22 times higher than that of ACBD material.

Table 2: Results of 2D image analysis of particles

Parameter	Material	
	ACBD material	**Local material**
Maximum area (μm^2)	342.48	417.79
Minimum area (μm^2)	10.3	9.55
Average area(μm^2)	40.51	48.83
Average circularity	0.37	0.32
Average solidity	0.63	0.62

Fig. 6 shows the variation of needle shaped particle area in ACBD material and local material, respectively.

It can be seen that majority of the particle area is less than 150 μm^2.

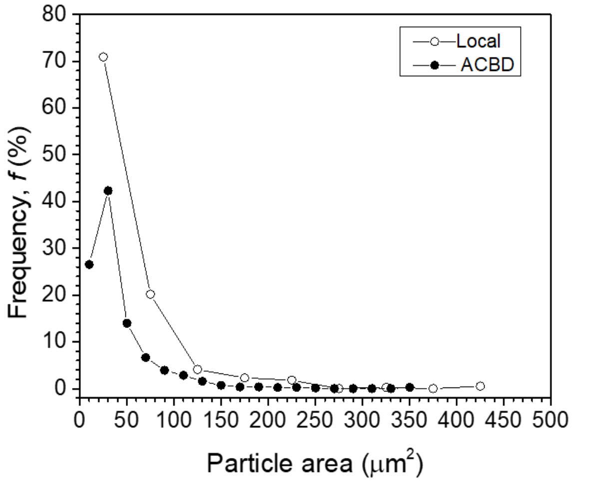


Fig. 6 Variation of needle shaped particle area in ABCB and local material.

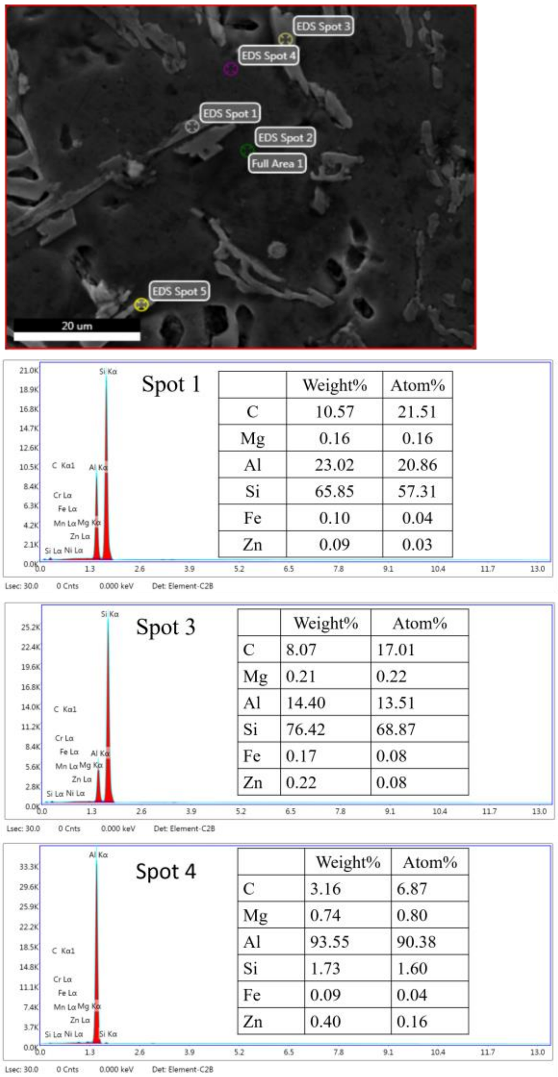
3.5 Particle composition analysis

EDS analysis has been carried out to understand the composition of particles in both ACBD and Local material. Fig. 7 showed the EDS spectrum results and elemental composition of ACBD material. Note that in Fig. 7 the EDS spectrum results and elemental composition of Spot 1, Spot 3, Spot 4 (marked in SEM image Fig. 7(a)) is shown. Spot 2 and Spot 4 both are located on the matrix, and showed almost identical composition, whereas Spot 3 and Spot5 are on particles and also showed almost identical composition. Therefore, in Fig. 7 the EDS spectrum results and elemental composition of Spot 2and Spot 5 is not shown. The results clearly showed that the needle shaped particles in ACBD material is mainly composed of Al-Si.

Fig. 8 showed the EDS spectrum results and the corresponding element composition for local material. In this case three representative spots labelled as Spot 1, Spot 2, and Spot 3 of three different needle shaped particle is shown only. The results clearly showed that the needle shaped particles in local material is also composed of Al-Si. Careful observation clearly revealed that in local material the needle shaped particles contain Cu, where as in ACBD material the element Cu is totally absent. On the other hand, the needle shaped particles in ACBD material contain a trace amount of Zn, Mg, and Fe.

4. Discussion

In the present study, 2D microstructural features of SME manufactured marine propeller is evaluated using an Optical microscope and scanning electron microscope equipped with energy dispersive spectroscope. Generally Optical microscope is considered as one of the oldest technique to acquire knowledge about general microstructural features such as pore and particle morphology and distribution but no information regarding composition of constituent phases can be achieved.



Spot 1

	Weight%	Atom%
C	10.57	21.51
Mg	0.16	0.16
Al	23.02	20.86
Si	65.85	57.31
Fe	0.10	0.04
Zn	0.09	0.03

Spot 3

	Weight%	Atom%
C	8.07	17.01
Mg	0.21	0.22
Al	14.40	13.51
Si	76.42	68.87
Fe	0.17	0.08
Zn	0.22	0.08

Spot 4

	Weight%	Atom%
C	3.16	6.87
Mg	0.74	0.80
Al	93.55	90.38
Si	1.73	1.60
Fe	0.09	0.04
Zn	0.40	0.16

Fig. 7 SEM image and EDS point analysis of ACBD material.

In contrast, scanning electron microscope with EDS can provide both particle morphology at fine scale as well as composition of constituent phases. Our investigations have clearly shown that both material showed the presence of pores, with the average pore area in local material is 1.5 times higher compared to that of ACBD material (Fig. 1 and Fig. 4). Numerous casting defects such as shrinkage, porosity is considered to the most vexed topics of foundry industries. Parameters that could affect the casting process induced defects are: (i) Composition of Moulding sand, (ii) pattern quality, (iii) mould thickness and design, (iv) temperature of molten metal (pouring pre-heat), (v) timing (pouring, melt holding, degasification), pouring velocity [18-19]. In this Industry 4.0 era, product defect rate reduction is considered as one of the most important Key Performance Indicator. Hence numerous research has been carried out around the globe to produce parts with minimal defect rate. With an aim to reduce casting defects thereby improving product quality, extensive amount of research has been carried out to optimize various casting parameters, namely: (i) use of computer aided manufacturing [20], (ii) effect of riser positioning and heat dissipation rate on casting defects [21], (iii) use of solidification simulation process for defect detection and elimination [22], (iv) mould sand process parameter analysis and its influence on casting defects [23], (v) analysis of feeder system using FEM based software [24], (vi) optimization of gating system [25], (vii) optimization of process parameters such as pouring temperature, moisture content, binder percentage [26], (viii) application of machine learning [27].

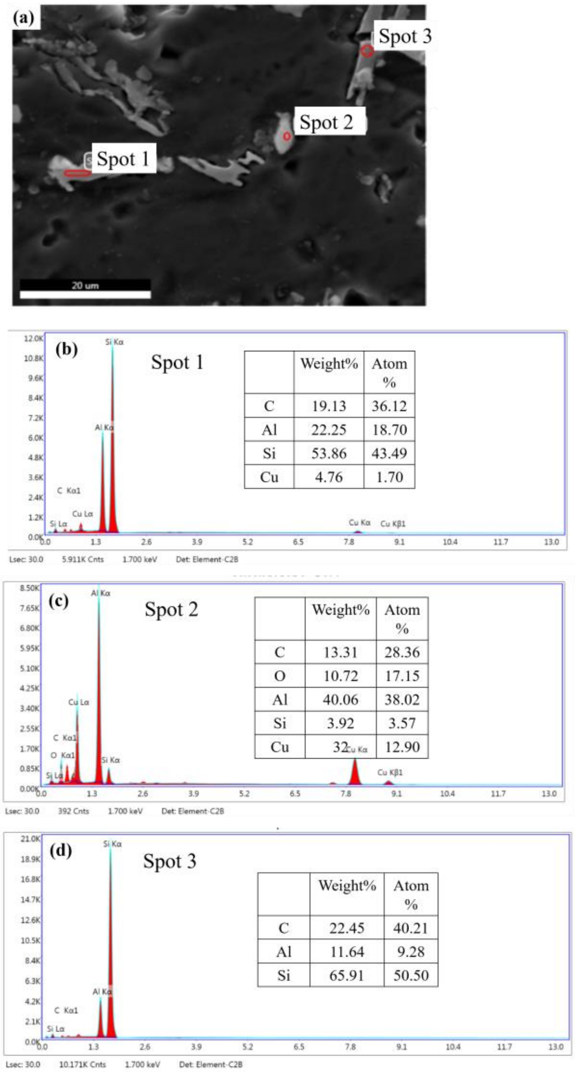


Fig. 8 SEM image and EDS point analysis of local material.

This suggests that a thorough research needs to be carried out to identify and classify the root cause responsible for defective casting production. In the context of Bangladesh, the manufacturer neither provide any access to their production unit nor they provide any information regarding their source of raw materials, composition of raw material, therefore, it is almost impossible to predict the causes that may be responsible for the observed serious casting defects in both ACBD and local material. It is well documented that porosity leads to poor mechanical properties such as limited strength and ductility, variation in fracture toughness, irregular crack nucleation and crack propagation characteristics, therefore, porosity is considered as one of the major cause of rejection of the parts fabricated using casting methods [28]. Porosity also severely affects the fatigue life as well as fatigue strength [29-30]. Under fatigue loading porosity acts as a preferential site for fatigue crack nucleation, thereby reduces the crack nucleation time, which finally resulted decreased fatigue life of the component. On the other hand, fracture under tensile loading in metals and alloys consists of three steps: (i) void nucleation, (ii) void growth, and (iii) void coalescence. It is now well known that the void nucleation on conventional ductile fracture involve fracture of secondary particles, and/or debonding of secondary particles at the interface [31-32]. The conventional particle fracture mechanism take effect only after the maximum applied load in the metals or alloys, where as the presence of pores may exhibit premature growth immediately at the beginning of plastic deformation. Since the average pore size in ACBD material is about 1.5 times smaller than that of local material, it is reasonable to assume that ACBD material will have better load carrying capacity.

4. Conclusion

From the microstructure and compositional investigation, following conclusions can be drawn:

1. Microstructure of both materials consist of pores, acicular particle, and Chinese script like features embedded on the aluminum matrix.
2. EDS results clearly showed that the matrix is mainly composed of Aluminum. The needle shaped particles in ACBD material is composed of mainly Al and Si with trace amount of Zn, Mg, Fe, where as the needle shaped particle in Local material is mainly composed of Al and Si with trace amount of Cu.
3. The average pore size in ACBD material is about 1.5 times smaller than that of local material. The conventional particle fracture mechanism take effect only after the maximum applied load in the metals or alloys, where as the presence of pores may exhibit premature growth immediately at the beginning of plastic deformation. Therefore, it is reasonable to assume that ACBD material will have better load carrying capacity

5. References

[1] Hossain, M., SME sector in Bangladesh and policy priorities, *The Business Standard*, 27-Jun-2021. https://www.tbsnews.net/economy/sme-sector-bangladeshand-policy-priorities-266821.
[2] Alauddin, M., Chowdhury, M. M., Small and Medium Enterprise in Bangladesh-Prospects and Challenges Small and Medium Enterprise in Bangladesh-Prospects and Challenges, *Global Journal of*

Management and Business Research: C Finance, vol. 15, no. 7, 2015.
[3] Odonkor, A. A., How can smes Spur inclusive growth in Bangladesh? – *The Diplomat*, 23-Dec-2021. https://thediplomat.com/2021/12/how-can-smes-spur-inclusive-growth-in-bangladesh/.
[4] Islam, M. E. M., Rahman, M., Rikta, N. N., A Note on the Contribution of Small and Medium Enterprises to GDP in Bangladesh, Policy Analysis Unit, Bangladesh Bank, Jun-2008.
[5] Yoshino, N., Taghizadeh-Hesary, F., The role of SMEs in Asia and their difficulties in accessing finance, ADBI Working Paper, no. 911, 2018.
[6] Ahmad, F., Light Engineering Products: From local workshops to export baskets, *The Business Standard*, 27-Jan-2020. https://www.tbsnews.net/opinion/light-engineering-products-local-workshops-export-baskets-39481.
[7] Rahman, M. M., Khondkar, M., Small and Medium Enterprises (SME) Development and Economic growth of Bangladesh: A Narrative of the Glorious 50 years, Barishal University Journal of Business Studies, 7 (1), 9-24, 2020
[8] Rahman, M. F., Potential of Small and Medium Enterprises, The Daily Star, November 19, 2022. https://www.thedailystar.net/supplements/24th-anniversary-the-daily-star-part-2/potential-small-and-medium-enterprises-70927
[9] Hela luz Zaman, A. K. M., Islam, M. J., Small and Medium Enterprises Development in Bangladesh: Problems and Prospects, ASA University Review, 5 (1), 145-160, 2011.
[10] Islam, M. R., Sustainable Entrepreneurship in the Light Engineering Industries: A Developing Country Perspective, The Journal of Nepalese Business Studies, XIV, 1-17, 2021.
[11] Majumder, S., Dey, S., Light Engineering Industry Sector in Bangladesh: Challenges and Prospects, The Cost and Management, 48 (1), 46-57, 2020,
[12] Majumder, S., Dey, S., Light Engineering Industry Sector in Bangladesh: Challenges and Prospects, The Cost and Management, ISSN 1817-5090, Vol. 48 (01), 46-56, 2020.
[13] Ahmad, F. U., Jahan, S. M., Demand Dynamics of Light Engineering Sector of Bangladesh and Recommendations for Local Enterprises, IOSR Journal of Business and Management, 19(1), 1-7, 2017.
[14] Sazzad, A., Light engineering sees emerging business, January 222019, hub. The Daily Industry. http://www.dailyindustry.news/lightengineering-sees-emerging-business-hub/
[15] Schlesinger, M. E., Aluminum Recycling, New Edition, Taylor & Francis Inc., 2013
[16] AlMarzooqi, F. A., Bilad, M. R., Mansoor, B. Arafat, H. A. A comparative study of image analysis and porometry techniques for characterization of porous membranes," *Journal of Materials Science*, vol. 51, no. 4, pp. 2017–2032, 2015.
[17] Bhuiyan, M. S. Rahman, M. A., Farabi, M. S., Hasan, M. M., Tensile behavior of geometrically irregular bagasse fiber, *Applied Mechanics*, vol. 2, no. 2, pp. 274–288, 2021.
[18] Fracchia, F., Lombardo, S., Rosso, M., Case Study of a Functionally Graded Aluminum Part, Appl. Sci., 8, 1-9, 2018.
[19] Kandpal, B. C., Johri, N., Kumar, B., Patel, A., Pachouri, P., Alam, M., Talwar, P., Sharma, M. K., Sharma, S., Experimental study of foundry defects in aluminum castings for quality improvement of casting, Materials Today, 46 (20), 10702-10706, 2021.
[20] Chalekar, A. A., Daphal, S. A., Somatkar, A. A., Chinchanikar, S., S., Minimization of investment casting defects by using computer simulation-A case study, J. Mech. Eng. Autom., 5,43-46, 2015.
[21] Dabade, U. a., Bhedasgaonkar, R. C., Casting defec analysis using design of experiments (DoE) and computer aided casting simulation technique, Procedia CIRP, 7, 616-621, 2013.
[22] Bijagare, V., Deulgaonkar, V., Modeling and Finite Element Analysis for a Casting Defect in Thin-Wall structures, 3, 77-82, 2015.
[23] Patel, B.V., Diwedi, D., Finite Element Analysis of solidification of L-shaped casting using ANSYSparametric design, Int. J. Emer. Eng. Res. Technol, 3, 87-95, 2015
[24] Guharaj, S., Haq, N., Karuppannan, K. M., Optimization of green sand casting process parameters by using Taguchi's method Int. J. Adv. Manuf. Technol., 30, 1040-1048, 2006.
[25] Hussain, H., Khandwawala, A. I., Optimal design of feeder for sand casted steel dumbbell: simulation studies for techno-economic feasibility, Am. J. Mech. Eng., 2, 93-98, 2014.
[26] Chen, W. J., Lin, C. X., Chen,Y. T., Lin, J. R., Optimization design of a gating system for sand casting aluminum A356 using a Taguchi method and multi-objective curlture based QPSO algorithm, Adv. Mech. Eng. 8, 1-14, 2016.
[27] Pastor-Lopez, I., Sanz, B., Tellaech, A., Psaila, G., de la Puerta, J. G., Bringas, P. G., Quality assessment methodology based on machine learning with small datasets: industrial casting defects, Neurocomputing, 456, 622-628, 2021.
[28] Boileau, J. M., Allison, J. E., The effect of porosity size on the fatigue properties in a cast 319 aluminum alloy. SAE Trans 110: 648–59, 2001.
[29] Couper, M. J., Neeson, A. E., Griffiths, J. R., Casting defects and the fatigue behavior of an aluminum casting alloy, Fatigue Fract Eng Mater Struct,13(3), 213–27, 1990.
[30] Buffie`re, J-.Y., Savelli, S., Jouneau, P. H., Maire, E., Fouge`res, R., Experimental study of porosity and its relation to fatigue mechanisms of model Al–Si7–Mg0.3 cast Al alloys, Mater Sci Eng A, 319, 115–26, 2001.
[31] Goods, S. H., Brown, L. M., The nucleation of cavities by plastic deformation, Acta Metall, 27 (1), 1-15, 1979.
[32] McClintock, F.J., A criterion for ductile fracture by the growth of holes, Appl Mecha, 35 (2), 363, 1968.