Industrial Operation Feasibility for Red Gypsum-Based Brick Manufacturing

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ABSTRACT---- ***The red gypsum (RG) waste is one of the major solid wastes generated in Malaysia. Currently the RG is mainly sent to secured landfill within the premise of the waste generators. In this study, the RG was investigated for its potential to be used as replacement for cement and sand in the manufacturing of cement brick using industrial brick manufacturing facility. An industrial guideline for RG brick manufacturing industry was established based on the outcome of this study. The guideline can be used by RG brick manufacturer to select the best water/cement (w/c) ratio to be used in the RG brick manufacturing for a specific market segment in order to maximize its profit and competitiveness.***

Keywords--- Red gypsum (RG); brick manufacturing; feasibility; industrial setup.

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1. INTRODUCTION

Red gypsum (RG) is mainly a by-product of titanium dioxide extraction from the ilmenite ore. It is produced from the neutralization of iron sulphate. Recently, the RG-based by-products have been used as substitute of cement [1]. Usually, in order to neutralize the acidic effluent of the process, lime or limestone is added to the weak acidic stream and thus neutralising the effluent [2]. Generally, the dumping of RG often consumes a lot of space as it often appears in the shape of big solid chunks with a reddish colour. It may also reflect a green colour as the iron oxidises inside the chunks. The red appellation attached to its name is due to the presence of ferric floc. RG is reported in previous studies to have similar chemical characteristics as white gypsum ($CaSO_4$) [3]. The RG chunks are normally subjected to further processes to produce powder-like texture in order to facilitate its proper mixing with other substances. The production of RG is estimated at around 400,000 tonnes per annum, from a typical titanium dioxide plant. The major problem associated with RG is mainly due to its disposal as it is often disposed by mere dumping in disposal sites and other landfills which are not properly managed. Reports from previous research had shown that waste RG has the potential of being valorized, thereby contributing to sustainable global environment.

Notably, the chemical compositions of RG are mainly calcium oxide (CaO) and sulphate oxide (SO_3) as reported whereas the main crystalline phase in RG is $CaSO_4 2H_2O$ [4]. RG also has high TiO_2 content of around 5 % which originates from weak acid. On the other hand, the iron oxide which is responsible for the reddish colour manifested by the RG constitutes about 8 %. Based on their research, it was concluded that the close resemblance in chemical composition makes it a suitable replacement to natural gypsum. More interestingly, recent research has confirmed that RG generally contain low level of radioactive materials, well below the permitted level stated in the environmental regulation. This makes it desirably suitable for use in different applications especially as a construction material. Manufacturing or casting of bricks can be done using lab or industrial scale. Casting of bricks in lab scale is usually done for educational and research purposes. Among others, the approach is used to analyze the mechanical and chemical performance of the bricks produced. Studies mostly focuses on how bricks performed in relation with the usage of other materials. Therefore, subsequent sections focus on the casting of conventional cement bricks. Casting of bricks or mortar in lab scale includes preparing mix, mixing, moulding and curing.

In contrast, the bricks manufacturing industry is using different approach to suit bricks production in large scale. The production of bricks using industrial approach has been established for a long time and this industry has an important link to the construction industry. The production of bricks using industrial approach is a little different as there are several considerations that need to be made. These include the costing of the bricks produced in relation to the desired performance of the bricks itself. Researches showcasing the quality of bricks or mortar using this method are rarely found due to equipment requirements.

As discussed earlier in the previous sections, industrial operation parameters setup differs from the lab scale production of bricks. Apart from the importance of cost consideration, there are quite numbers of modification that need to be implemented such as parameters and condition of experiment in suiting the operating condition of the industrial approach brick machine. The modification was needed in order to create a formulation which is compatible to the standard and can be made easily referred by the industrial players. Besides, the changes were done as some of the parameters cannot be run smoothly or the casted sample cannot be tested for mechanical performances such as compressive strength test and flexural strength test. In this section, the effects of w/c ratio and raw materials used on the quality, quantity and the production line operation were discussed.

2. EXPERIMENTAL

Materials

The red gypsum was obtained from a company located at Kemaman, Terengganu. The supplier of this waste, Huntsman Tioxide, had already dried and packed the RG in one tonne bags before it is being transported to Pekan, Pahang. However, for the experimental purpose, the RG was further sun-dried and sieved to maximum grain size around 4.75 mm to its use in the casting process.

3. RESULTS AND DISCUSSIONS

Effect of w/c ratio on the quality, quantity and production capacity

In producing bricks, w/c ratio has been known to be an important parameter in meeting the requirement set by MS standard 76: 1972 especially in meeting the compressive strength and water absorption limit. However, in manufacturing bricks industrially, apart from quality, w/c ratio also affects the quantity and production capacity (production time and number of workers needed). To elaborate further on these issues, three ranges of w/c ratio were selected and discussed based on its impact on the quality, quantity and production capacity of the plant. The quality of bricks was measured based on the thickness and surface morphology of the bricks. The three selected ranges w/c ratio were operable w/c range (0.35 to 0.55), under w/c range and over w/c range.

In production of cement bricks in the operable w/c range, w/c ratio can be set at any number which is possible to produce the bricks. In lab scale experiment, the w/c ratio can be set up to 2.42 without compromising the quality of the produced bricks as seen in Table 1. However, in industrial scale production of RG bricks, based on this study, the suitable and operable range of w/c ratio which can produce acceptable quality of bricks is between 0.35 to 0.55. This range of w/c ratio able to produce bricks which can be measured in term of mechanical performances although the quality of bricks produced for each ratio varied. At w/c ratio of 0.35, the bricks produced were thicker than the standard size bricks (standard thickness of bricks from this machine is 75 mm), in which the average thickness was 78 mm. The increased thickness was due to insufficient compaction of the moulded bricks. Water plays a role of lubricating the mixes upon which helps in movement of particles within the mixes to rearrange and become compact during pressing stage. The mixes contained mostly of fines and very fines aggregates where these types of material need more water to lubricate the movement of particles during compaction.

Table 1. Mix composition of conventional cement bricks in lab scale [5-14].

No.	C:S	Water/cement ratio	Replacement Material
1	1:3	0.44	Iron slag
2	1:3	0.45	Rice husk ash
3	1:3	0.50	Crushed limestone sand
4	1:3	0.50	Fly ash
5	1:4	0.50-0.60	Iron ore
6	1:3	0.47	Ferronickel slag
7	1:1	0.35	Oyster shell ash
8	1:5	0.94-2.42	Fly ash, bottom ash
9	1:3	0.50	Fly ash
10	1:3 – 1:5	0.50	Rice husk ash
11	1:5	0.50 – 1.20	GGBS

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At the range of 0.40 to 0.55 w/c ratio, the thickness of bricks produced were in the range of 73 mm to 75 mm, indicating enough compaction during pressing. The quality of bricks with w/c ratio of 0.40 and 0.45 were seen very good where the thickness was uniform and having relatively smooth surfaces. On the other hand, in the range of 0.50 to 0.55 w/c ratio, the bricks produced were slightly wet and created difficulty in handling since the bricks started to stick onto the pressing mould and drying pallet. Nevertheless, the thickness and surface roughness were still acceptable and within the standard range. In addition, when operating at w/c ratio above 0.50, the wetted solid mixture tends to stick onto the propeller and the wall of the mixing chamber. Problem also arise during transportation of the wetted solid mixture to the pressing mould via conveyor belt since the mixture tend to stick onto the conveyor belt. Hence, additional delay is expected as cleaning of the mixing chamber and the conveyor belt are required to avoid further problem arising from hardening of the mixture on the surfaces. At another angle indirectly, the w/c ratio also affected the quantity and capacity of the manufacturing plant. Operating the production of bricks at w/c ratio above 0.50 will reduce the quantity of bricks produced per day since significant time is required to be allocated for the cleaning of the machinery upon which the operation needs to be stop. On the other hand, even though bricks produced at w/c ratio of 0.35 are slightly thicker, it does not pose any difficulty in handling the mixture during operation.

In production of cement bricks in the under range w/c ratio of 0.30, the average thickness of bricks produced were around 90 mm to 95 mm. The increased thickness was due to insufficient compaction of the moulded bricks, similar issue as encountered in w/c ratio of 0.35 but at a greater extent. This imposed a problem in the operation since the pressing mould was designed to mould bricks with maximum thickness of 80 mm. In the normal operation, the excess thickness of the bricks will be automatically trimmed by the pressing mould as soon as the conveyor belt starts moving to transfer the bricks to the next section. This situation occurred because after pressing, the mould is lifted upwards automatically to give clearance of 80 mm for the release of the moulded bricks. When the thickness of the moulded bricks exceeds 80 mm, the excess thickness of the bricks, which is still within the vicinity of the moulding blocks, will be trimmed by the moving action of the conveyor belt. Figure 1 shows the illustration on how the thickness affected the surface of the bricks. The trimming action by the edge of the pressing mould produced uneven and rough surface of bricks. In order to avoid this, the pressing mould need to be further lifted by the worker manually before allowing the conveyor belt to start transferring the bricks to the next section. The under-range w/c ratio also affected the shaping of bricks since lack of moisture in the solid mixture reduced the lubricating, shaping and binding effect of water in the mixture.

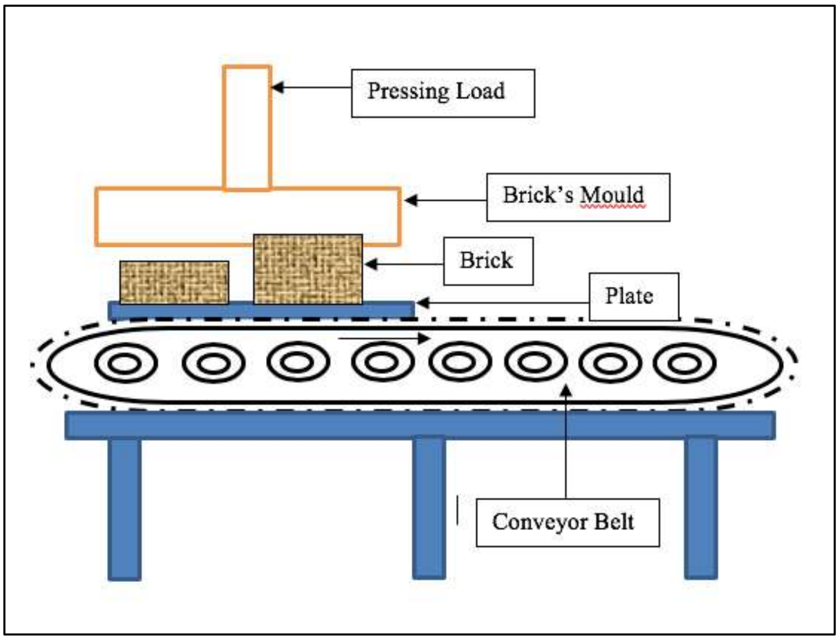

Figure 1. Illustration on how thickness affects the surfacing of bricks.

In mixing operation, the under-range w/c ratio imposed the mixing to be conducted at a slower speed to avoid dusty condition and loss of cement and RG powder. Hence, the mixing operation needs to be prolonged to give a good mixing of materials. Another challenge faced is the transferring of this under-wetted solid mix to the pressing machine via the conveyor belt. The mix tend to slide back into the mixer due to lack of binding strength to hold together the particles in the solid mix. In conducting this study, the mix of this w/c ratio required assistance from the workers to avoid the mix from sliding down during conveying the mix into the pressing machine. Another serious problem encountered during pressing of under range w/c ratio solid mix was skewing of pressing mould alignment as a result of over pressing the under lubricated mixture. When this problem occurred, the pressing operation needs to be stopped and realignment of the pressing mould is required. All the problems arise from running at under range w/c ratio contributed to the loss of operation time and hence reduce the amount of bricks produced per day. The quality of bricks produced with the under-range w/c ratio are also affected. In most cases, the compressive strength of the bricks falls below the minimum standard (i.e. below 5 Mpa).

In the production of over range of w/c ratio, when operating at w/c ratio above 0.55 (over range), physically, the condition of the solid mix became over wet. The process of mixing the solid material was made easy as lubrication by the water was overwhelmed and dusty condition was eliminated. However, during the transportation process of the solid mix from the mixer to the pressing machine, excess water sipped through the solid mix and flew down the conveyor belt back into the mixer since transferring the solid mix on the conveyor belt from the mixer to the pressing machine was at incline position. The solid mix also faced challenges during pressing of the solid mix to produce bricks. The mix was unable to be compacted by the machine since the material was too watery and unable to take shape after the mould pressing. In addition, as the mould was lifted after pressing, some of the solid mix stacked onto the inner wall of the mould blocks.

Effect of cement to sand (c:s) ratio on brick manufacturing

In brick manufacturing industry, the ratio of cement to sand (c:s) need to be clearly determined as this ratio may affect the quality, quantity and profitability of the brick manufacturing plant. The typical c:s ratio used in the laboratory scale production of cement brick is 1:3, yielding an average compressive strength of 8-10 MPa, whereas in industrial scale production, the same c:s ratio will give an average compressive strength of 30-35 MPa. The minimum requirement of compressive strength set by the authority according to MS 72:1976 is 5 MPa. Nevertheless, most cement brick manufacturing plants produce cement bricks with compressive strength in the region of 9-11 MPa. This is to reduce breakage of bricks during transportation for curing process within the manufacturing plant premise and during transportation of the finished products to the customers. In most instances, c:s ratio of 1:9 is used to produce such quality of cement bricks.

Similarly, in this study, c:s ratio of 1:9 also produced RG bricks with compressive strength of 9-11 MPa. The main differences between the cement brick and the RG brick are the surface roughness and water absorption. The surface of cement brick is relatively very rough in comparison to the RG brick. In addition, cement brick has low water absorption value as compared to RG brick. These differences are due to the presence of 25% RG in the sand portion as discussed thoroughly in the previous section.

In the preliminary study, bricks with compressive strength of 5.0MPa to 5.5MPa can be achieved with usage of 5% (c:s ratio of 1:18) to 7% (c:s ratio of 1:14) of cement volume. The usage of this low volume cement reduces the cost per unit bricks as cement is the major cost for raw material in production of bricks. However, the low performance bricks tend to create problem during production especially handling the bricks during drying, stacking and transporting to the site. After the pressing process, the newly casted bricks were transported to the drying section. Figure 2 shows the illustration of transportation of bricks for curing process.

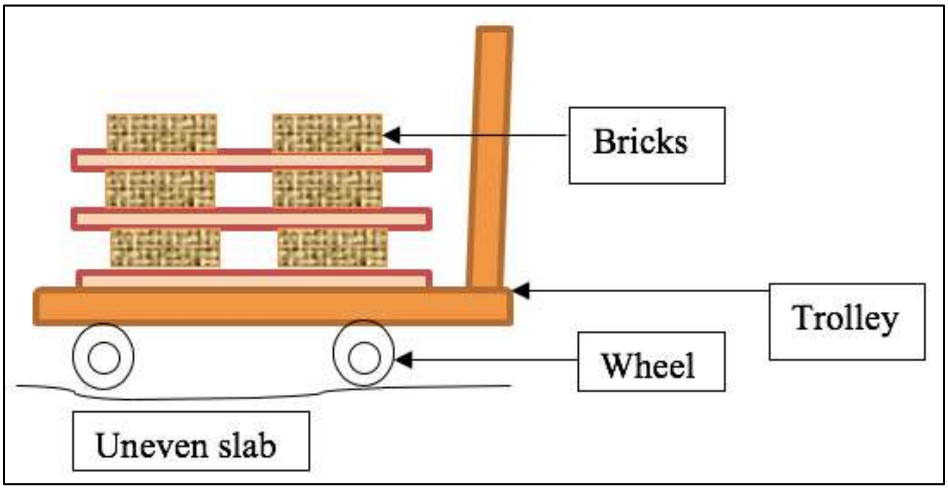

Figure 2. Illustration on transportation of bricks

After casting, the soft bricks were sent to the drying section by means of a trolley as shown in Figure 3. At low c:s ratio (above 1:11), more than 10% of total bricks tend to break due to strong vibration of the trolley, moving on uneven and rough slab surface during the transfer process. To reduce the impact of vibration, big manufacturing plants normally install roller or conveyor belt to transfer the casted bricks to the drying section. Else, the trolley needs to be pushed delicately to reduce the breakage, hence, will lengthen the production cycle time and eventually reduce the production capacity of the manufacturing plant. To reduce further breakages on the bricks produced from low c:s ratio, wooden blocks can be placed in between plates before stacking them for transporting and drying as illustrated in Figure . This will avoid load being placed onto the soft bricks to ensure the bricks able to maintain its form during transferring to the drying section and air curing process.

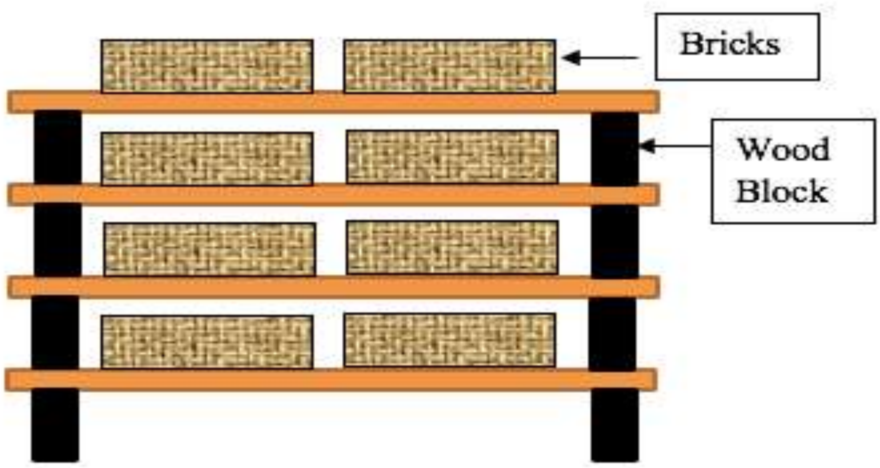

Figure 3. Illustration of transportation and drying with wood block

Drying of bricks on these plates takes up to 24 hours before the bricks were transferred and arranged on pallets. However, bricks with low c:s ratio required longer duration to dry/cure in order to ensure enough strength was obtained before arranging on the pallets. Thus, bigger space is required to cater for the longer period of initial drying. Therefore, careful consideration is required to decide whether one should opt to reduce the material costs by implementing low c:s ratio and having a bigger space for drying or using higher c:s ratio formulation with shorter drying time, bigger production capacity and better quality of bricks.

Industrial guideline for RG brick manufacturing

This section proposed some practical guideline on how to operate an industrial RG brick manufacturing effectively based on market segment of infrastructure, middle cost housing and office projects, and decorative & artwork. The guideline focusses on five aspects, namely production capacity, quality, maintenance of equipment and accessories, profit margin and marketability. Outcome from the industrial research on RG brick manufacturing carried out at Universiti Malaysia Pahang was used as the database to design the guideline. Rubric was applied in all the parameters to translate the information into quantitative measurement to allow comparison made quantitatively and more indicative. Based on the outcome of the research, the operable range of parameters which produced RG bricks that complied with the MS76:1972 and commercially viable are listed in Table 2.

Table 2. Operable range for Industrial Guidelines.

No	Parameter	Requirements
1	C:S ratio	1:9
2	RG Replacement	25%
2	w/c ratio	0.35 to 0.55

In order to give a better understanding on the guideline, it is required to elaborate the five aspects including production capacity, quality, maintenance, profit margin and marketability. Production capacity refers to the quantity of RG bricks produced daily. This parameter is very much dependent on the w/c ratio used in the operation since the w/c ratio affects directly the handling of materials, quality of products, and the operation cycle time. When all other parameters are fixed, the quality of RG bricks is dependent on the w/c ratio used in the operation. A small variation in the w/c ratio (between 0.35 to 0.55) gives a big impact on the quality of the products in terms of its compressive strength and the physical outlook of the bricks. Variation in w/c ratio (between 0.35 to 0.55) would give significant impact on the maintenance of equipment and accessories because the characteristics (degree of wetness and texture) of the solid mix influence the handling activity of the materials during the operation. Hence, this will also influence the operation cycle time, production capacity and profitability of the plant. The profit margin is calculated based on the unit cost and selling cost of the RG bricks. The unit cost of the bricks does not vary significantly since the same amount of cement is used even though the w/c ratio is varied. Cement is known to be the major cost in brick manufacturing; therefore, the unit cost does not differ greatly. However, the selling price of the product is much dependent on the performance and function of the bricks. Marketability of the bricks is dependent on the function and performance of the bricks. Variation of function of the bricks is classified into three different job class which are infrastructure work, middle class housing and office work and decorative and artwork.

Production capacity

Table 3 shows the comparison of production capacity in terms of number of bricks produced per batch, number of bricks produced per day, and cycle time per batch for w/c ratio of 0.35 up to 0.55, respectively.

Table 3. Production capacity with handling time

No.	Details	0.35	0.40	0.45	0.50	0.55
1	Unit (per batch)	128	128	130	130	130
2	Handling Time per batch (minutes)	7	7	7	8	9
3	Units (per day)	8777	8777	8914	7800	6933
	Scale	4	4	5	3	2

The data tabulated in Table 3 were gathered from the results discussed earlier in the previous sections. Scale between 1 (least favourable) and 5 (most favourable) assigned to each w/c ratio to indicate the performance of each w/c ratio in terms of the production capacity. It is also highlighted here that similar approach was used in evaluating other aspects of concerned discussed later in this section.

Cycling time per batch was calculated based on the time taken to complete processing one batch of production, inclusive all the activities, namely mixing, conveying solid mix to the pressing mould, pressing, racking and cleaning. For a smooth operation, without any arising problem, it took 7 minutes to complete one batch of production, as recorded in w/c ratio of 0.35, 0.40 and 0.45, respectively. At w/c ratio above 0.45 (0.50 and 0.55), longer time was needed since extra activities were required to be conducted such as cleaning the mixer, the pressing mould and the pressing plate, to remove leftover of wet solid mix sticking onto the surfaces.

Maintenance of equipment and accessories

Analogous to cycling time per batch, as discussed earlier in the above, maintenance of equipment and accessories becomes more rigorous when the degree of wetness of the solid mix is high (i.e. at w/c above 0.45). Table 4 shows the comparison of maintenance issues and difficulties faced in handling different sets of w/c ratio. On the other hand, when the solid mix contains less water (such as at w/c ratio of 0.35), the hydraulic presser needs to work harder in order to maximize the compaction of the mixes to obtain the required thickness. This presser needs to undergo regular assessment in order to avoid failure on the hydraulic system. Besides, pressing the dry mix at high pressure, exceeding the threshold limit, will skew the alignment of the pressing mould, disallowing the pressing operation to continue. Scale of 1 to 5 was assigned to the w/c ratio indicating the degree of favourable for the production based on its maintenance issue.

Table 4. w/c ratio on maintenance of brick manufacturing machine

No.	w/c ratio	Maintenance	Equipment and Accessories	Scale
1	0.35	High	Pressing units Mould alignment	2
2	0.40	Average	Pressing unit	3
3	0.45	Good	Less maintenance of pressing unit	4
4	0.50	Average	Wooden Plate Mixer	3
5	0.55	High	Corrosion of steel equipment includes mixer, pressing units and mould Wooden plate	1

Quality

Table 3 shows the comparison of brick quality based on its compressive strength and surface smoothness at w/c ratio ranging from 0.35 to 0.55. As indicated by the scale assigned at each w/c ratio, the quality of the bricks produced is proportional to the w/c ratio, within this operable range.

Table 5. Compressive Strength and surface of bricks

No.	Details	0.35	0.40	0.45	0.50	0.55
1	Compressive Strength (MPa)	6.81	7.57	8.23	11.64	12.14
2	Surface of bricks	Very Rough	Rough	Average	Smooth	Very Smooth
	Scale	1	2	3	4	5

From Table 5, the compressive strength and the smoothness of the bricks increased with the increased of w/c ratio. The increased of both parameters has seen to increase the quality of the bricks based on the scaling given.

Profit Margin of one-unit brick

In order to calculate the profit margin, the unit cost of a brick needs to be determined. Calculation was made based on a 400 kg mix per batch. Table 6 shows the calculated total cost per batch.

Table 6. Total cost per batch

No	Material	Weight (kg)	Cost (RM)
1	Cement	40	16
2	Sand	270	2.70
3	RG	90	0
	Total	400	18.70

The profit margin is calculated based on the unit cost and selling cost of the RG bricks. The unit cost of the bricks does not vary significantly since the same amount of cement is used even though the w/c ratio is varied. As mentioned earlier, cement is known to be the major cost in brick manufacturing, hence the unit cost does not differ greatly. However, the selling price of the product is much dependent on the performance and function of the bricks. Table 7 shows the unit cost, selling price, profit margin per unit brick and monthly profit margin.

Table 7. Unit cost, selling pice, profit margin per unit brick and monthly profit margin

No.	w/c ratio	Unit Cost (RM)	Selling Price (RM)	Profit Margin per unit (RM)	Daily Profit Margin (RM)	Rubric
1	0.35	0.15	0.20	0.05	438	1
2	0.40	0.15	0.22	0.07	614	2
3	0.45	0.14	0.22	0.08	713	3
4	0.50	0.14	0.25	0.11	858	4
5	0.55	0.15	0.30	0.15	1039	5

The unit cost was calculated based on the production capacity and the total cost per batch. The selling price of the bricks was set based on the function of the bricks, besides the quality and the performance. The selling price of the lowest quality bricks was set at RM0.20 (like the conventional cement bricks) as the brick is of lower compressive strength and rough surfaces. The selling price was gradually increased as the quality and performance of the brick improved accordingly. The low-quality bricks are usually been used as a non-critical loading material such as for infrastructural works (drainage system, fencing etc). Average compressive strength bricks can be used for internal wall with plastering as the surface is not very smooth while a higher performance with smooth surface can be used as decorative bricks with no plastering applied on the surface of the bricks.

Marketability

In this study, the bricks have been classified as a low performance bricks, average performance bricks and decorative bricks. The classification of the bricks is based on the performance especially the compressive strength and the surface roughness of the bricks. However, different selling price contributes to different group of users and different size of manufacturing competitors. For low performance bricks, the bricks are commonly used for infrastructure works such as drainage and landscaping work where high strength is not compulsory. This type of bricks is cheaper compared to other type of bricks. However, the demand for this type of brick is very high, as infrastructural work is a very common job in construction. Besides, this low performance bricks are also used in low cost housing project for interior walls. For average performance bricks, this bricks usually been used for medium cost housing projects for interior wall and office partition. The demand for these bricks is good but relatively low compared to the low performance bricks. The high performance or decorative bricks is known to have very good compressive strength and surfacing where the bricks are usually used without plastering. This type of bricks is usually used in an exclusive way where the demand is very low. However, there are few manufacturing plants producing this type of bricks based on its demand. Table 8 shows the marketability study based on w/c ratio.

Table 8. Marketability study based on w/c ratio

No.	w/c ratio	Marketability	Rubric
1	0.35	High demands	5
2	0.40	High demands	4
3	0.45	Medium demands	3
4	0.50	Medium demands	3
5	0.55	Low demands	1

Summary of w/c ratios performances

Table 9 summarises the performances of all the w/c ratios based on the five aspects considered in the guidelines. From the summary of the w/c ratios performances, a specific brick plant can be developed to serve for a specific market segment. The following section discussed on three market segments, as comparison, to show how the information above is to be applied.

Table 9. Summary of the rubric

No	Parameter/w/c ratio	0.35	0.40	0.45	0.50	0.55
1	Production capacity	4	4	5	3	2
2	Quality	1	2	3	4	5
3	Maintenance	2	3	4	3	1
4	Profit Margin	1	2	3	4	5
5	Marketability	5	4	3	3	1

Infrastructure works

For infrastructure work, the volume of usage and demand of the product is high especially for drainage work. However, the quality of the bricks is not the main concern, if it meets the compressive strength requirement set by MS 76:1972. In order to select the most suitable w/c ratio to maximize its profitability, RG brick manufacturer focusing on supplying RG bricks for infrastructure work market segment may use Table 9, but concentrating only on the two related aspects of concern, namely the production capacity and marketability. Table 10 shows the performance of w/c ratios based on the two related aspects with a total scores of scales of each w/c ratio at the bottom of the table. From Table 10, w/c ratio of 0.35 recorded the highest scores compared to the rest of the ratios. This suggests that w/c ratio of 0.35 should be used by the manufacturer in order to maximize its profitability and able to compete strongly in the infrastructure market segment.

Table 10. Calculation for manufacturer focusing on infrastructure work

No.	Parameter/w/c ratio	0.35	0.40	0.45	0.50	0.55
1	Production capacity	4	4	5	3	2
2	Marketability	5	4	3	3	1
	Total score	9	8	8	6	3

Middle cost housing and office project

For middle cost housing and office project segment, the usage and demand for bricks is considered moderate. To be competitive in selling RG bricks for this market segment, the manufacturer should consider the four aspects of concern, namely the production capacity, quality, profit margin, and maintenance, in order to select the most suitable w/c ratio for the manufacturing of the RG bricks. Table 11 shows the performance of w/c ratios based on the related aspects. From Table 11, it can be seen that w/c ratio of 0.45 recorded the highest scores, in which the result recommended the manufacturer to use w/c ratio of 0.45 in its manufacturing the RG bricks in order to perform well in the market segment.

Table 11. Calculation on medium and high cost of housing project type bricks

No	Parameter/w/c ratio	0.35	0.40	0.45	0.50	0.55
1	Production capacity	4	4	5	3	2
2	Quality	1	2	3	4	5
3	Profit Margin	1	2	3	4	5
4	Maintenance	2	3	4	3	1
	Marketability	5	4	3	3	1
	Total Score	13	15	18	17	14

Decorative and artwork bricks

For decorative art bricks, quality and appearance of the bricks are of utmost important. However, the demand for this specialized brick is rather small. Thus, the only important aspects to be considered in choosing the suitable w/c ratio are quality and profit margin. Table 12 shows the performance of w/c ratio based on decorative art bricks. From Table 12, the most suitable w/c ratio to be used by the manufacturer is 0.55. Operating at this condition will allow the company to fulfil the needs of the market segment and enable the products to compete strongly with other products in the market.

Table 12. Calculation on decorative art bricks

No	Parameter/w/c ratio	0.35	0.40	0.45	0.50	0.55
1	Quality	1	2	3	4	5
2	Profit Margin	1	2	3	4	5
	Total Score	2	4	6	8	10

4. CONCLUSION

The third part of the study was focusing on the operation of manufacturing the RG bricks. In this section, the important parameters from this study were evaluated in order to know the correlations between these parameter and industrial operations setups. Based on the discussion, it was found out that w/c ratio had given a huge impact on the operations setup. Based on this correlation and additional of important parameters from industrial manufacturing, a guidelines of RG bricks manufacturing were developed. From this guideline, there are at least three market segments were identified referring to all the parameters.

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