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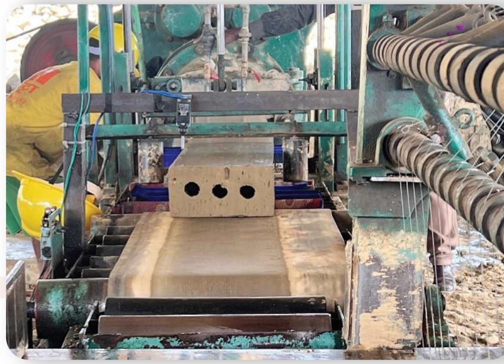
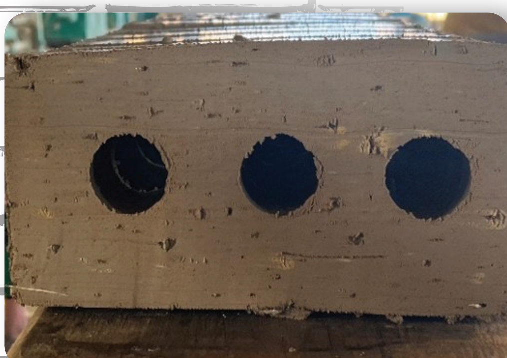


Manual for

HOLLOW FIRED BRICK PRODUCTION



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Manual for

HOLLOW FIRED BRICK PRODUCTION

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Disclaimer

This publication is funded by the European Union under the SWITCH-Asia Grants Programme. Its contents are the sole responsibility of the BEEN project and do not necessarily reflect the views of the European Union.

The methods described in this manual for resource-efficient hollow fired bricks production are based on the practical experiences of the authors, findings of applied research, and consultations with experts and hollow fired brick producers. While every effort has been made to ensure the accuracy and reliability of the information presented, the quality of hollow bricks depends on various factors such as the quality of clay, type of machines used for green brick production and production practices. Thus, the authors, publishers, funders or any legal entity or person associated with the design of this manual disclaim any responsibility for any losses or damage resulting from the suggested procedures, from any undetected errors, or from the readers' misunderstanding of the text. Moreover, this manual is not intended to replace or override any legal or regulatory requirements nor endorse any specific product or organization.

Preface

Fired bricks, primarily handmade solid bricks, are one of the most common building materials in Nepal. Approximately five billion bricks are produced annually in Nepal. Unlike solid bricks, hollow fired bricks have holes within them. Depending on the type and number of holes, they are also referred to as perforated bricks. The holes reduce the amount of clay needed for their production and decrease fuel consumption during firing, making them more resource-efficient and environmentally friendly than solid bricks. Additionally, the holes provide resistance to heat transfer, enhancing the thermal performance of the buildings constructed with hollow bricks.

This *Manual for Hollow Fired Brick Production* is designed to serve as an essential resource for brick entrepreneurs, supervisors and individuals involved in, or interested in, starting the production of hollow or perforated bricks in Nepal. It offers practical guidance on manufacturing hollow fired bricks, covering topics such as the selection and preparation of raw materials for brick manufacturing, mechanical equipment for brick production, steps on the mechanical green brick production process for hollow bricks, guidelines on the firing process, quality control measures, and troubleshooting.

This manual aims to lay a groundwork for the transformation of the Nepalese brick sector towards resource-efficient and environmentally friendly brick production practices. The authors welcome ideas and suggestions for improving the quality of this manual in future editions.

The manual has been prepared by the BUILDING Energy Efficiency in Nepal (BEEN) project, funded by the European Union (EU) under the SWITCH-Asia Grants Programme. The BEEN project is being implemented by a consortium of organizations led by the University of Innsbruck, Austria, in partnership with MinErgy Pvt Ltd, Nepal, Greentech Knowledge Solutions Pvt Ltd, India, and Asociación Española de Normalización (UNE), Spain. The project aims to promote sustainable building practices and improve energy efficiency in buildings in Nepal through retrofitting of existing buildings, construction of new energy-efficient buildings, and capacity building of building professionals and stakeholders in the country.

Government of Nepal
Ministry of Federal Affairs & General Administration
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Your Ref No.:

Our Ref. No.:

Message

Within the scope of its green economy programme, Nepal's Sixteenth Plan endorses a policy that prioritizes investments in energy efficiency and climate adaptation for buildings, including residential buildings. Furthermore, underscoring the importance of energy efficiency, Annual Budget 2081/82 explicitly calls for giving priority to climate responsiveness and adaptation in all physical infrastructure constructions. Therefore, the federal, provincial and local level governments will prioritize climate adaptation and energy efficiency in their building constructions. These policies will contribute to Nepal achieving the Nationally Determined Contributions (NDC) targets of net-zero greenhouse gas (GHG) emissions by 2045.

A highly energy-intensive process, brick production is a major contributor to CO_2 emissions. The widespread preference for solid bricks as a walling material among consumers poses a big challenge to meeting the net-zero GHG emission targets. As Nepal progresses towards its goal of net-zero GHG emissions, the production and adoption of resource-efficient building materials have become more crucial than ever.

Transitioning from the traditional solid fired bricks to hollow bricks aligns with the NDC strategy of "adoption of low-emission technologies in the brick and cement industries to reduce coal consumption and air pollution by 2030". A shift to the use of hollow bricks will not only contribute to CO_2 reduction but also lower energy demand, apart from enhancing thermal comfort in buildings. Additionally, embracing energy-efficient and sustainable building materials will improve air quality, create a greener and more resilient Nepal, as well as help mitigate and adapt to climate change impacts, ensuring a better future for generations to come.

The *Manual for Hollow Fired Brick Production*, developed by the BUILDING Energy Efficiency in Nepal (BEEN) project, which is funded by the European Union under the SWITCH-Asia Grants Programme, marks a significant step towards promoting resource-efficient building materials. This manual, it is hoped, will serve as an invaluable resource for brick entrepreneurs, producers and production workers, guiding them in the production of resource-efficient hollow bricks that are competitive in both strength and quality. This will ultimately help reduce the carbon footprint of building materials in Nepal.

I commend the BEEN project for this initiative to publish such an evidence-based knowledge product and encourage all stakeholders, particularly private brick producers, to adopt and promote these practices.

....

Kali Prasad Parajuli
Joint Secretary
20 September, 2024

EUROPEAN UNION

DELEGATION TO NEPAL

Head of Cooperation

The building sector is one of the key sectors with significant energy consumption and emissions in the world. In the European Union, buildings are the primary energy consumer, contributing to 40% of total energy consumption and 36% of Greenhouse Gas (GHG) emissions. This data sets the urgency for providing sustainable and energy-efficient solutions in the building sector in order to reduce environmental problems and mitigate climate change impact.

Given the critical role of the building sector in minimising resource and energy consumption, thereby reducing the carbon footprints, the European Union (EU) has devised various policies to achieve its energy and climate goals. These policies aim to minimise energy consumption, improve thermal comfort of existing buildings, and promote smart solutions and the use of resource-efficient materials in the construction of new buildings. In particular, the EU's legislative framework, which includes the revised Energy Performance of Buildings Directive and the revised Energy Efficiency Directive, sets ambitious targets for new and renovated buildings. These targets aim to reduce GHG emissions by at least 60% in the building sector by 2030 and achieve a decarbonised, zero-emission building stock by 2050. These directives for energy-efficient buildings promote the use of renewable energy sources and encourage the renovation of existing buildings to make them more sustainable. By implementing these measures, the EU is taking significant steps towards a more climate-friendly and energy-efficient future.

The experiences from the European Union have demonstrated that adoption of energy efficiency policies can play a crucial role in reducing energy consumption and subsequent emissions from the building sector. It is noteworthy that those lessons learnt and experiences are making a meaningful contribution in Nepal through the BUILDING Energy Efficiency in Nepal (BEEN) project, funded by the European Union under the SWITCH-Asia Grants Programme.

The *Manual for Hollow Fired Brick Production,* prepared by the BEEN project, is indeed expected to enlarge the production base of hollow or perforated bricks. This knowledge product will provide valuable information and guidance on the production process, including capacity building, quality standards, energy efficiency measures and technology transfer. As a result, more manufacturers will be encouraged to adopt this technology and expand their production capabilities.

The Manual will be very helpful for stakeholders such as brick producers, construction companies and other players in the building construction sector. The benefits can be maximised if challenges are also addressed through effective policy measures while adopting energy efficiency measures in both renovated and new construction of buildings.

Overall, the lessons learnt and the best practices of the BEEN project will have a lasting impact, hence shall be promoted and contribute to creating evidence-based policies. Also, by promoting the practices set in motion by BEEN we hope to roll out the benefits of the energy-efficient measures in homes and buildings throughout the country, ultimately contributing to Nepal's Nationally Determined Contributions targets and the Sustainable Development Goals agenda.

Finally, I would like to express my sincere gratitude to all project stakeholders, particularly the Government of Nepal, the private sector participating in the project and especially the team of professionals of the BEEN project, for their invaluable contributions to this knowledge product.

....

Jose Luis VINUESA-SANTAMARIA
Head of Cooperation
Delegation of the European Union to Nepal
Kathmandu, 25 September 2024

नेपाल ईट्टा उद्योग महासंघ
Federation of Nepal Brick Industries (FNBI)

पत्र संख्या :
चलानी नं. : 82/081/082

Date : September 20, 2024

Message

The Federation of Nepal Brick Industries (FNBI), established in 2007, is dedicated to the advancement of brick industries in Nepal and actively embraces technological innovations to enhance the sector. The FNBI is mindful of its members' capabilities and strives to ensure that new technologies are compatible with local soil conditions and the limitations of entrepreneurs. It supports and promotes initiatives that drive progress and excellence.

Since its inception in 2014, Technology Research and Development Committee (TRDC)—the research and development unit of the FNBI—has played a crucial role in connecting technology partners and donors directly with the FNBI. The TRDC has demonstrated that involving leading entrepreneurs as trainers is the most effective method for technology transfer and implementation.

This comprehensive manual represents a significant milestone in our collective endeavours to enhance sustainable practices and improve the quality of hollow bricks. It will undoubtedly serve as an invaluable resource for brick manufacturers, providing them with necessary guidelines and best practices to produce high-quality hollow bricks.

This initiative not only contributes to the advancement of the brick industry but also aligns with our shared commitment to sustainability and clean environment. We are confident that it will have a lasting positive impact on our industry. Therefore, we urge all brick kilns throughout Nepal to adopt this manual wherever possible in the promotion and adoption of hollow brick production. We also urge the Government of Nepal and other development agencies to facilitate access to preferential (soft) loans for brick entrepreneurs to purchase machinery for the production of hollow fired bricks. This support will accelerate the adoption of hollow fired bricks within the industry, contributing to more sustainable brick production practices.

The FNBI acknowledges the hard work of the technical team and all contributors of this manual as well as the collaboration involved in bringing this project to fruition. The meticulous research, dedication and expertise demonstrated by the team throughout this project are truly commendable. On behalf of the FNBI, I would like to express our appreciation to the BUILDING Energy Efficiency in Nepal (BEEN) project team for their outstanding efforts in developing this manual. Thank you for your dedication and exemplary contribution.

Lastly, we look forward to continued collaboration and future successes together.

SBChand
....
Shankar Bahadur Chand
President
Federation of Nepal Brick Industries (FNBI)

Message

Nepal, with its four bioclimatic zones, experiences extreme variations in temperature and weather. Due to this, there is urgency for efficient thermal insulation and energy efficiency in buildings. The development and adoption of innovative construction materials can effectively tackle these challenges.

Hollow bricks offer a promising solution for enhancing energy efficiency in buildings, as they provide thermal insulation, structural integrity and sustainability. They also reduce the overall weight of the building. By incorporating hollow bricks into construction practices, we can make significant contributions to lowering energy consumption and reducing greenhouse gas emissions, thereby helping Nepal move towards a more sustainable future.

The BUILDING Energy Efficiency in Nepal (BEEN) project, funded by the European Union under the SWITCH-Asia Grants Programme, has developed this manual, offering detailed guidelines and practical insights into the production of hollow bricks. The manual covers aspects ranging from material selection, clay preparation, required equipment, die assembly, brickmaking, drying and firing techniques, and best practices. It aims to equip architects, builders and homeowners with the knowledge needed to incorporate these resource-efficient solutions effectively.

This manual aligns with the broader objectives of the EU Green Deal, which aims to promote sustainability, reduce carbon emissions and encourage innovation in building practices. By adopting the recommendations outlined in this manual, Nepal can move closer to a future in which energy-efficient and environmentally friendly buildings become the standard.

The development of this manual has been a collaborative effort involving experts, stakeholders and the BEEN project team. I express my sincere thanks to all who contributed to the development of this invaluable resource. Their insights and expertise were instrumental in shaping a guide that is practical.

I encourage all stakeholders in the construction and building sectors to implement the guidelines and techniques detailed in this manual. The journey towards sustainable development is a shared responsibility, and, with the right tools and knowledge, we can achieve remarkable outcomes, benefiting both people and the planet.

Warm regards

DI Dr. techn. Daniel Neyer

Project Leader (BEEN)

Acknowledgement

We express our sincere gratitude to all those who contributed to the development of the *Manual for Hollow Fired Brick Production*.

Firstly, we extend our deepest appreciation to the European Union for providing funding support under the SWITCH-Asia Grants Programme to implement the BUILDING Energy Efficiency in Nepal (BEEN) project. We would like to express our gratitude to Dr Ranjan Prakash Shrestha, Senior Programme Manager, Delegation of the European Union to Nepal, for continuously guiding and supporting us.

We extend our heartfelt gratitude to Dr Sameer Maithel, Former Director, Greentech Knowledge Solutions Pvt Ltd, India, for his invaluable contributions, insights and inputs throughout the process. Dr Maithel's expertise and dedication have significantly enriched both content and quality of this manual.

The Federation of Nepal Brick Industries (FNBI) played an invaluable role in the development of this manual. The input from all participants of the validation workshop, organized by the FNBI in collaboration with the BEEN project, has been immensely valuable in finalizing this manual. We particularly acknowledge the team of resource persons who participated in the validation workshop. Last but not least, we extend our gratitude to Mr Shyam Maharjan and Mr Mangal Krishna Maharjan, both brick entrepreneurs, for their invaluable feedback and technical insights, which were instrumental in ensuring the comprehensiveness and accuracy of the manual.

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Abbreviations and Acronyms

Al	Aluminium
Al_2O_3	Alumina
API	Atterberg Plasticity Index
BEEN	BUILDING Energy Efficiency in Nepal
C	Carbon
Ca	Calcium
CaO	Calcium oxide
CCTV	Closed Circuit Television
CO_2	Carbon dioxide
EU	European Union
Fe	Iron
Fe_2O_3	Iron oxide
FNBI	Federation of Nepal Brick Industries
GHG	Greenhouse Gas
K	Potassium
K_2O	Potassium oxide
Mg	Magnesium
MgO	Magnesium oxide
MnO_2	Manganese
MSMEs	Micro, Small and Medium Enterprises
Na	Sodium
Na_2O	Sodium Oxide
O_2	Oxygen
OHS	Occupational Health and Safety
PPE	Personal Protective Equipment
Si	Silicon
SiO_2	Silicon dioxide
VSBK	Vertical Shaft Brick Kiln

1

INTRODUCTION

1.1 Background

In Nepal, there are 1,349 brick kilns, which together produce 5.14 billion bricks annually. The annual coal consumption is estimated to be 504,750 tons (ICIMOD, 2019). The CO_2 emission from the brick sector is estimated to be about 1.3 million tons per annum.

Although solid fired bricks consume huge quantities of clay, water and coal during their production, making them resource inefficient, they are the most common construction material in Nepal. Consumers have very few alternatives to solid bricks for wall construction.

Hollow fired bricks, also known as perforated bricks, are resource efficient and environmentally friendly compared to solid bricks. These bricks have tubular hollow cavities. Since hollow bricks require less clay, they require less water during the production of green bricks and consume less fuel during firing, making them a resource-efficient building material. Reduced fuel consumption also leads to lower emissions, further enhancing the environmental benefits of hollow brick production. A study shows that 15 percent hollowness in bricks can save 10 to 20 percent of clay and 22 to 30 percent of fuel (TERI, 2017).

Moreover, the tubular hollow cavities of hollow fired bricks improve their insulation properties, which ultimately reduces the operational costs of buildings. Hollow brick walls have up to 25 percent lower U-value compared to solid brick walls. It is estimated that up to 5 percent of air-conditioning energy could be saved if rooms are made of hollow instead of solid brick walls (Heierli & Maithel, 2008). Therefore, hollow bricks present a win–win solution for both producers and users, fostering sustainable production and consumption practices.

While hollow bricks are extensively used in European countries as well as in some Asian countries, like China and Vietnam, their production and use in building construction in Nepal are negligible. One of the primary hindrances to hollow brick production is the need for an extruder machine, as hollow bricks cannot be manufactured manually. Very few brick enterprises in Nepal possess extruder machines. Furthermore, limited demand for such products due to inadequate consumer awareness poses a challenge. To effectively promote the use of hollow bricks, it is essential to implement a comprehensive market awareness programme and provide capacity-building opportunities for both brick producers and masons.

1.2 Objectives

This manual has been developed to provide detailed information and instructions on hollow brick production. The specific objectives of this manual are:

- To offer detailed instructions and guidelines on the production of hollow fired bricks;
- To enhance the skills and capacity of brick MSMEs (micro, small and medium enterprises) in the production of hollow bricks, thereby supporting sustainable construction practices;
- To encourage sustainable building practices by emphasizing the production of hollow fired bricks;
- To improve energy efficiency in buildings by promoting the use of hollow fired bricks, thereby reducing energy consumption for heating and cooling; and
- To enable local stakeholders to effectively adopt the production of resource-efficient building materials by facilitating the transfer of knowledge of hollow fired brick production.

1.3 Target Audience

The manual is intended for individuals involved in the brick industry, including brick kiln managers, supervisors, operators and technicians. It can be useful for, among others:

- ***Hollow brick producers and new operators:*** As a training tool for learning the process of hollow brick production.
- ***Experienced machine operators:*** As a reference guide for refreshing knowledge or troubleshooting problems.
- ***Factory managers:*** As a resource for ensuring that the production process is being carried out correctly and efficiently.
- ***Technicians:*** As a resource for maintaining and repairing the equipment used in the production process.
- ***Entrepreneurs:*** As a guide for starting hollow brick production.

2

HOLLOW/PERFORATED BRICKS

2.1 Introduction

Hollow or perforated clay bricks contain hollow cavities within their structure. Hollow bricks have large holes within their body, while perforated bricks contain small holes or perforations. These holes can be circular, square, or any other shapes, and typically are evenly spaced across the surface of the brick.

The hollow cavities reduce the weight of the bricks, making them easier to handle and transport, and reduce their costs by shortening the drying and firing time, while providing thermal insulation to the structure when used in external walls. (Watt, 1990) These cavities can be filled with concrete or insulation materials, further enhancing the strength and insulation properties of the brick.

They offer several advantages, including providing maximum resistance to vertical pressure or crushing forces and forming a vertical bond, which make the construction more solid. Hollow bricks are a popular choice in modern construction due to their strength, durability and thermal insulation properties.

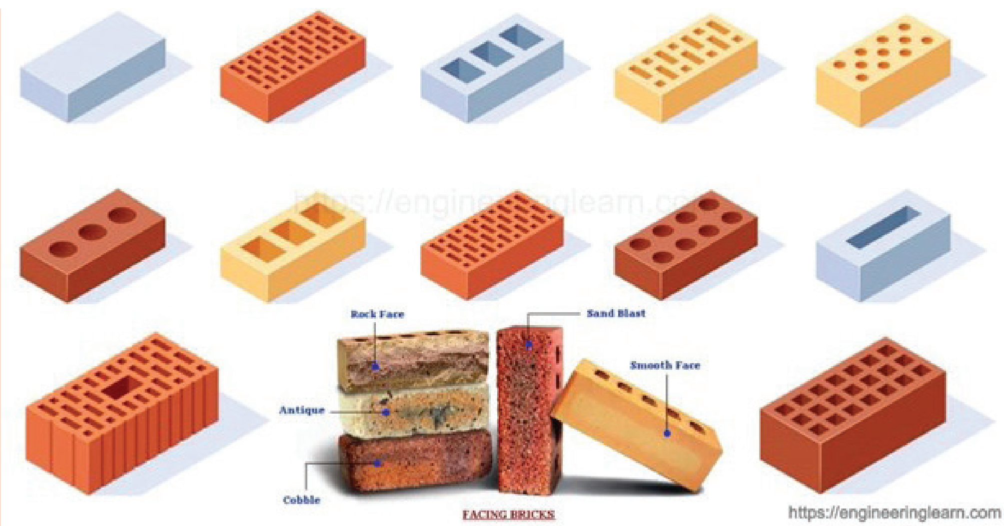
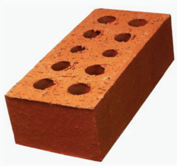


Figure 1: Types of hollow and perforated bricks

Table 1: Categories of bricks based on the area of perforation

S. No.	Category	Condition
1	Solid bricks 	√ Do not have any holes.
2	Perforated bricks 	√ Consist of a pattern of small holes through them, removing at least 15% of the brick's volume. √ Small holes refer to those with an area less than 500mm². √ The holes may be circular, square, rectangular or any other regular shape.
3	Hollow bricks 	√ Consist of a pattern of large holes, removing at least 15% of the brick's volume. √ Contain a pattern of large holes, removing at least 15% of the brick's volume.

2.2 History of Hollow Bricks

Since time immemorial, solid fired bricks have been widely used for construction before hollow bricks were introduced. Ancient Romans used hollow clayware in their structures. Many ancient church buildings incorporated hollow earthenware vases. The development of hollow clay bricks began in Europe in the early eighteenth century.

Figure 2: A Roman hollow tile excavated at Bath

Robert Beart of Godmanchester pioneered the production of hollow bricks with multiple vertical perforations. He achieved this by forcing earth through a mould with a series of cores, forming holes in bricks. This method produced lighter bricks that burned more efficiently. He made bricks with the help of a small extrusion machine, which produced bricks in various shapes and sizes, making it easy to integrate them into standard building schemes.

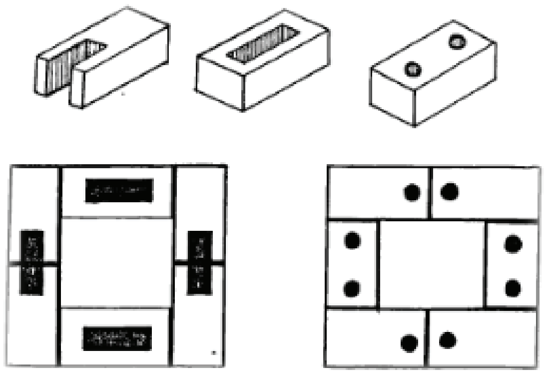


Figure 3: Benford Deacon's ventilating hollow bricks

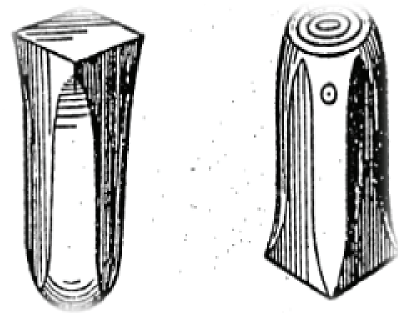


Figure 4: Hollow clay pots used for vaulting

2.3 Deep Frogged Bricks

In brickmaking, the term "frogged" refers to depressions or indentations on one or more faces of a brick. Indentations reduce the weight of the brick, making it easier to handle them during construction, and improve the mortar adhesion. Deep frogged clay bricks have deeper indentations than standard frogged clay bricks, which reduces the amount of clay needed during the green brickmaking process and lowers coal consumption during firing.

Figure 5: Deep frogged bricks

2.4 Benefits of Hollow/Perforated Bricks

i. ***Eco-friendly:*** Hollow bricks are considered an eco-friendly building material as they require less natural clay and energy compared to traditional solid bricks, resulting in a relatively small environmental footprint.

ii. ***Energy conservation:*** Due to their reduced mass, the energy required to fire raw hollow bricks is lower than that for solid bricks. Additionally, their thermal insulation properties can substantially reduce energy costs over the lifespan of buildings.

iii. ***Cost-effectiveness:*** Hollow bricks are much lighter than solid bricks, resulting in relatively low overall structural costs.

iv. ***Thermal and sound insulation:*** The voids in hollow bricks provide superior thermal and sound insulation compared to solid bricks. They help keep the building interiors cool in summers and warm in winters.

v. ***Aesthetic appeal:*** Exposed hollow bricks have an aesthetically pleasing appearance, making them a popular choice for architects for use on exposed surfaces. This also reduces the plastering and painting costs.

vi. ***Better usage and strength:*** The compressive strength of hollow bricks is comparable to that of solid bricks, ensuring their durability.

vii. ***Seismic performance of structure:*** The seismic force acting on a structure is directly proportional to its mass. Therefore, the use of hollow bricks, which have a reduced mass compared to solid bricks, results in a smaller lateral force during earthquakes. Additionally, the lighter weight of the structure reduces the load on foundations, enhancing earthquake resistance.

3

HOLLOW BRICKMAKING PROCESS

The hollow brickmaking process involves several steps, starting from the extraction of raw material to the final firing of bricks. The general process is presented below:

1. ***Raw material selection:*** The first step in brickmaking is selecting the right type of soil and other raw materials. To produce good-quality bricks, the soil must possess properties such as grain size, plasticity and cohesiveness.

2. ***Excavation and transportation:*** Once suitable soil deposits have been identified, the soil is mined or excavated and transported to the brick kiln site.

3. ***Soil preparation:*** The soil is then mixed with other types of soil or additives, like sand, clay, sawdust, rice husk and ash, to enhance its quality, if necessary, and then mixed with water to form homogeneous and workable clay paste.

4. ***Extrusion:*** The prepared clay is shaped into bricks in large quantities quickly and uniformly, using a machine. Hollow or perforated bricks cannot be produced manually.

5. ***Drying:*** Once the bricks are shaped, they are left to dry in open air or in drying chambers. This step removes excess moisture from the bricks, preventing them from cracking during the firing process.

6. ***Firing:*** The dried bricks are fired in the brick kiln to harden and strengthen them. Hollow bricks can be fired in any type of kiln.

7. ***Cooling:*** After firing, the bricks are allowed to cool down slowly to avoid any sudden temperature changes, which can cause cracks.

8. ***Unloading:*** Once cooled, the bricks are unloaded from the kiln and transported to the market or storage facility.

The entire process is illustrated in Figure 6.

Figure 6: Brickmaking process flow chart

4

EQUIPMENT FOR EXTRUSION

Extruded bricks are produced using machines, which ensures a more consistent and controlled manufacturing process. This results in the production of bricks of uniform shape, size and density as well as enhanced strength and durability.

The major benefits of machine-made bricks are:

Compression and high pressure: During the extrusion process, the clay is subjected to high pressure, which compresses and solidifies it. This compression contributes to the structural integrity and strength of bricks.

Even drying: Machine-made bricks are dried evenly and at controlled temperatures, reducing the risk of cracks and defects that can weaken the final product.

Precision cutting: Extruded bricks are cut with precision, ensuring smooth surfaces and straight edges, which improves their strength and overall aesthetics.

Consistent firing: Machine-made bricks undergo consistent firing temperature and duration, enhancing uniformity and increasing their strength.

Minimal variability: Compared to handmade bricks, machine-made bricks have less variation in their physical properties, leading to more reliable performance.

Enhanced design features: Extruded bricks often have specific design features such as perforations or hollow cores, which can increase their strength-to-weight ratio without compromising their durability.

4.1 Layout of Machinery Line-up for Green Brick Production

Designing an efficient layout for a green brickmaking plant involves organizing machinery and workstation in a logical flow to ensure smooth operations, minimal material handling and optimal productivity.

The layout of green brickmaking machinery plant flow is shown in Table 2.

Table 2: Layout of machinery line-up for green brick production

Machinery Line-up	Location	Function
Raw material storage	At the start of the plant	Storage area for raw materials such as clay, shale, sand and additives
Stone screening	Right before box feeder	Screens the big size boulders or rocks
Box feeder	Adjacent to the raw material storage	Feeds controlled amounts of raw materials into the production line
Magnetic separator	Just after the box feeder	Removes ferrous metal contaminants to protect downstream machinery
Primary crusher (Hammer crusher)	Following the magnetic separator	Crushes raw materials into smaller, manageable pieces
Secondary crusher	After the screener	Reduces material size to the desired fineness
Mixer/Pugmill	Following the crushers	Homogenizes the clay mixture, adding water and other additives for consistency
De-airing extruder	After the mixer/pugmill	Removes air pockets and shapes the clay into continuous columns or blocks
Cutter	Immediately after the extruder	Cuts clay columns into individual green bricks

4.2 Stone Screener

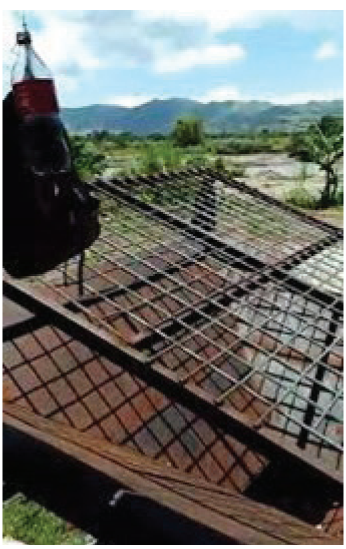


Figure 7: Stone screening

If the clay contains large rocks or stone boulders that cannot be easily removed, a stone screener should be installed at the top of the box feeder machine. This screening device effectively prevents large boulders from entering with the clay.

Figure 8: Stone screening mounted on a box feeder

4.3 Box Feeder

Box feeder ensures a consistent and precise supply of clay to the extruder machine. It typically consists of a hopper and a feeding mechanism that regulates the feeding of raw materials into the extruder. The hopper serves as a storage container for raw materials, while the feeding mechanism controls the rate at which these materials are fed into the extruder.

Figure 9: Box feeder

Figure 10: Box feeder

Figure 11: Box feeder

4.4 Magnet

Figure 12: Magnet

The clay used in brick production may contain metal impurities, such as nails, screws and metal fragments. These iron contaminants can damage downstream equipment, like crushers, mixers and extruders, causing wear and tear of machinery parts and degrading the quality of bricks. To prevent these risks, magnets should be installed at strategic positions. The optimal positions for installing magnets are: immediately after the box feeder, just before the hammer crusher and just before the rollers. Using a strong industrial-grade magnet such as an overband magnet or a magnetic pulley can effectively remove even small ferrous particles from the bulk material.

4.5 Hammer Crusher

A hammer crusher is used for crushing and grinding raw materials, such as clay, shale and coal gangue, into fine particles so that they can be formed and shaped into bricks. The hammer crusher is specifically used for dry clay, and is suitable for clay containing high amounts of stones or hard materials

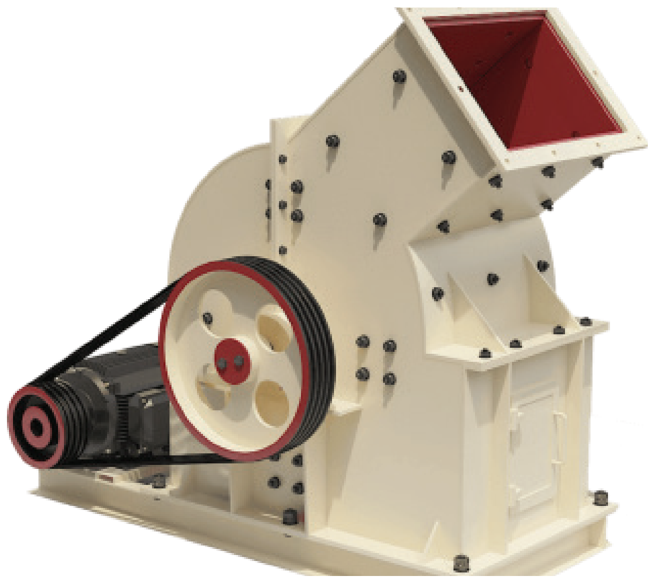


Figure 13: Hammer crusher

4.6 Screener Mechanisms

A screener is an essential piece of equipment in the clay brick manufacturing process. It is used to separate and grade crushed raw materials of different sizes, ensuring that only particles of appropriate size proceed to the next stage of production. Screeners contribute to the uniformity and high quality of finished bricks. The most common types of screeners are **vibrating screens** and **rotary screens**.

Figure 14: Rotary screens

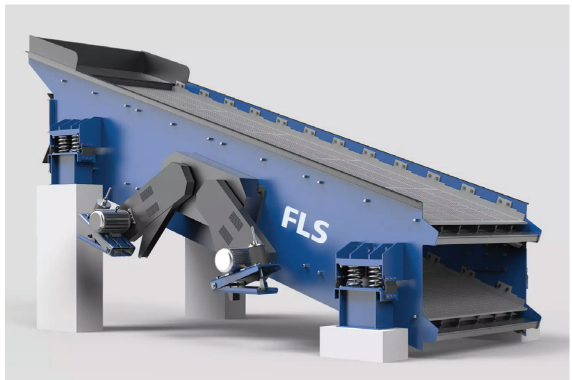


Figure 15: Vibrating screens

4.7 Conveyor

A screener is an essential piece of equipment in the clay brick manufacturing process. It is used to separate and grade crushed raw materials of different sizes, ensuring that only particles of appropriate size proceed to the next stage of production. Screeners contribute to the uniformity and high quality of finished bricks. The most common types of screeners are vibrating screens and rotary screens.

Figure 16: Belt conveyor system

4.8 Stone Crusher

The first step in the clay selection process is avoiding clay containing large stone boulders. When such clay cannot be avoided, stone boulders should be broken down into smaller manageable sizes with the help of a mechanical stone crusher. Several types of crushers are available for pulverizing stones into powder for clay brickmaking.

4.8.1 Roller Crusher

Roller crushers are heavy-duty machines used in brickmaking for crushing and grinding clay, rocks and stones into fine powder. They can be adjusted to crush stones of various sizes, but they are mostly used for medium-sized rocks or stones. The crushed clay is then mixed with water to form a clay slip. The roller usually consists of a large motor-powered steel drum. The drum is equipped with hardened steel or carbide teeth that crush and grind the clay as it rotates.

Figure 17: Toothed roller

Rollers come in different sizes and designs, tailored to different applications and industries. Two types of rollers are commonly used for crushing or grinding clay:

- *i.* ***Toothed rollers:*** These rollers are equipped with steel or carbide teeth. They are typically used for heavy-duty applications and can handle large volumes of clay.
- *ii.* ***Smooth rollers:*** These rollers do not have teeth and are used for compressing and levelling the clay. They are typically used for light-duty applications, such as compacting the clay and creating a smooth surface.

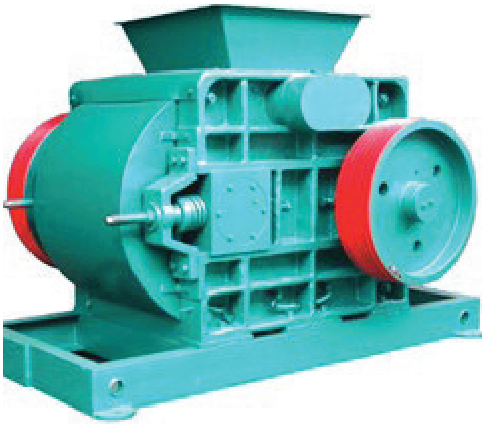


Figure 18: Smooth roller

The choice between the toothed and smooth rollers depends on the type of clay, the scale of operation and the desired output.

4.8.2 Pan Mill

A pan mill is a specialized machine used for crushing, grinding and mixing clay. The clay that emerges from the roller may still contain small stone fragments. It is further refined into a powder-like consistency using a pan mill. In Nepal, brick kilns with extruders often use a double set of rollers instead of a pan mill. The pan mill is particularly well suited for brick kilns that handle clay with high content of rocks and hard clay. It is also effective for processing both dry and wet soils.

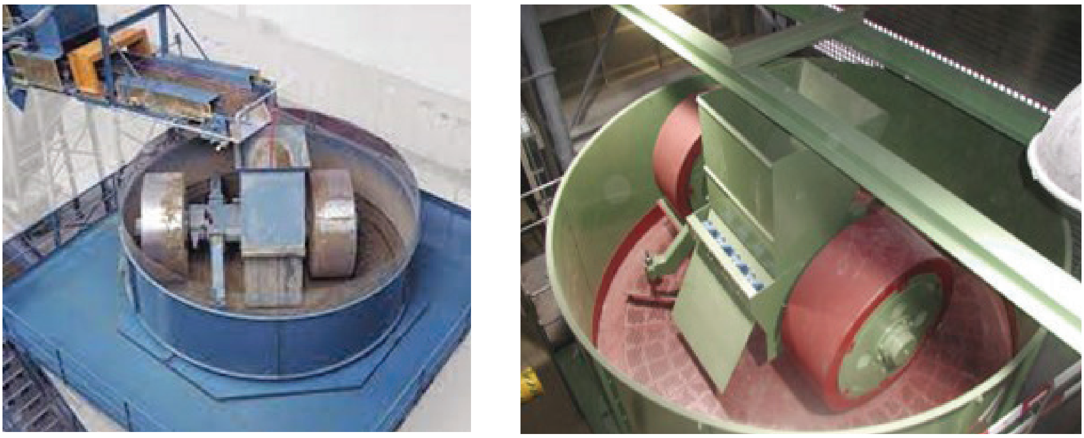


Figure 19: Pan mill

4.9 Mixer

A mixer is used for mixing clay and other materials, apart from homogenizing the raw material and ensuring consistency in the mixture. Mixers are available in various designs and sizes. Two types of mixers commonly used in brickmaking are:

4.9.1 Pugmill mixer

This type of mixer features a mixing chamber and an auger. The raw material is fed into a hopper and mixed by the auger as it passes through the chamber. Pugmill mixers can handle large volumes of material. Mixtures with an auger perform better than those with blades. Pugmill mixers can handle large volumes of material. Mixtures with auger perform better than those with blades.

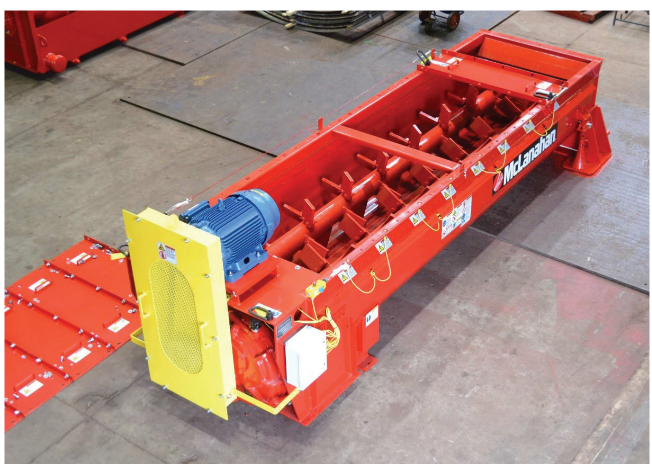


Figure 20: Pugmill mixture

4.9.2 Ribbon mixer

A ribbon mixer consists of a horizontal cylinder with a rotating spiral ribbon inside. Raw materials are fed into the cylinder and are mixed together by the rotating ribbon. Ribbon mixers are used for small- to medium-scale operations and can handle only small volumes of material. The choice of mixer depends on factors such as the type of bricks, the scale of operation and the desired output of material. The choice of mixer depends on factors such as the type of bricks, the scale of operation and the desired output.

Figure 21: Clay mixture machine

4.10 Extruder

An extruder machine is used for mixing and kneading the clay and other materials together and then forcing the mixture through a die to mould bricks of desired shapes. Extruders come in various designs and sizes, and are used for producing bricks of different shapes and sizes.

There are two types of extruder machines commonly used in brickmaking:

4.10.1 Single-stage extruder

This type of extruder consists of a single screw that both mixes and kneads the clay and other materials together. The mixture is then forced through a die or mould to create the desired shape of bricks. Single-stage extruders are generally used in small- to medium-scale operations and can handle small volumes of material.

4.10.1 Single-stage extruder

This type of extruders has two screws: one for mixing and kneading and the other for extruding. The mixture is first mixed and kneaded by the first screw and then forced through a die or mould by the second screw to create bricks of desired shape. Double-stage extruders are typically used in large-scale operations and can handle large volumes of material.

Figure 22: Extruder machine

4.11 Pressure Head and Die Assembly

Figure 23: Hollow brick die

4.11.1 Pressure Head

The pressure head and die assembly are attached to the end of the extruder. A standard combination of pressure head and die assembly for soft extrusion is illustrated in Figure 23.

In the extruded brickmaking process, the shaping stage is crucial for producing well-formed and high-quality green bricks. It is essential to maintain a consistently-shaped extrusion body throughout the shaping process, guiding it to ultimately conform to the geometry of the desired end product while minimizing excessive shear stress. The design of the pressure head and die plays a key role in optimizing the speed and stress profile of the extrusion body, as well as ensuring a uniform and constant speed across the entire cross-section of the column.

Slides are fixed to the pressure head to regulate the clay column before it reaches the die. Adjusting them can also regulate extensive alterations to the core bar. However, over-adjusting them can narrow the cross-section of the flow, leading to variations in the speed of the mass. Excessive adjustments may reduce the cross-sectional area of the flow, potentially impacting the velocity of the mass flow.

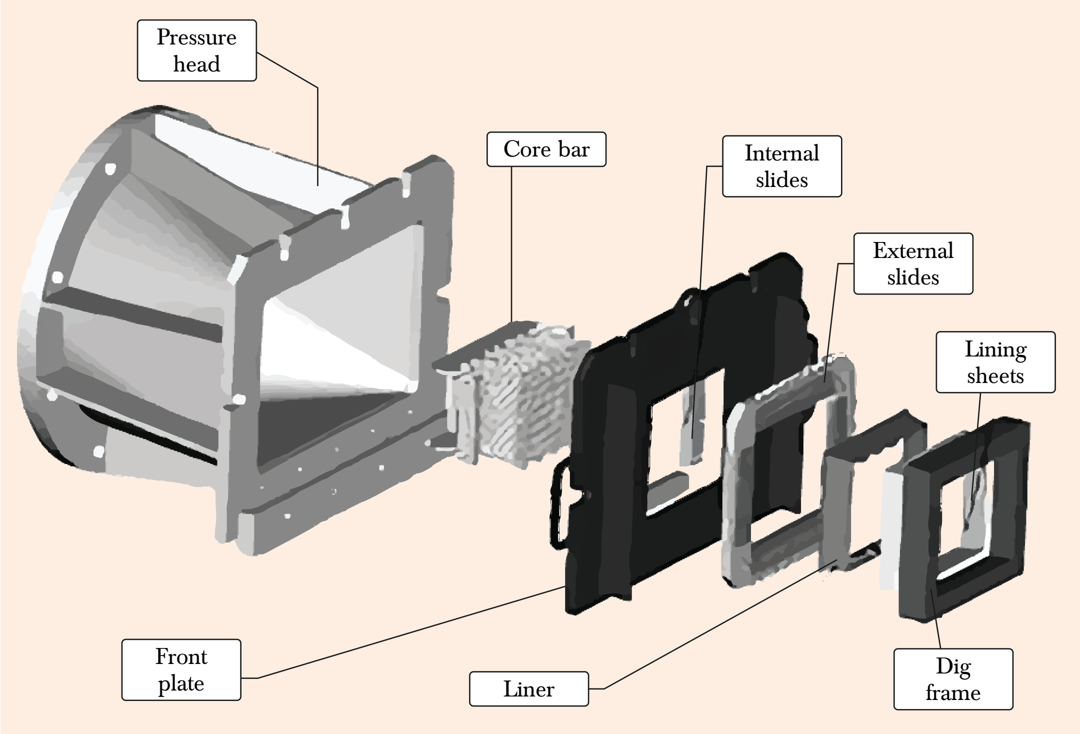


Figure 24: Standard combination of pressure head and die assembly for soft extrusion

4.11.2 Core Bar

The core bar is a critical component of the die for achieving optimal extrusion. The core bar has the highly demanding task of minimizing frictional resistance and at the same time keeping the cores in the correct position. Its design is heavily influenced by the core pattern, particularly in brick manufacturing. The pattern could range from three holes to complex patterns of perforations. Cores with complex patterns require considerably stable core-holder designs.

Figure 26: Backside of the die to form perforated bricks

Figure 25: Types of dies: 3 holes, solid brick and perforated bricks

4.11.3 Cores

Cores are used for achieving the ultimate compaction of the clay and determining the shape of the holes. Therefore, they should be designed for optimal efficient flow and facilitate the clean release of clay with well-finished holes. Hard chrome-plated cores are considered as the most flexible and ideal for flow technology.

Figure 27: Core bar for perforated bricks

4.11.4 Slide Regulation

Slide regulation is done to adjust a die without the need for disassembling and reassembling, saving substantial time. Slides can be adjusted externally while the production process is ongoing, eliminating the need to halt production. This feature can adjust and balance minor irregularities in the flow in the best possible way, especially in the tongue and groove areas.

An example of slide regulation in a multi-column die is shown in Figure 28.

In practice, the most common problems in extrusion arise through:

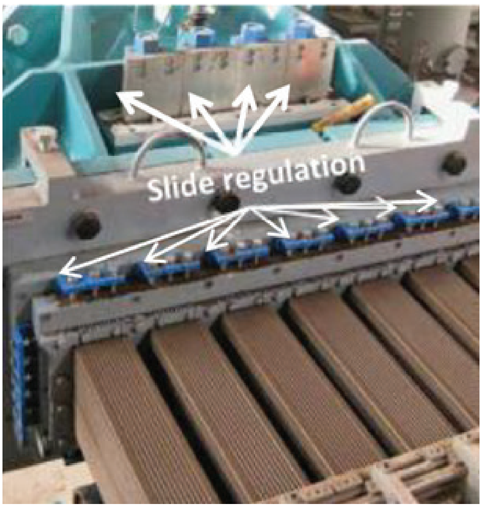


Figure 28: Slide regulation at the pressure head and the die

- Modifications to the rheological properties of the mass, for example through variations in the moisture or in the homogeneity;
- Changes to profiles, which can lead to increased flow resistance in the nozzle;
- Wear on the screw or on the cylinder inserts or modifications to the screw or cylinder surfaces, which leads to an increased proportion in the flowback or to a reduced capacity for the forming pressure of the screw;
- Increase in the flow rate, combined with increased strand speed;
- Vacuum errors due to leakage;
- Vacuum errors despite a faultlessly sealed vacuum aggregate; and
- Mouthpiece (die) errors.

4.12 De-airing Machine

Most de-airing machines feature a vacuum de-airing mechanism integrated into the extruder set-up. Auger-type de-airing machines are also available, but they are less commonly used in Nepal.

4.13 Cutter Machine Set-up

The cutter machine set-up comprises two key components: ***clay column cutter*** and ***precise cutter.*** The clay column cutter trims the clay column to the desired length, whereas the precise cutter cuts the clay columns in precise thickness into bricks. These machines are designed to accurately and efficiently cut extruded clay bricks into desired shapes and sizes.

Figure 29: Cutter machine set-up

5

RAW MATERIAL SELECTION AND TESTING

Clay is the primary raw material used in clay brick production. In Nepal, brick kilns consume approximately 13.9 million tons of clay annually. Producing hollow bricks can reduce the demand for natural clay, thereby reducing clay extraction as well as transportation costs.

To achieve optimal results in producing high-quality hollow or perforated bricks, having a good understanding of the nature of clay, including their types as well as both physical and chemical properties, is crucial. The following section provides a brief overview of essential clay properties.

5.1 Types of Soil

5.1.1 According to Soil Strata

A typical clay profile can be divided into three layers:

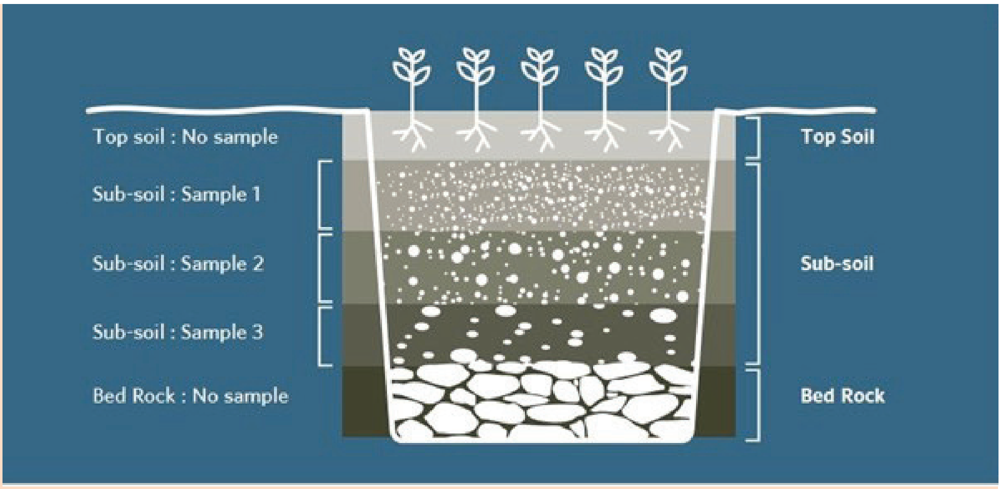


Figure 30: A cross-sectional view of earth showing different layers of clay

Source: VSBK Programme Nepal, 2008

Topsoil: Rich in organic matter, this layer is generally fertile and suitable for cultivation and is, therefore, not recommended for brick manufacturing. Unfortunately, many brick kilns in Nepal use topsoil, depleting this valuable resource and subsequently decreasing agricultural fertility. The 2010 Industrial Policy of Nepal explicitly emphasizes the importance of conserving the fertile topsoil during industrial activities (MoI, 2010).

Subsoil: Also known as impure clay or brick clay, this layer contains minimal organic content. Brick clay primarily comprises minerals such as silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), lime (CaO), magnesia (MgO), and alkalis (K_2O, Na_2O). The proportions of these chemical constituents significantly influence the quality of fired bricks.

Bedrock: Consisting of large lumps and rocks, the bedrock is generally unsuitable for brickmaking unless crushed into smaller particles.

5.1.2 According to Grain Size

Clay (Grain size: < 2 µm or 0.002 mm):

Clay enhances the workability and strength of bricks. It helps bind coarse particles, contributing to the overall strength of fired bricks. However, excessive clay content in the soil can reduce its workability in brickmaking and increase the shrinkage rate, resulting in shrinkage cracks during drying.

Table 3 provides the recommended range of clay and other elements in the soil for bricks of optimal quality.

Silt (Grain size: 2–63 µm):

Silt helps prevent excessive shrinkage cracks during drying. Although it does not contribute to the binding activity like clay, it fills the gaps between sand and clay, creating a homogenous structure that ultimately increases the overall strength of fired bricks.

Table 3 provides the recommended range of silt content in the soil for optimal brick production.

Sand (Grain size: > 63 µm):

Sand plays a vital role in brickmaking by opening up the fine clay structure, enhancing the workability of the soil and preventing the soil from sticking to hands or the die. Additionally, during brick firing, sand helps in reducing high firing shrinkage, thus preventing firing cracks,

Table 3: Recommended values of clay, silt and sand for brickmaking

S. No.	Elements	Recommended Range
1	Clay	20–35%
2	Silt	25–45%
3	Sand	20–45%

Source: VSBK Programme Nepal, 2008

warpage and abrupt vitrification. Moreover, sand contributes to the compressive strength of green bricks during stacking and prevents sagging during firing.

5.1.3 According to Soil Colour

Soil colour is determined by the various chemical elements and minerals present in the soil. Soils tend to have distinct variations in colour due to change in chemical elements. For example, iron (Fe_2O_3) gives a characteristic red hue, whereas calcium (CaO) gives a whitish colour and manganese (MnO_2) gives a black tint to the soil. The presence of other minerals can sometimes mask the colour of individual minerals. For example, if the calcium content in the soil exceeds 2 percent, a soil containing iron more than 6 percent might exhibit a dark yellow tint instead of its typical red colour.

The effects of soil colour on brick quality are discussed below.

Black soil: Black soil has high organic content, which reduces the energy required during firing. However, bricks made of black soil exhibit a high degree of shrinkage, and, if not properly managed, are prone to cracking during drying.

Yellow soil: Yellow soil contains very low organic matter, necessitating higher energy input for firing the bricks made with it. The bricks made from yellow soil experience less drying shrinkage compared to those made from black soil. Therefore, bricks made of yellow soil generally have uniform shape and size.

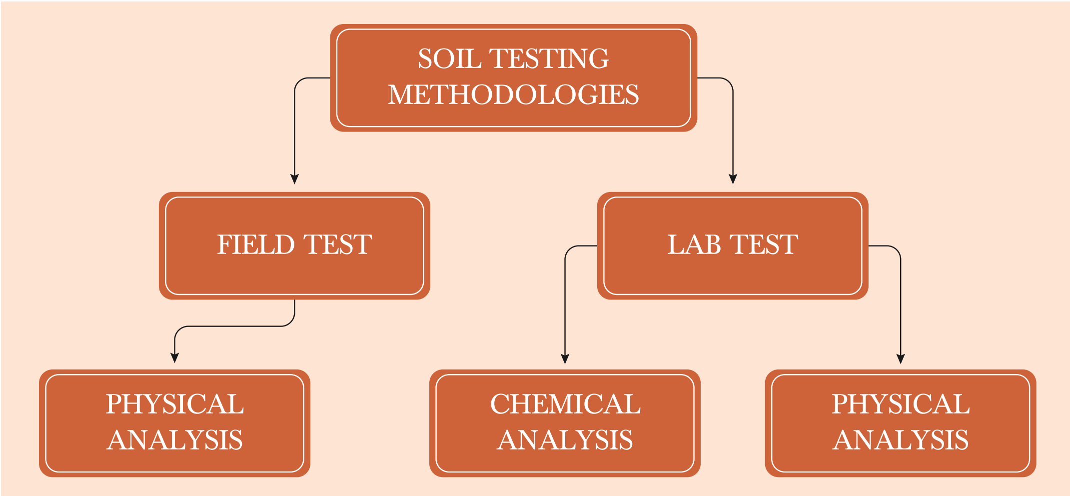
Dark black soil: Due to its high humus content, the use of dark black soil is not recommended for brickmaking. Its high plasticity and presence of hard lumps make it difficult to mix it with water. This type of soil leads to excessive shrinkage, making the bricks highly susceptible to cracking during both drying and firing.

Red soil: The red colour of soil is caused by the oxidation of iron. The higher the iron content, the lower the vitrification temperature of the brick will be, provided the grain size distribution is appropriate, thereby saving energy.

Note: *Generally, the word "soil" is not commonly used in common parlance, and, instead, the word "clay" is often used when referring to soil. The term "soil" is typically associated with fertile ground. Therefore, in this manual, the term "clay" will be used henceforth to represent soil.*

5.2 Clay Testing

Before transporting clay, its suitability for brickmaking should be assessed at the quarry itself. The testing methodologies outlined below aid in assessing the suitability of clay for brick production, thereby cutting down on transportation costs and minimizing losses due the use of low-quality bricks.



5.2.1 Field test

Field test is a quick and cost-effective method for assessing the quality of clay in the field. Several basic field-testing techniques offer initial insights into the suitability of clay for brickmaking. Some of these methods are discussed below:

Note: *In clay testing, the topsoil should be avoided for brickmaking, as it contains fertile soil.*

5.2.1.1 Smearing Test

- Collect a sample of loose clay for brickmaking.
- Add an appropriate amount of water to the clay gradually to make a sticky paste.
- Mix the clay paste thoroughly by hand until it is fully saturated with water.
- Form the saturated clay into a ball.
- Pinch a small amount of the clay and smear it between your thumb and index finger.

Table 4: Results of the smearing process

Sandy or silty clay	– The clay does not form a smooth and thin layer. – After drying, if the layer falls off or can be removed easily, then the clay is sandy or silty. – If the clay sticks to the thumb and the index finger after drying, it suggests high plasticity. – Observe the clay smear for coarser particles. It gives a measure of the coarse sand in the clay.
Plastic clayey clay	– The thin clay layer is shiny and evenly spread out over the thumb. – Too much sticky clay means the clay is clayey.

Figure 31: Smearing test *Source: VSBK Programme Nepal, 2008*

5.2.1.2 Ball test

- Take a handful of clay and add just enough water to make a dough.
- Mix the clay thoroughly until it is uniform, then shape it into a ball.
- If the clay is too wet, add dry clay and mix again.
- Observe the smoothness of the ball's surface.

Figure 32: Ball test *Source: VSBK Programme Nepal, 2008*

5.2.1.3 Wet ball test

- Immediately after the ball is properly formed, drop it from a height of at least 1 metre or the shoulder height with the hand straight.
- The surface on which the ball is dropped must be level, dry and clean.

Table 5: Results of the wet ball test

Sandy or silty clay	– The ball flattens out upon hitting the floor.
Plastic clayey clay	– The ball retains its shape with few deformations.

5.2.1.4 Dry ball test

- Dry out the clay ball.
- Repeat the drop test as mentioned in the wet ball test.

Table 6: Results of the dry ball test: appearance

Sandy or silty clay	– The surface will appear dull and rough, making it difficult to make a round ball.
Plastic clayey clay	– The surface will be shiny and uniform.

Table 7: Results of the dry ball test: drop

Sandy or silty clay	– The ball cracks into many pieces after hitting the floor.
Plastic clayey clay	– The ball breaks into two or three pieces only.

5.2.1.5 Sedimentation test

The sedimentation test, also known as the bottle test, provides insights into the proportions of clay, sand and silt in the clay. The test procedure is explained below:

- Fill a quarter of a glass beaker with the clay sample.
- Add half a teaspoon of salt to speed up the deflocculation process.
- Add water to approximately 50 percent of the clay level.
- Allow the water to seep down to the bottom (noticeable colour difference will appear between the dry and wet clay).
- Vigorously stir the clay and water mixture with a spoon for at least 2 minutes, ensuring the mixture has a uniform colour.
- Transfer the stirred slurry into a measuring cylinder.
- Add water to the beaker, then pour all the clay into the measuring cylinder.
- Repeat the process of adding water to the beaker until it is completely empty.
- While transferring the clay into the measuring cylinder, make sure no clay adheres to the cylinder's sides to prevent distorting the proportions.

- Position the measuring cylinder on a level surface and let it sit for at least 12 hours or until the water becomes clear at the top.
- Once the water becomes clear, distinct granulation layers will appear, representing the sample's fineness/plasticity or coarseness/non-plasticity.
- Measure the height of the bottommost visible layer, which is categorized as sand, and calculate the sand percentage.
- Measure the uppermost visible layer, classified as clay, and calculate the clay percentage. The layers between the top (clay) and bottom (sand) indicate the silt content of the clay sample.

Figure 33: Sedimentation test *Source: VSBK Programme Nepal, 2008*

5.2.1.6 Lime test

Lime is one of the most detrimental minerals in brickmaking. The presence of lime needs to be detected during the initial clay testing stage itself. While it does not affect the quality of green bricks, once fired bricks containing lime nodules are exposed to open air, they absorb moisture from the atmosphere and expand, causing the solid brick to burst—a phenomenon known as "lime bursting". The following method outlines a straightforward field test for detecting the presence of lime in the clay.

Figure 34: Lime test

Source: VSBK Programme Nepal, 2008

- Extract a clay sample from the site or depth within the selected clay for brickmaking.
- Avoid collecting loose clay, as lime nodules, if present, may not be adequately represented in a small amount of loose clay.

- Inspect the clay lumps for white spots.
- Take a clay sample that accurately represents the overall composition and crumble it by hand to achieve a loose consistency.
- Place a small portion of the crumbled clay in a petri dish.
- Do not add water to the clay, as it will hinder the acid reaction process.
- Using a pipette, apply a small quantity of acid (any common market acid, such as lime juice, toilet cleaner) onto the clay sample in the petri dish.
- Observe the reaction.

The presence of lime can be confirmed if the reaction results in effervescence (a type of melting) or bubbling action.

Observation result: If no bubbling occurs, repeat the test with a different clay sample. This test should be repeated as many times as possible with clay samples from various quarries until all doubts are eliminated.

5.2.1.7 Pencil test

- Take a handful of clay and add an adequate amount of water to shape the clay into a pencil-like form.
- Knead the clay in your hands for a while to develop plasticity in the clay particles.
- Ensure that the water amount is not excessive, as the mixture should not turn slurry but should be workable enough to moisten the clay and form a dough by hand.
- Thoroughly blend the clay and water with your hands and fingers until the mixture is uniform.
- Once evenly mixed, place the moist clay between your palms and shape it into a fine pencil-like form.
- The rolled clay should resemble an actual pencil, neither too thick nor thin.

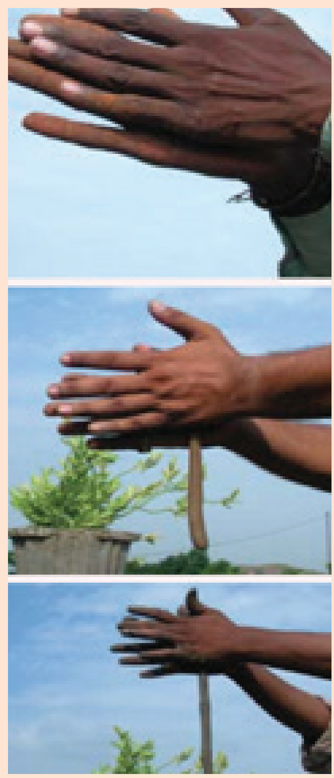


Figure 35: Pencil test

Table 8: Results of the pencil test

Sandy or silty clay	– The clay breaks easily.
Plastic clayey clay	– The clay can be rolled into a long pencil-like shape without breaking or disintegrating.

Note: *Excessive clay content can reduce workability during brick moulding and increase the shrinkage rate, forming cracks during the drying and firing processes. Similarly, excessive sand distorts plasticity, resulting in a high breakage rate.*

5.2.2 Laboratory test

Performing laboratory tests to determine the chemical composition of clay samples before transportation of clay is essential to ascertain its suitability for brickmaking. Such tests encompass both physical and chemical analyses.

5.2.2.1 Chemical testing

The most abundant elements in clay are oxygen (O), silica (Si), aluminium (Al), iron (Fe), carbon (C), calcium (Ca), potassium (K), sodium (Na), and magnesium (Mg). Among them, silica (SiO_2), alumina (Al_2O_3) and iron (Fe_2O_3) are used for determining the quality of bricks. While other chemical properties also influence brick quality, they are present in small quantities.

The mineral content of clay is assessed through chemical analysis, which is one of the most reliable methods for assessing the suitability of clay for brick firing. The key chemicals analysed include alumina, silica, iron oxide, calcium oxide, manganese oxide, sodium oxide, and potassium oxide

The following table outlines the parameters to be monitored during chemical analysis, along with the preferred values for brickmaking.

Table 9: Chemical parameters of clay and their values for a good sample

S.No.	Test parameters on dry basis (% by mass)	Examples of good results	Effects on fired brick property
1.	**Loss of ignition**	3–8%	Excessively high loss of ignition is harmful, causing high porosity, shrinkage and chances of black coring.
2.	**Silica as SiO_2**	50–60%	Silica is the primary constituent of any clay. Structural silica within clay mineral gives strength to the fired brick, whereas free silica gives strength and rigidity to green bricks. Structural silica present in the clay reacts with alumina to form mullite, which also gives the required strength to fired bricks.
3.	**Alumina as Al_2O_3**	20–30%	Fired bricks will only increase in strength if the amount of alumina content is equalized with silica in the 2:3 ratio. An excess amount of alumina in clay may cause bricks to shrink, warp or crack on drying and burning, as any other cementing material.
4.	**Iron oxide (Fe_2O_3)**	> 3%	Iron oxide acts as a flux, helping silica to fuse at a low temperature. It imparts the red colour to bricks on burning. Iron also increases the durability and impermeability of bricks.

S.No.	Test parameters on dry basis (% by mass)	Examples of good results	Effects on fired brick property
5.	**Sodium as Na_2O**	< 0.1	More than 1% content will affect the fired brick properties, causing white scums in fired bricks when they come in contact with water.
6.	**Potassium as K_2O**	< 2.7	Higher quantities present in the clay will lead to lower vitrification temperatures but with a high firing shrinkage.
7.	**Calcium as CaO**	Traces	Is extremely harmful in lump form, resulting in lime bursting. However, in a fine state (< 2 mm), and if the amount is more than 2%, it will mask the red colour given by iron, resulting in buff-coloured fired bricks.
8.	**Magnesium as MgO**	< 1.2%	A small proportion of magnesium decreases shrinkage and gives a yellow tint to bricks. An excess amount causes bricks to decay. It is beneficial for fired brick properties since it acts as a catalyst during vitrification and aids in denser and stronger bricks.
9	**Organic carbon**	< 1%	Measure of heat producer in the clay. Acts as an internal fuel, reducing external fuel consumption.

Source: //civiltoday.com and VSBK Programme Nepal, 2008

5.2.2.2 Physical test

To assess the suitability of clay for brickmaking, it is necessary to evaluate several key physical parameters such as the proportions of clay, silt and sand, as well as the clay's shrinkage and plasticity. Assessing clay plasticity involves testing indicators, such as plasticity index, liquid limit and plastic limit. Various laboratory techniques are available for testing plasticity indicators, with the Casagrande Apparatus Method being the most common. The clay, silt and sand percentages can be determined through physical analysis, often performed using the wet sieve analysis method, in a laboratory. Understanding the significance of these clay properties requires a clear grasp of the physical meanings of the terms, as explained below.

Particle size distribution

The particle size distribution offers insights into the presence of different physical constituents, like clay, silt and sand particles in the clay. By passing a sample of clay through a set of sieves of defined mesh sizes, one can gain an understanding of its particle size distribution.

For extruded brickmaking, an optimal clay sample should ideally consist of fine particles constituting no less than 70 percent and preferably exceeding 80 percent, as fine particles are essential for properly shaping bricks and blocks. Excessive coarse clay is not favourable for shaping and can result in bricks of low strength (NIIST, 2011).

Drying shrinkage

To avoid issues such as shrinkage cracks, warping, low strength and distortions in unfinished products, drying shrinkage must be minimal. To control shrinkage, additives can be mixed into the clay. A plastic clay mass can be blended with sand, coarse clay, or sometimes burnt clay. For brick and tile making, shrinkage should be below 10 percent.

Plasticity

Plasticity of clay refers to the ability of clay to be moulded and shaped without cracking or breaking. This is a crucial property in brickmaking, ceramics and pottery, as clay must be pliable and workable during the forming process. The level of plasticity in clay is influenced by its mineral composition, particle size, moisture content, and the presence of organic matter.

Clay with high plasticity is often preferred by artists and potters because they allow for intricate and detailed sculpting or throwing on the wheel. In brickmaking, however, low to moderate plasticity is needed for moulding and shaping. Generally, the more plastic the clay, the more it shrinks when dried or fired. Therefore, achieving a balance between adequate plasticity and low shrinkage is essential for brickmaking.

Plasticity index

The plasticity index of clay is a measure of the clay's ability to undergo deformations without cracking. It indicates the range of the moisture content at which the clay remains plastic. The plasticity index is calculated by taking the difference between the liquid limit and the plastic limit of the clay.

In mathematical terms:

Plasticity Index = Liquid Limit − Plastic Limit

The **plastic limit** of the clay is the moisture content at which the clay starts behaving as a plastic material, whereas the **liquid limit** is the water content at which the clay starts behaving as a liquid.

A higher plasticity index indicates a greater range of moisture content over which clay remains in a plastic state. In practical terms, the Atterberg Plasticity Index (API) is commonly used to identify the plasticity of clay. For practical purposes, an API in the range of 10–20 is generally considered most satisfactory. The mechanical composition range, considered ideal for alluvial clay in wire-cut brickmaking, is shown in Table 10.

Table 10: Physical characteristics of clay suitable for quality brickmaking

Elements	Percentage
Clay	20–35%
Silt	25–45%
Sand	20–45%
Plasticity index	15–30
Drying shrinkage	<10%

Source: IS 11650:1991

5.2.2.3 Trial production test

To ensure the quality of clay for brickmaking, a substantial quantity of clay should be transported from the quarry site and at least 1,000 fired bricks should be produced as trial production. This will provide an idea of the suitability of the clay for brickmaking.

6

CLAY PREPARATION

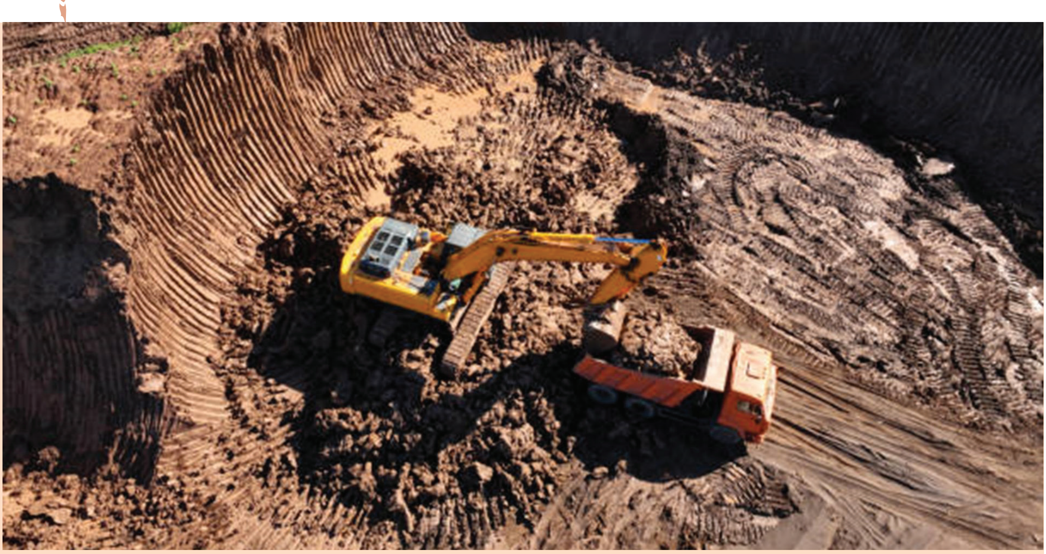
Clay preparation involves treating the clay to make it suitable for moulding, ensuring it is workable for producing bricks of desired quality. This process transforms the raw material from a hard and unyielding state into a plastic and mouldable state.

Why clay is prepared

- To improve its quality
- To improve the quality of bricks
- To reduce breakage of green and fired bricks
- To reduce labour drudgery, thereby increasing labour productivity, and
- To increase profitability

6.1.1 Clay mining and dumping

6.1.1.1 Clay mining



Source: https://www.istockphoto.com

Figure 36: Clay mining

Mine selection

Select a quarry site that has the right type of clay for brick production. The clay should meet the required quality standards, including the right proportions of clay, silt and sand. The site should be as close to the brick kiln as possible to reduce transportation costs. Furthermore, it should possess a sufficient quantity of clay to meet production needs for brick manufacturing, making it essential to accurately estimate the clay reserves when selecting the site.

Sustainable practices

Adopt sustainable mining practices to minimize environmental impact. Consider measures such as minimizing clay erosion and avoiding the topsoil.

Quality assurance

Regularly collect and test clay samples to ensure the mined clay maintains a consistent quality. Cut the clay vertically so that the clay strata are mixed during mining. Periodically monitor and control the quality of the mined clay to ensure it meets the specifications required for brickmaking.

Equipment and machinery

Use appropriate equipment and machinery for the extraction and transportation of clay. Regularly maintain and inspect the equipment and machines to ensure safe and efficient operations.

6.1.1.2 Clay dumping/storing

Clay must be properly dumped or deposited in small layers. To ensure its steady supply, clay should be transported from the quarry site to the brick kiln and allowed to undergo suitable aging (seasoning) period.

Figure 37: Clay dumping or storing

6.1.2 Clay mixing

Determine the properties of clay: The first step in mixing clay for brickmaking is determining its properties, including the content of the clay, silt and sand. Understanding these properties will help in determining what other types of clay need to be added to improve its quality.

- ***Adding clay:*** If the clay is too sandy, adding a clay-rich clay or a clay-rich amendment such as kaolin or bentonite can improve its plasticity and strength.
- ***Adding sand:*** If the clay is too clay-rich, adding a sandy clay or a sandy amendment such as fine gravel or crushed stones can improve its workability and reduce shrinkage.

Figure 38: Clay mixing

6.1.3 Additive mixing

In green brickmaking, the following types of additives are used:

- Internal fuel
- Anti-shrinkage material and
- Structure-opening material

Internal fuel

For internal fuel brickmaking, a calculated amount of fuel is mixed in the clay during the mixing and pugging process. Internal fuel brick firing saves fuel consumption and reduces external fuel consumption. It also reduces stack emissions. Additionally, it upgrades the quality of fired bricks. Internal fuel can be coal or a waste material produced by the processing industries, such as:

- Coal dust
- Industrial waste, such as boiler ash, distillery waste and sponge iron waste, and
- Agro-waste, like rice husk and saw dust.

Anti-shrinkage material

To transform highly plastic clay for brickmaking, anti-shrinkage agents are added to avoid high shrinkage and cracks during drying under direct sunlight. Depending upon availability, various materials can be used as anti-shrinkage agents, including:

- Fine sand
- Medium sand
- Stone dust, and
- Sandy clay

Figure 39: Anti-shrinkage material *Source: VSBK Programme Nepal, 2008*

Structure-opening material

During very low humidity and high temperature periods (eg March–June), green bricks face serious drying shrinkage cracking and warping problems. To prevent damage of green bricks through rapid drying, structure-opening materials can be used. Structure-opening materials also act as anti-shrinkage agents. The materials generally used for structure opening are:

- Rice husk
- Saw dust and
- Mustard husk

Figure 40: Structure-opening materials *Source: VSBK Programme Nepal, 2008*

7

GREEN BRICKMAKING

The general green brickmaking process involves several key steps, starting with the preparation of clay mixture, which passes through various mechanical equipment, as described in the previous chapter. Subsequently, this mixture is forced through a die or mould to form bricks of desired dimensions, shape and hole pattern. Thereafter, the extruded clay material is sliced to the desired length and dried before being placed in the kiln for firing.

The key steps in the green brickmaking process for hollow or perforated bricks are as follows:

7.1 Stone Segregation

Stones are segregated before the clay enters the hopper or the box feeder.

7.2 Milling

Initially, a primary crusher such as a rotary crusher breaks down large lumps of stones into manageable sizes (< 100 mm). These are fed into a secondary crusher, for example a secondary roller with small gaps, between 5 and 15 mm, between the rollers. At this stage, water can be added in what is known as a 'wet pan'. Alternatively, if a dry pan is being used, the clay is reduced to between 5 mm and dust, with water added later. Further crushing is done using pairs of high-speed rollers, which break the clay particles down to approximately 1–2 mm.

7.3 Clay Mixing

The clay is introduced into a mixer for thorough blending to achieve homogeneity and improve its quality. At this stage, the final quantity of water is added and thoroughly mixed. Most modern mixers feature a double shaft with blades or paddles set at specific angles to both mix and convey clay along a large trough.

7.4 Water Mixing

The moisture content of the raw material plays a critical role in the extrusion process, as it affects the plasticity and extrusion ability of the clay. It is an important factor in determining the quality of the extruded clay bricks.

- **Too dry:** Clay becomes difficult to extrude and may result in cracked or misshaped bricks.
- **Too wet:** Clay becomes sticky and difficult to handle. Too high moisture content may also deform the extruded bricks. (Fig. 41)

Figure 41: Green bricks deformed due to high moisture content

The moisture content should be controlled to ensure proper bonding of the clay particles, as well as to prevent cracking and warping during firing.

The content depends on the type of clay, the shape and size of bricks, and the firing conditions. For uniformity of finished bricks, the moisture content should be consistent throughout the batch of the raw material.

In the soft extrusion process, a clay body of maximum plasticity with 20 to 25 percent moisture content is used. The body is extruded with the help of a pugmill through a die into a column of plastic clay. The die forms the outer dimensions of the product. The column is then cut into bricks by taut wires of a cutting machine. In stiff extrusion, the clay body contains 10 to 15 percent moisture (Brick Industry Association, 2006).

Figure 42: Water mixing

7.5 Extrusion

The clay mixture is prepared and fed into an extruder machine, where it is subjected to high pressure and forced through a die to form a continuous column of clay with the cross-sectional shape of bricks. The extrusion process can be categorized into two main types:

- ***Stiff mud process:*** Clay is mixed with water within a range of 12 to 15 percent to achieve plasticity (Brick Industry Association, 2006).
- ***Soft mud process:*** This method is suitable for clay with high water content. The clay is mixed with 20 to 30 percent water and then shaped into bricks using moulds (Brick Industry Association, 2006).

7.6 De-airing

During the mixing process, air bubbles can get trapped within the clay, leading to cracked and uneven bricks. De-airing is the process of removing air bubbles from the clay mixture before extrusion. To remove these, the clay is passed through a de-airing chamber, where a vacuum of 15 to 29 inches (375 to 725 mm) of mercury is maintained. De-airing eliminates air holes and bubbles (Brick Industry Association, 2006). The de-airing chamber is typically designed to expel any trapped air. Two types of vacuum system are used for de-airing:

- ***Vacuum de-airing:*** In some advanced set-ups, a vacuum chamber is used to remove air from the clay mixture more effectively. The vacuum chamber creates a negative pressure environment, causing the air to be drawn out of the clay.
- ***Auger de-airing:*** Some extruders use augers that continuously push and compress the clay, forcing any air pockets to the surface where they can be released. This system is less common in Nepal.

7.7 Cutting

Before being cut, the extruded clay emerges from the mouthpieces as a single piece, forming a continuous column known as the clay column. This column is usually supported by a conveyor belt or other suitable surfaces. When the clay column reaches the desired length, it is cut into individual bricks by a brick-cutting machine, usually located at the end of the extrusion line. The machine precisely slices the clay columns into bricks of desired dimensions. The detailed steps in the cutting operation are as follows:

Figure 43: Brick-cutter operation

Brick-cutter operation: The brick-cutting machine consists of one or more cutting wires or blades to slice through the clay column. (Fig. 43) These wires or blades are set at appropriate spacing to ensure that bricks of desired length are produced.

Figure 44: Precision cutting

Precision cutting: The cutting must be precise to ensure uniformity in the dimensions of bricks. The cutting machine is typically equipped with guides or stops to ensure consistency in the length of bricks. (Fig. 44)

Conveyor for collecting waste bricks: During precise cutting, the two bricks at each end of the clay column are always of irregular size and need to be recycled. Similarly, damaged green bricks must be recycled. To facilitate this, a conveyor system is installed to collect the waste bricks and automatically transport them back to the mixer.

Figure 45: Collecting bricks

Collecting bricks: As the clay column is cut into bricks, the individual bricks are either collected manually or by an automated system for further processing, such as drying and firing in a kiln.

Quality control: Throughout the cutting process, operators monitor the dimensions of the bricks to ensure they meet the required specifications. Any bricks that do not meet the standards may be discarded or reprocessed.

8

DRYING

Wet bricks from moulding or cutting machines contain 7 to 30 percent moisture, depending on the forming method. The drying process must be slow and carefully controlled to avoid rapid drying and shrinkage. Rapid drying can force moisture out of the bricks, resulting in shrinkage cracks. Green bricks should be carefully handled during stacking to prevent distortions and cracking.

The drying process of green bricks can be broadly categorized into natural drying and artificial drying. In **natural drying**, bricks are left to dry using natural ambient conditions, such as wind and sunlight. **Artificial drying**, on the other hand, employs automated or machine-driven systems to accelerate and control the drying process. Brick handling is more involved in natural drying compared to artificial drying, and the duration can range from two days to six weeks. The drying method may vary depending on climatic conditions, as well as on the specific needs and the investment capacity of the enterprise. The specific timeframe depends on the type of material being dried and the prevailing ambient conditions.

8.1 Drying Mechanism

Bricks dry through evaporation of water from their exposed surfaces. Evaporation takes place in several stages, as detailed below:

a. ***Free evaporation:*** Water from inside the brick moves to the surface to continually replenish the evaporated water.

b. ***Particle shrinkage:*** As the water separating the clay particles, ie bricks, is transferred to the surface, the particles move closer until they touch each other, ceasing the shrinkage.

c. ***Breakdown of water film:*** The continuous water film on the surface breaks down, but evaporation still takes place from the ends of the pores, which still receive water from inside the brick.

d. ***Final drying:*** Usually, it takes place as part of the firing process, where the remaining interstitial water is removed.

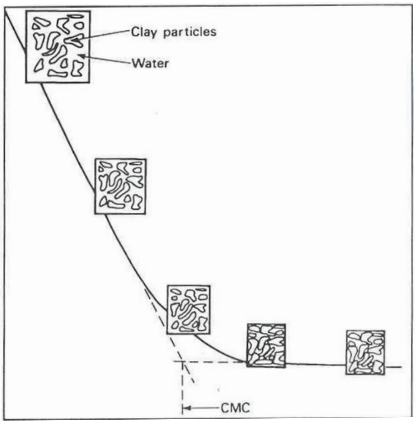


Figure 46: Drying curve

A critical stage in the drying process occurs when particles start touching each other. At this point, shrinkage virtually stops, but considerable amounts of water still remain in the brick. In fact, stages (a) to (d) above do not take place in such a well-ordered way throughout the brick or throughout a mass of bricks set to dry. In production, bricks are either set together or individually in the drying place, covering at least one face. For example, when single bricks are set on the ground, the face which is lying on the ground is covered, and evaporation cannot take place from that face at the same rate as from the exposed faces. In bricks set in stacks, different parts of various faces might be effectively covered by being in contact with other bricks, resulting in unequal drying rates. External factors like sun, wind and hot air also cause differential drying. As drying progresses, when the surface of the brick is drier than its inside, stresses and strains are caused within the brick, which cause the brick to crack. Therefore, proper mixing and aging should be carried out before brick moulding.

8.2 Drying Mechanism

8.2.1 Atmospheric drying

Green bricks are set out to airdry either in an open environment or within a sheltered area to dry out the remaining moisture. In the case of drying in a sheltered area, the following things should be taken care of:

- The drying period varies with weather conditions, typically ranging from 15 to 20 days in summer and 30 days or more in winter. Therefore, the drying shed should have the capacity to accommodate bricks for a minimum of 30 days.
- The shelter should be well-oriented to facilitate proper airflow.
- The shed should prevent rainwater from entering through the sides.
- The storage space design should include a suitable drainage system to prevent waterlogging.

In the case of open-air drying, the brick stacks must be covered with jute bags for several days to shield them from direct sunlight. Direct exposure to sunlight can accelerate the drying process, causing rapid moisture evaporation from the bricks, which can crack their surfaces. In both drying methods, a flat brick soling should be used as the foundation for drying green bricks.

Figure 47: Natural drying under shed

Figure 48: Fired brick soling

Figure 49: Natural drying under direct sun

8.2.2 Artificial drying

Artificial drying uses automated or machine-driven systems to accelerate and control the drying process of green bricks. Instead of relying solely on natural air drying, which can be time-consuming and weather-dependent, artificial drying employs various technologies to efficiently reduce moisture content. One common artificial drying method involves the use of fans or blowers to circulate warm or dry air through the brick kiln, expediting the evaporation of moisture from bricks. These systems are designed to maintain specific temperature and humidity levels to ensure uniform and controlled drying.

Artificial drying offers several advantages, such as:

- ***Faster drying:*** It significantly reduces the drying time compared to natural air drying.
- ***Consistency:*** Artificial drying allows precise control of temperature and humidity, ensuring consistent brick quality.
- ***Reduced weather dependency:*** Production can continue regardless of weather conditions.
- ***Energy efficiency:*** Some systems reuse waste heat from the brick kiln itself, enhancing overall energy-efficiency of the whole brick kiln system.
- ***Increased production capacity:*** Quicker drying time allows the kiln to handle relatively large quantities of green bricks.

The drying speed of brick is regulated by adjusting the temperature, humidity level and airflow. A standard drying process typically begins with low temperature (approximately 30° C) and high humidity, gradually progressing to high temperature (up to 120° C) with reduced humidity. Fans are employed to control air circulation, ensuring even distribution around the product and removal of moisture-laden air. Various types of dryers are available. High-end brick kilns adopt the following artificial drying techniques:

8.2.2.1 Chamber drying

The chamber dryer is gradually filled with pallets of wet bricks, which are supported on frames or stillages. Once the chamber reaches its capacity, the door is closed and the drying cycle begins. This process usually takes between 24 and 48 hours to complete.

Figure 50: Chamber drying

8.2.2.2 Tunnel drying

In tunnel drying, bricks are transported through the dryer on trucks or frames. The dryer is designed to create a drying profile along its length, such that bricks are cooler at the entrance and hot and dry towards the exit. The bricks are 'pushed' through the tunnel to the exit at the far end.

Figure 51: Tunnel drying

Note: *Given that artificial drying requires less space compared to natural drying, as well as considering decreasing land availability, artificial drying may become the only viable option for most brick kilns to operate sustainably.*

9

FIRING

The brick firing process transforms dried green bricks into fired bricks by exposing them to high temperatures, usually 900–1100^0 Celsius. The firing process is influenced by multiple factors, including the type of clay used, type of brick kiln and the type of fired product. One of the major differences in the firing processes is the brick firing technology itself. While the firing processes for solid and hollow bricks share similarities, specific considerations come into play in firing hollow bricks.

Several brick kiln technologies are used for firing bricks, such as Zigzag Kiln, Hoffman's Kiln, Hybrid Hoffman's Kiln, and Tunnel Kiln. In Nepal, the predominant kiln technology is the Zigzag Kiln. Therefore, the firing practices of the Zigzag Kiln are briefly discussed here.

Since hollow brick firing is relatively new in Nepal, long-term experience is limited. So far, only a few thousand hollow bricks have been fired, over hardly a couple of days, in a few chambers. Therefore, the actual scenario of firing hollow bricks for a relatively long duration is yet to be seen. Although we lack first-hand experience in hollow brick firing, necessary precautions need to be taken in this process.

The key considerations for hollow brick firing are:

- The brick stacking pattern in each chamber is exactly the same as that for solid bricks.
- Only solid bricks should be used in the walls of each chamber in Zigzag Kilns since the purpose of the walls is to regulate the airflow where hollow bricks can let the air pass through the hollow cavities.

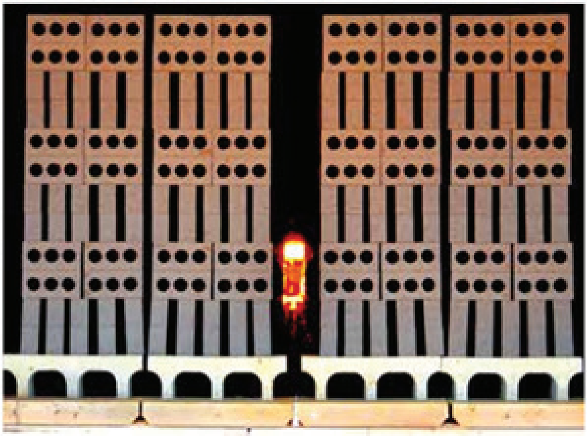


Figure 52: Hollow brick firing in a tunnel kiln

- Temperature control is essential for producing high-quality bricks. Kiln operators must monitor the temperatures in different chambers to ensure they rise uniformly and reach the desired firing temperature, typically approximately 900 to $1{,}100^0$ Celsius.
- The ideal firing curve for best brick firing should be maintained.
- The fuel-feeding process is similar to that for solid bricks. However, since hollow bricks have a lower mass, they require lesser fuel input. During the transition from solid to hollow bricks, coal feeding should be gradually decreased at the beginning, while observing the fire condition; however, the coal-feeding process remains the same.
- The firing procedures for any types of kilns have their own distinct procedural steps. While introducing hollow bricks into the firing process does not require a major overhaul of the firing procedure, certain precautions must be taken, and continuous monitoring and precise adjustments in fuel feeding are essential to maintain optimal firing conditions and to prevent damage.

Figure 53: Hollow bricks firing in a zigzag kiln

10

MACHINE OPERATION AND MAINTENANCE

The operator must possess a thorough knowledge of the following:

- Quality, quantity and composition of clay
- Each and every machine and its parts
- All control board switches
- Flow of raw material quantity and moisture content in the clay
- Pressure at which bricks of the best quality are produced
- Tools for repair and maintenance
- Installation of pulleys and belts
- Procedures for greasing, oiling, cleaning and welding, and
- Installation of the mouthpiece

10.1 Operation

Safe and efficient operation of the green brickmaking extruder involves several key steps. The general operating guidelines for a typical green brick extruder can be divided into three stages: i. Pre-operation ii. During operation and iii. Post-operation. The steps in each of these stages are described below.

i. Pre-operation

- **Reading the manual:**
  - Thoroughly read the manufacturer's manual or instructions for your extruder model. The manual provides essential information about the machine's features as well as maintenance and safety precautions.
- **Safety precautions:**
  - Wear appropriate and necessary gear and personal protective equipment (PPE), such as gloves, safety glasses and ear protection.
  - Ensure the machine is installed safely
  - Restrict access to the operating area only to authorized personnel.
  - Ensure that the machine is properly grounded to prevent electrical hazards.

- **Preparation:**
  - Inspect the machine for any visible damage or issues before each use.
  - Ensure that all moving parts are well lubricated.
  - If the clay has high quantity of stones, install stone-screening arrangements.
  - Ensure that the clay or raw material is prepared and adequately mixed.
  - Operate each machine freely without any raw material to ensure it is running smoothly.
  - Ensure that the clay is dry before putting it in the hopper of the box feeder.
  - Check the condition of water, electricity and mechanical equipment.
  - Fill in the checklist before operation.

ii. During operation

- After ticking off all the fields in the checklist, turn on the switch.
- Adjust the clay feed rate and extrusion pressure according to product requirements.
- Load the clay or raw material into the machine's hopper or feed mechanism.
- Distribute the material evenly to prevent clogs.
- Adjust the water quantity based on clay consistency.
- Start the extruder according to the manufacturer's instructions.
- Monitor the extrusion process to ensure the desired shape and size of bricks.
- Adjust settings as necessary during the process.
- Check the clay cake emerging from the extruder for cracks and other defects.

iii. Post-operation

- **Shutting down:**
  - Turn off the extruder and any associated equipment.
  - Thoroughly clean the extruder, removing any residue.
  - Disconnect the power source and lock the machine to prevent unauthorized use.
  - Clean out any residual clay from the mixture and the extruder machine at the end of the day.

10.2 Quality Control and Maintenance

- Periodically inspect extruded bricks for quality and consistency.
- Adjust the machine settings or raw materials to maintain quality.
- Regularly clean the machine, especially the extrusion chamber, to prevent material buildup.
- Check for wear and tear of components and promptly replace damaged parts.
- Keep spare parts, especially those prone to wear, such as bearings, extruder blades and auger blades, in stock.
- Lubricate moving parts as specified in the manual.
- Have tools, such as air pressure blowers and water jets, on standby for maintenance.
- Ensure that the operators and supervisors always check the machinery parts at regular intervals

10.3 Record-keeping

- Maintain records of **production runs, maintenance** and any issues or adjustments made during operation.
- For production records, ensure that brick count sensors, machine run loggers and other similar tools are available in the market.
- Maintain record of accidents, if any, their causes and the preventive measures taken.

11

TROUBLESHOOTING

Troubleshooting in the clay green brickmaking process involves identifying, analysing and resolving any problem or issue.

Some common problems that arise during machine-made brickmaking, their causes and solutions are:

Table 11: Problems related to quality of clay

Issue	*Cause*	*Solution*
Poor quality of bricks		
Substandard green and fired bricks due to poor clay composition	Inconsistent clay composition	• Ensure uniform clay characteristics. • Select a clay raw material site with proper quality of clay. • If the clay consistency does not match the required quality, mix different types of clay.
	Inadequate screening	• Enhance the screening process to remove unwanted matter. • If the clay contains pebbles, rocks, etc, use multiple screening layers to remove them with a roller crusher.
	Inconsistent supply of clay	• Source clay from multiple sources and ensure proper mixing.
Moisture content variability		
Distorted green bricks due to inconsistent moisture content in the clay	Inadequate mixing	• Mix water with clay thoroughly and uniformly. • Regularly monitor the moisture content in the clay mix.
	Exposure to weather conditions	• Control the storage environment to prevent moisture variations. • Store clay in a covered area to prevent moisture absorption.

Clay granularity		
Uneven particle size in the clay mixture	Inefficient grinding or crushing	● Optimize the clay preparation equipment. ● Examine the roller surface for any signs of wear and tear. ● The metal surface may develop bigger gaps, allowing larger particles to enter. Plug these gaps by filling in additional metal liner in the roller at regular intervals, adjusting the frequency based on the clay type and the quality of the roller metal. ● Use multiple sets of rollers. If the clay contains high amounts of stone particles, use a combination of large- and small-diameter rollers.
	Inadequate mixing time	● Extend the mixing duration to achieve a more uniform blend.
Clay homogeneity		
Non-uniform distribution of clay constituents	Insufficient mixing intensity	● Increase mixing time or adjust mixer settings. ● If the clay quality is not proper, mix clay with different properties to achieve the desired quality of clay.

Table 12: Problems related to machine

Issue	***Cause***	***Solution***
Equipment malfunctions		
Issues with clay mixing machinery	Lack of regular maintenance	● Implement a scheduled maintenance plan for equipment. ● Upgrade the equipment, consider upgrading machinery for improved efficiency.
Box feeder jam		
Box feeder jam	Overloading of raw material	● Maintain a steady flow of the raw material. ● Avoid sending large lumps of clay, rock pieces and highly wet clay.
Inconsistent brick dimensions		
Uneven size of bricks	Uneven clay feed	● Ensure the clay mixture is consistent.
	Worn or misaligned dies	● Inspect and replace worn dies, and ensure proper alignment.

Extruder blockages		
Frequent jamming of the extruder	Inconsistent clay consistency	• Ensure the clay mixture has a uniform texture. • Ensure no impurities (like jute, rubber, grass, roots) are mixed in the clay.
	Worn or misaligned dies	• Inspect and replace worn or damaged parts. • Regularly maintain the auger.
Problems in rollers		
Roller wear and tear	Rock materials in clay	• Remove the rock materials with a screener. • Regularly inspect the roller's condition and weld it, if necessary. • Use high-grade steel rollers.
Roller jam	Use of moist clay and rock materials in clay	• Check the moisture level of clay. • Remove the rock materials with a screener.
Problems in conveyors		
Conveyor jam	Heavy flow of raw material	• Maintain a steady flow of clay on the conveyor. • Regularly inspect the flow of raw materials on the conveyor.
Misalignment	Faulty installation of conveyor's or roller's position or heavy flow of raw material	• Check the alignment during installation. • Maintain a steady flow of clay on the conveyor.

Table 13: Problems related to clay column

Issue	***Cause***	***Solution***
Issues with the clay column		
Dragon teeth at corners of clay columns (Fig. 54)	• Uneven moisture distribution or air pockets in the clay mixture. • Worn-out or damaged extrusion die or nozzle. • Variation in plasticity due to improper mixing in the double shaft mixture.	• Properly mix in the double shaft mixture with right amount of moisture level. • Check the condition of the mouthpiece.
Bent clay column (Fig. 55)	• Misaligned transport table • Stress from extruder and pressure head	• Adjust the height of the table according to the height of the mouthpiece.

Figure 54: Dragon teeth in clay column

Figure 55: Clay column bent due to incorrectly positioned transport table

Figure 56: Clay column bent due to stress in the extruder and pressure head

Figure 57: Round-bodied green brick

Bent clay column sideways (Fig. 56)		• Produce a stiffer clay column. • Provide a concave die (dished).
Rounded green brick (Fig. 57)	• Insufficient compaction and high moisture content	• Adjust the compactness. • Adjust the moisture level.
Cracking or breaking		
Bricks crack or break during or after extrusion	• Insufficient moisture content	• Adjust clay moisture levels. • Reduce the extrusion speed.
Drying issues		
Uneven drying of bricks	• Inadequate drying time	• Increase the drying time.
	• Inconsistent drying conditions	• Ensure proper air circulation and temperature control.
Cracks appearing during drying	• Rapid drying	• Slow down the drying process.
Uneven moisture distribution	• Insufficient moisture content	• Ensure uniform moisture content in the clay mixture.

12

OCCUPATIONAL HEALTH AND SAFETY

- Observe all safety instructions and warnings on the machine or plant.
- Use prescribed Occupational Health and Safety (OHS) equipment as required by circumstances or as mandated by legal regulations.
- Only use the machine or plant when it is in a technically perfect condition, maintaining constant awareness of safety concerns and potential risks.
- Promptly rectify any malfunctions that compromise machine safety.
- Do not wear jewellery, including rings, while operating machinery.
- Ensure that garments are close fitting and long hair is tied back. Prohibit workers from wearing loose dresses, like *saree* or *kurta*, in the machine room to avoid injuries due to, for example, parts of clothes, hair, etc being caught up by or pulled into the machine.
- If any alterations have been made to the machine or plant that are relevant to safety or changes to its operational behaviour that raise safety concerns, halt the machine or plant operation without delay and promptly report the issue to the appropriate maintenance authority or personnel.
- Do not make any modifications, additions or conversions to the machine or plant that may impair safety without the presence of experts and technical advice.
- Allow only skilled personnel to perform adjustments, servicing and inspections.
- Switch off the machine or plant before any type of repair and maintenance work, and secure it to prevent its being switched back on unexpectedly.
- Lock the principal control room; remove keys and/or attach a warning sign to the main switch.
- Familiarize the team with emergency shutdown procedures and safety protocols in case of accidents or malfunctions.
- Avoid performing maintenance work alone; ensure that a team or at least one helper is present during maintenance.
- Install CCTV cameras on the premises for safety and security.

13

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