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DESIGN AND RESEARCH OF ELECTRIC BRICK CONVEYING TROLLEY IN UNFIRED BRICK FACTORY

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ABSTRACT

Under the background of building energy saving society, unfired bricks emerge as the time requires. The unfired bricks need to be conveyed to the maintenance site after being pressed and moulded, a lot conveying equipment in unfired brick factory especially small brick kilns at present are still unsteady and inefficient. In order to improve the production efficiency and conveying efficiency, the scheme of electric brick conveying trolley is put forward. This paper is centered on the design of electric brick conveying trolley. Firstly, the shortcomings of existing brick conveying equipment and the areas needing improvement are expounded, the main research contents and the main structure scheme are put forward. Secondly, specific design is carried out including structure design of main frame and loading carriage, calculation and selection of lifting system including motor, reducer and chain, calculation and selection of driving system including motor and chain, selection and design of steering system and braking system. Finally, finite element analysis(FEA) of bearing components is carried out and the design is summarized. The electric brick conveying trolley designed in this paper has the advantages of energy saving, environmental protection, high conveying efficiency and simple operation. It has broad application prospects in the future

KEYWORDS

Unfired brick, Brick conveying trolley, Electric drive, FEA

INTRODUCTION

There are approximately 80,000 brick kilns in China. It was estimated that China produced 340 billion bricks in 2012[1]. Over the past 30 years, great changes have taken place to the development of green building materials. Under the background that the Chinese government strongly encourages the development of new building materials for energy conservation, environmental protection and waste utilization [2], unfired bricks appear which use fly ash, cinder, coal gangue, tailings, chemical slag or natural sand, coastal mud (one or more of the above raw materials [3-7]) as the main raw materials without high-temperature calcination. It is mainly made of industrial waste residue and other materials. It does not need sintering in the manufacturing process and meet the use requirements only by curing at room temperature. It is very environmentally friendly building material, meanwhile the performance of unfired brick is

excellent: light weight, high strength and good heat and sound insulation performance.

After being pressed and formed by the unfired brick machine, the unfired brick needs to be cured to meet the use requirements in plant conveying. At present, there are still many small and medium-sized brick plants, which have different types of brick conveying equipment, including handcart, truck, forklift and so on [8-9]. Some uncontrollable factors such as vibration of these equipment during conveying will greatly affect the quality of unfired bricks. These brick conveying equipments have the disadvantages of time-consuming, laborious, high labor intensity, low conveying efficiency, low automation level and high brick crushing rate [10-11]. These disadvantages greatly limit the production efficiency and affect the quality to a great extent. The manufactured products have rough process and poor performance. It is in urgent need of adjustment and innovation.

Up to now, many brick making factories are already running with high level of mechanization and automation for proportioning, mixing, pressing and forming [12-13], in plant transportation, normal temperature maintenance and stacking. As to the conveying equipment, automatic stacking and conveying system has been used to transport non-cured or cured unfired bricks. The system is controlled by programmable logic controller, frequency converter and so on with stable startup process, fast transportation speed and high production efficiency [14]. There are also shortcomings as to the high investment, large floor spaces and complicate devices and software which are far beyond ability of small brick making plants.

Therefore, according to the special situation of China's unfired brick making industry, a new type of brick conveying equipment need to be developed for small and medium-sized brick plants to improve the conveying efficiency of unfired bricks. According to the design in this article, the energy is supplied by the storage battery. The principle of the brick conveying car effectively combines the work of forklift and stacking machinery [15]. It adopts the design of special loading carriage, so as to reducing conveying vibration and noise, brick making cost and workers' labor intensity, improving producing efficiency and product quality and saving energy. At the same time, it also responds to the call of national energy conservation and environmental protection.

OVERALL STRUCTURE DESIGN

Vehicle layout and design parameters

The electric brick conveying trolley adopts electric driving mode and three-wheel form. The rear single wheel is the driving wheel and the steering wheel, and the front two wheels are respectively fixed on the frame. The loading carriage is placed in the main frame at the front of the vehicle, the driver's seat is in the middle and upper part of the vehicle, the battery and lifting motor are in the middle and lower part of the vehicle, and the rear of the vehicle is the driving wheel and driving motor. The driver's position in the middle and upper part can make it easier for the driver to observe the loading of unfired bricks and road conditions, so as to facilitate the driver's control of the vehicle. The loading carriage is electrically driven and lifted by the lifting chain driven by the lifting mechanism. The steering mechanism adopts mechanical steering mode and the braking mode adopts front wheel belt braking. The energy supply device of the brick conveying trolley is a battery pack.

The main technical parameters of the brick conveying trolley are shown in Table 1.

Tab. 1: Main technical parameters

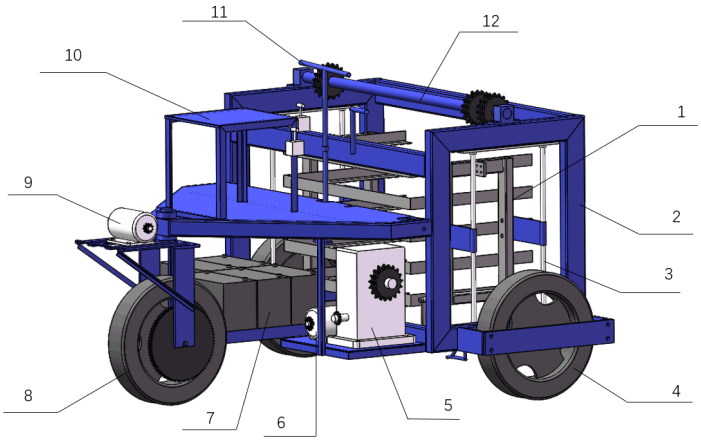
Technical indicators	Values and units
equipment weight	700kg
Loading weight	800kg
External dimension	≤2000×1900×1300mm
Battery	Capacity-140ah，more than 5 batteries
Loading capacity	Standard brick 6 plates
Lifting speed	0.2m/s
Vehicle speed	2m/s
Standard brick size	240×115×53mm

Overall design scheme

The main frame is a frame structure, which is mainly welded and connected by steel plate, welded square pipe and angle steel. The frame structure is used to place the loading carriage. A limit rod needs to be designed on the loading carriage to limit the shaking of the loading carriage. An intermediate shaft needs to be set on the upper part of the frame to transmit the torque output by the reducer to realize the lifting of the loading carriage.

The loading carriage is divided into two parts: the main body of the loading carriage and the hinged support plates on both sides of the bottom layer. The loading carriage is welded by rectangular pipe and angle steel, and the front-end opening is designed to facilitate loading and unloading of unburned bricks. The bottom support plate and the main body of the loading carriage are hinged, so that when the unfired bricks are unloaded, the bottom support plate can be opened to both sides, and the lower unfired bricks can support the upper unfired brick support plate, so as to enable the brick conveying trolley to unload the unfired bricks smoothly. The lifting chain is firmly connected with the loading carriage by bolts.

The lifting mechanism is mainly composed of motor, reducer, transmission chain, intermediate shaft and lifting chain, which is controlled by forward and reverse switch and speed regulating handle. The driving mechanism is composed of reduction motor, sprocket, chain and wheel. These components are fixed in the rigid structure. The rigid structure is hinged with the steering handle by pull rod. The driver rotates the handle to control the steering wheel to realize vehicle turning. Considering that the design speed of the brick transport trolley is low and the required braking torque is small, and the brake requirements are low, the manual braking mode is adopted. The brake lever and the brake pedal are connected together by pull rod and hinged to realize the driver's control over the vehicle speed. The overall structural layout is as shown in Figure 1.



1- Loading carriage, 2- Main frame, 3- Limit lever,4- front wheel,5-decelerator,6-motor for Lifting,7-battery,
8-steering wheel, 9-drive motor, 10- Driver's seat, 11- Steering handle, 12- Intermediate shaft
Fig.1 - General layout of brick conveying trolley

Maintenance and use requirements

Before using the electric brick conveying trolley, the battery needs to be fully charged to meet the needs of one day. Do not use the battery until it is completely dead before charging. Long term wrong use of the battery will shorten its service life, reduce its capacity and shorten its working time. When the trolley is placed in an open and dry place, the charger needs to be ventilated for recharging. In addition, in actual use, each chain needs to be lubricated regularly, and the lubrication cycle depends on the actual use.

When in use, it is necessary to turn on the main power switch manually. The steering handle in front of the driver is used for vehicle steering. The rotation direction of the steering handle is the same as that of the vehicle. The right front of the floor of the brick conveying trolley is the vehicle brake pedal, which is used by the driver to control the vehicle brake. The forward and reverse switch on the right side of the driver's seat controls the forward and reverse rotation of the drive motor. The handle on the right side of the steering handle is used to adjust the speed of the drive motor. When the brick cart needs to travel, the driver needs to confirm the handle position of the forward and reverse switch. The forward and reverse switch at the front left of the steering handle is used to control the forward and reverse rotation of the lifting motor, and the fixed speed regulating handle at the front right is used to control the speed regulation of the lifting motor. During the loading of unburned bricks, the loading carriage needs to be lowered to a suitable position. The driving direction of the brick transport trolley must be parallel to the direction of the sidelines on both sides of the unburned brick support plate, and the unburned brick position needs to be located in the middle of the brick transport trolley. The driving position can be determined with the help of external references. When unloading the unburned bricks, a relatively flat ground shall be selected to ensure that the unburned bricks will not dump after being unloaded, resulting in unnecessary losses. The physical drawing of the whole vehicle is as shown in Figure 2.

Fig. 2 - Physical drawing of the whole vehicle

In actual use, it is necessary to properly protect key parts such as battery and motor to prevent damage caused by sundries such as rain. In this design, a thermal relay is set in the circuit to protect the motor. However, in actual use, if sundries jam the chain, resulting in abnormal noise or failure to work, the driver needs to cut off the main circuit switch to repair the vehicle, so as to ensure that it can be used again after troubleshooting.

DESIGN AND CALCULATION OF KEY COMPONENTS

Design and calculation of loading carriage

The loading carriage is very important in the design of the brick conveying trolley, because it directly supports the unfired brick support plate. The structural design of the loading carriage will greatly affect the quality of the unfired brick. In the process of pressing and forming the unfired brick, the mixed raw materials are loaded into the mold and pressed on the unfired brick support plate by the unfired brick machine, Then, the palletizing device is used for palletizing [16-17]. After palletizing, there is no gap between each plate of unfired bricks. If only the lowest supporting plate is lifted for conveying, the vibration and extrusion during conveying will greatly affect the quality of unfired bricks and increase the brick crushing rate.

The loading carriage in this design is mainly composed of the main carriage on the fifth floor and the hinged support plates on both sides of the sixth floor, as is as shown in Figure 3 and Figure 4. The hinge mode is adopted so that when the unfired brick is removed, the support plate at the lowest layer can be opened to both sides through the action of the limit device, as is shown in Figure 5. In this way, the loading carriage can continue to descend, so that the lower layer of unfired bricks supports the upper layer of unfired bricks. When the top layer of unfired bricks is completely pressed on the next layer of non-fired brick, the support plates on both sides of the loading carriage are completely separated from the unfired brick support plate, which is no longer effective. Then driving the brick conveying trolley backward will meet the requirements of easy loading and unloading, time-saving and labor-saving [18-21]. The unfired bricks are stacked automatically when they are unloaded.

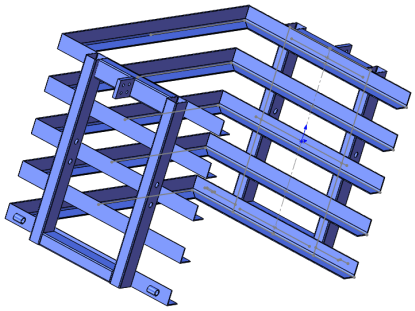


Fig. 3 - Loading carriage body

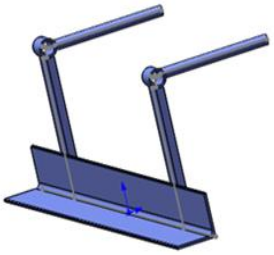


Fig. 4 - Hinged support plate

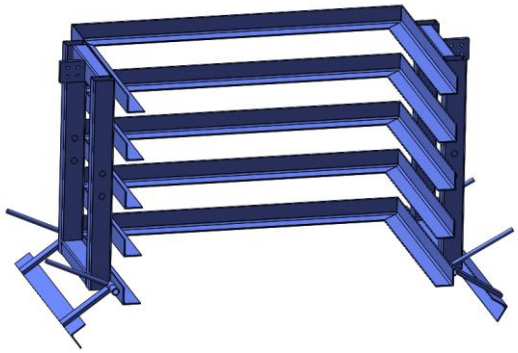


Fig. 5 - Overall loading carriage

In this design, the loading carriage adopts a U-shaped structure with a front-end opening welded by stainless steel welded square pipe and angle steel, and the front-end opening design is used to facilitate the loading or unloading of unburned bricks. Support plates are set on both sides of the loading carriage to support the unfired brick support plate, and the distance between each two layers of support plates is greater than the height of unburned bricks placed on the pallet, so that there is a gap between each two layers of unfired bricks, so as to avoid squashing of unfired bricks.

The internal dimension of the loading carriage is determined by the size of unburned brick, the thickness of unburned brick support plate and the loading capacity. The brick transport trolley mainly transports the ninth five-year plan standard bricks, and the standard brick size is

240X115X53mm. The supporting plate adopts the size of 900, which is mostly used in brick factories at present 900X600X35mm PVC supporting plate, the supporting plate is placed horizontally, and the loading capacity is 6 plates. The support plate of the upper five layers is fixed by stainless steel welded square pipe, and the connection method is welding. The support plate of the sixth layer is hinged with the upper five layers for loading and unloading. The upper part of the loading carriage is welded with two pieces, with a length of 180mm and a specification of 100 × 7 flat steel plate. The flat steel plate is firmly connected with the lifting chain by bolts to realize the lifting action of the loading carriage.

Holes are arranged on the stainless steel welded square tubes on both sides to install the limit device of the loading carriage, and the limit rod is arranged on the main frame to reduce the horizontal vibration of the loading carriage and only produce the movement in the vertical direction relative to the main frame. This design uses the unique structure of angle steel as the support plate. Each layer of non-fired bricks in the loading carriage is supported by angle steel. The gap between each layer of non-fired bricks in the upper five layers is set as 20mm, and the gap between the sixth layer and the upper layer is set as 30mm. The specification of angle steel is L50X50X3mm. The specification of stainless steel welded square pipe is 40X60X2.0mm. Then the internal length of the loading carriage is 600+ 30=630mm and the width is 900+2X15=930mm. The external dimension is 633mm length, 1096mm width and 818mm height.

Design and calculation of main frame

At present, all vehicles with load-bearing body have a frame as the frame of the whole vehicle. Most parts and assemblies of the vehicle are fixed on the frame through various connection methods, including engine, body panel, transmission and steering system, passenger seat and other related parts. The frame plays a role of fixing and supporting these components and assemblies, and it bears the effects of various forces inside and outside the vehicle.

We shall design the structural form of the main frame according to the layout position, installation form and use requirements of various parts of the vehicle. During the operation of the vehicle, the change of loading or road conditions may lead to the deformation of the frame. The deformation of the frame may affect the normal operation of various components or affect the driving safety of the vehicle. Therefore, in order to overcome these frame deformations that are not conducive to the normal operation of the vehicle, we need to ensure that the stiffness and strength of the frame meet the use requirements. At the same time, in order to improve the overall lightweight level of the vehicle and save energy, the frame mass should be as small as possible.

On various special vehicles, various special devices are also directly or indirectly installed on the vehicle chassis frame (hereinafter referred to as the main frame). The main frame is also the main bearing component of special devices on special vehicles [22]. In this design, we directly or indirectly install the lifting mechanism, loading carriage, battery pack and driving mechanism on the frame, and the frame is the main bearing component. At the same time, it also fixes the vehicle steering system, driver's seat, braking system and other relevant operating mechanisms, as is shown in Figure 6, which ensures the stability and steering flexibility of the

vehicle when driving.

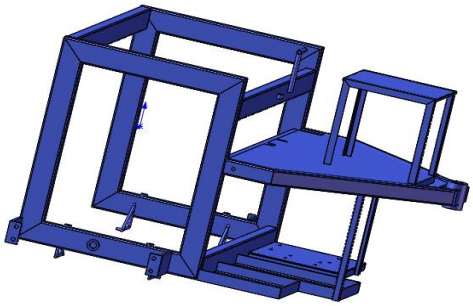


Fig - 6 Main frame structure

Stainless steel welded square pipe is widely used in various construction machinery because of its unique advantages: when the weight of components is equal, stainless steel welded square pipe has better torsion and flexural strength; And it has many specifications and models, which can provide users with a variety of choices. Angle steel can form various stress components of different shapes and sizes with various structural steels according to the actual required structures. It can also be used as a rigid connecting part between components. It also has good weldability, elastic deformation capacity and stiffness strength in practical use. Therefore, angle steel is widely used in various mechanical components and building structures. Therefore, the main frame of the special brick transport trolley is mainly welded by stainless steel welded square pipe, angle steel and steel plate.

The main frame is made of stainless steel welded square tubes with a specification of 50X100X3mm. Angle steel specification: L50X50X3mm. The main frame at the front end of the vehicle is in a frame structure to place the loading carriage and play a supporting role, and there is no cross beam under the front end of the vehicle to facilitate the loading and unloading of bricks without burning. A frame and platform structure welded by angle steel and steel plate are arranged below the middle of the frame to place the battery pack, lifting motor and reducer. The driver's seat and vehicle control device are equipped above the middle so that the driver can better observe and control the vehicle. The rear steering wheel and drive motor of the vehicle are fixed in the rigid structure and connected with the main frame through tapered roller bearings.

The height of the main frame mainly depends on the full load height and lifting distance of the loading carriage. According to the design of the above loading carriage, the full load height of the loading carriage is 818mm. The lifting distance depends on the distance between each layer of unburned bricks and the upper layer in the loading carriage and the ground height of the lowest layer of unburned bricks during full load transportation. It is designed from the above: the distance between each of the upper 5 plates is 20mm, and the distance between the sixth plate and the upper plate is 30mm. During full load transportation, in order to make the brick conveying trolley has certain trafficability, the distance between the lowest supporting plate and the ground is tentatively determined as 200mm. So the frame height is 950mm. The width of the frame mainly depends on the width of the loading carriage. The width of the loading carriage designed by the loading carriage is 1096mm, and the working space for lifting chain and transmission chain is reserved, the external width of the main frame is 1472mm. The distance between the

middle floor of the vehicle and the lower cross beam is determined by the size of the reducer, taking 500mm. The driver's seat is fixed on the floor in the middle of the vehicle. The seat is 400mm high, 400mm long and 400mm wide. The horizontal distance between the front end of the seat and the upper cross beam is set as 300mm as the driver's operation space.

Design and calculation of storage battery

Electric vehicles have become the inevitable direction of the future development of the automotive industry, which depends on the unique advantages of zero emission of electric vehicles. The driving energy of electric vehicles mainly comes from electric energy storage devices such as rechargeable batteries or super capacitors loaded on the vehicle. This energy supply mode determines the advantage that electric vehicles do not emit any harmful gases and particles into the atmosphere. At the same time, the electric energy of the power plant comes from the capture of various natural energy sources, such as coal, nuclear energy, tidal energy, wind energy, light energy, heat energy, etc. even if the power plant uses coal as fuel to obtain electric energy, it can still have relatively higher efficiency, which means that using electric energy can save limited oil resources. In addition, the brick truck driven by diesel engine brings inevitable vibration transmitted to the main frame, which will greatly increase the brick breaking rate. Therefore, using battery as energy supply device is the best energy supply scheme for brick truck. Under the background of the depletion of oil resources and the state's strong support for the development of electric vehicles, the electric vehicle industry has developed rapidly, and the battery industry has also developed rapidly. The developing power sources mainly include sodium sulfur battery, nickel hydrogen battery, nickel cadmium battery, lithium battery, fuel cell, flywheel battery, etc. The research and rapid development of power battery has laid a solid power foundation for the development of pure electric vehicles. In contrast, the development of lead-acid battery has a history of more than 100 years [23]. So far, the technology of lead-acid battery has become mature after continuous development and improvement.

Nowadays, lead-acid battery is the most widely used in the automotive industry, because it has been developed for many years and has a separate power battery type. This battery has the advantages of large instantaneous discharge current and can discharge at a large current all the time. Compared with the other types of power batteries, it has mature technology, stable discharge voltage and reliable performance [24], It allows deep discharge, can be recycled, and can be used in a wide temperature range. In practical use, the use requirements are low and the maintenance method is simple. In actual production, it can be mass produced with low production cost, simple structure, low price and higher cost performance.

Therefore, under the comparison of these batteries, lead-acid battery is the best choice for the energy supply device of brick conveying trolley. According to the requirements of the project, the capacity is 140ah. It is proposed to select 5 lead-acid batteries with rated voltage of 12V and capacity of 140ah. The size of the battery is 360 × one hundred and seventy-two × 253, each weighing 30kg.

Design and calculation of lifting system

The design adopts the scheme of chain drive lifting. The chain drive is not easy to slip, the transmission is more accurate, reliable, high transmission efficiency, and can adapt to the harsh environment of humidity, high temperature and dust. The lifting system is a special lifting device designed for the actual use requirements of the brick transport car. The lifting motor is driven by the battery to convert the electric energy into mechanical energy. The speed reducer is decelerated and the loading carriage loaded with unburned bricks is lifted through chain drive. The transmission diagram of lifting system is as shown in Figure 7. The flowchart of lifting system design process is as shown in Figure 8. According to the main frame design, the lifting motor and worm gear reducer are fixed on the frame structure or platform under the middle of the vehicle, and the connection method is bolt fastening connection. The lifting motor drives the input shaft of the worm gear reducer to rotate through the chain drive. After the worm gear reducer reduces the speed and increases the torque, the intermediate shaft placed above the main frame is driven to rotate through the transmission chain. The sprocket used for the transmission chain and the lifting chain are fixed on the intermediate shaft to make the lifting chain move, to realize the lifting or lowering action of the loading carriage.

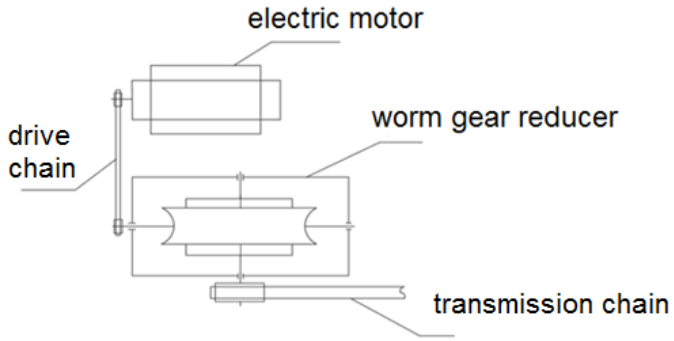


Fig. 7 - Lifting system transmission diagram

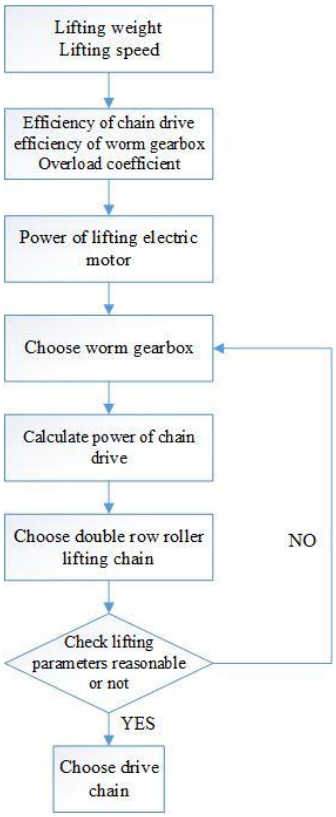


Fig. 8 - Flowchart of Lifting system design process

According to the design requirements, the lifting mass is 800kg. According to the mechanical design manual, the chain transmission efficiency is 0.96, the transmission efficiency of worm gear reducer is 0.9, and the overload coefficient is tentatively 1.3.

$$P = FV = 1600\text{W} \quad (1)$$

$$P_N = 1.3P/0.96/0.9 = 2407\text{W} \quad (2)$$

In the formula, gravity of the lifted unburned brick F is set as 8000N. The lifting speed V is set as 0.2m/s according to the design requirements.

It is proposed to select the lifting motor with the power of 2500W and the rated voltage of 60V according to the requirements of the subject. Subject to the requirements of the reducer reduction ratio, size and lifting speed, the DC series excitation reduction motor with horizontal foot installation, self-cooling, rated voltage of 60V and rated power of 2500W is finally selected as the lifting motor, and the motor reduction ratio is 5:1, The rated speed of the motor is 3000r / min, the output speed is 600r / min, the rated torque of the motor is 9.2N • m, and the output torque is 46N • m.

Reducer is often used in various power transmission systems. The main types include gear reducer, worm reducer, gear worm reducer and planetary gear reducer. These types of reducers have their own characteristics. Among them, gear reducers are most widely used because of their high transmission efficiency. Single-stage gear reducers are mainly used in occasions where the transmission ratio is less than 8. Simultaneous interpreting of the two-stage gear reducer can be divided into expansion, shunt and coaxial. The overall size of the single stage

gear reducer is smaller than that of the same gear ratio, but there are some disadvantages such as uneven load distribution and uneven bearing capacity.

The reduction ratio of single-stage worm reducer is generally suitable for occasions with a reduction ratio of 10 ~ 70, and its input and output shafts can be distributed at right angles, which can change the direction and height of power transmission. Its main feature is that the input and output shafts have a variety of layout forms, and can only transmit power in one direction, and self-locking will be realized in the reverse direction. The reduction ratio of gear worm reducer is generally not less than 35, and its principle is equivalent to two-stage reduction of gear reduction and worm reduction. It has two layout forms: worm drive at the high-speed stage and gear drive at the high-speed stage. Both have unique advantages: the latter has compact structure, small overall size, the former has high efficiency and less energy loss. Compared with the above reducers, planetary gear reducer is famous for its small volume, high precision, high transmission efficiency and wide speed regulation range. Therefore, it is widely used in all kinds of motor transmission systems.

According to the actual use requirements in the design, the electric brick transport trolley plans to select a 25:1 worm reducer. According to the output speed of the lifting motor of 600r / min, the output speed of the reducer is 24r / min. If the number of custom sprocket teeth is the same, z = 17, according to the formula as below.

$$P_C = \frac{K_A P}{k_z k_p} \leq P_0 \tag{3}$$

In the formula, P_C means calculated power of chain drive, P_0 means rated power, *P* means nominal transmission power, the power of lifting motor is set as 2500W, K_A means working condition coefficient, it is set as 1.3 from table 2, k_Z means small sprocket number factor, it is set as 0.887 from table 3, k_p means row number coefficient, it is set as 1.7 from table 4.

From the calculation, we get $P_0 \geq 2155W$, together with $n_1 = 24r/\min$, By look-up table ,16A type double row roller chain is chosen as transmission chain and lifting chain. The lubrication method is manual periodic lubrication.

Tab. 2 - Working condition coefficient

Load type	Working machine	Power machine		
		internal-combustion engine Hydraulic transmission	Electric motor or steam turbine	internal-combustion engine mechanical drive
Steady load	Liquid mixer, Medium and small centrifugal blower, Light conveyor, centrifugal pump	1.0	1.0	1.2
Medium load	Medium cranes and hoists, agricultural machinery, Food machinery, grinder	1.2	1.3	1.4
Large impact	construction machinery, Mining machinery, Forging machinery, Punch, Shearing machine, Vibrating machinery	1.4	1.5	1.7

Tab. 3 - Small sprocket number factor

Z	9	11	13	15	17	19	21	23	25
K_z	0.446	0.554	0.664	0.775	0.887	1.00	1.11	1.23	1.34

Tab. 4 - Multi row chain coefficient

Row number	1	2	3	4	5	6
K_P	1	1.7	2.5	3.3	4.0	4.6

$$\mathrm{d} = \frac{P}{\sin(180°/z)} \tag{4}$$

In the formula, P means Selected roller chain pitch, it is set as 25.4mm, Z means number of teeth of sprocket, it is set as 17.

From the calculation, we can get sprocket indexing circle diameter $d = 138mm$, perimeter of dividing circle is 434mm, number of sprocket teeth is the same, the intermediate shaft speed is $24r/\min$.

Lifting speed $V = 0.434\text{m} \times 24\text{r/min} = 0.1736\text{m/s}$.

Torque check:

$$T_1 = 46 \times 25/ \ (0.138/2) = 14417\text{N} \tag{5}$$

$$T_2 = 14417 \times 0.9 \times 0.96 = 12456\text{N} > 8000\text{N} \tag{6}$$

Then the reduction ratio of lifting motor and worm gear reducer meets the requirements. The model of worm gear reducer is determined as WPA-120-1/25-A according to the input shaft power, reduction ratio, input and output shaft position. The reducer base is 320mm long and 230mm wide, the whole machine is 430mm high, the input shaft diameter is 30mm, the length is 65mm, and the keyway size is 8 X 4； The diameter of output shaft is 45mm, the length is 85mm, and the size of keyway is 14 X5.5.

The lifting motor drives the worm reducer through chain drive. The selection of this drive chain is based on the following formula:

$$P_C = \frac{K_A P}{k_z k_p} \leq P_0 \tag{7}$$

In the formula, P_C means calculated power of chain drive, P_0 means rated power, *P* means nominal transmission power, the power of lifting motor is set as 2500W, K_A means working condition coefficient, it is set as 1.0 from table 2, k_Z means small sprocket number factor, it is set as 0.775 from table 3, k_p means row number coefficient, it is set as 1.0 from table 4.

From the calculation, we get $P_0 \geq 3266W$, together with $n_1 = 24r/\min$, By look-up table ,08A type single row roller chain is chosen as transmission chain. The lifting motor is used as the power source to drive the operation of the worm gear reducer.

According to the above calculation, the total mass of moving parts up and down $m = 880kg$, Rated power of lifting motor $P = 2500W$, Output speed $n = 600r/\min$, Reduction ratio of worm reducer $i = 25$, Efficiency of worm gear reducer $\eta = 0.9$, Number of sprocket teeth $z = 17$, Sprocket ratio $i = 1$, Double row chain type number 16A, Check the mechanical design manual for chain minimum tensile strength $F = 111.2KN$, pitch $p = 25.4mm$.

Average speed of sprocket $n = 24r/\min$, The average speed of the chain is according to the following formula:

$$\text{V} = \frac{Pzn}{60} \times 10^{-3} = 0.17m/s \tag{8}$$

In the formula, P means Chain pitch, z means number of sprocket teeth, n means average speed of sprocket.

The tension of chain tight edge is according to the following formula:

$$F_t = \frac{P\eta}{V} = 13235.3N \quad (9)$$

In the formula, P means Lifting motor power, η means transmission efficiency of worm gear reducer, V means average chain speed.

Chain speed $V = 0.6m/s$, it is low speed chain drive, The main failure form is the static tension fracture of the chain, so it is calculated according to the static tension strength and the safety factor S is checked.

$$S = \frac{F_u}{K_A F_t} = 6.46 \geq [S] \quad (10)$$

In the formula, minimum tensile strength of chain $F_u = 111.2KN$, tight edge tension of chain drive $F_t = 13235.3N$, Working condition coefficient $K_a = 1.3$, refer to the mechanical design manual, allowable value of chain static strength safety factor $[s] = 4-8$, tension on Chain $F_a = 8800\,N$.

The safety factor of static tension is based on the following formula:

$$S_T = \frac{F_u}{K_A F_a} = 9.7 \geq [S] \quad (11)$$

According to the above check calculation, the strength of the selected 16A double row roller chain meets the requirements.

In order to realize the lifting or lowering action of the loading carriage, the switch, speed control handle and motor controller should be installed in the circuit. In the process of working, the failure of the lifting device of the brick carriage may cause the motor to be blocked and damaged. The protection measures for the motor are to set the thermal relay in the circuit. The control of the forward and reverse switch can realize the positive and negative rotation of the motor, so as to lift or lower the loading carriage.

Design and calculation of driving system

The drive system of electric vehicle plays the role of effectively connecting the power storage system and the driving wheel and converting the form of energy. Since the brick conveying car adopts battery power supply, it needs to be driven by motor. There are three types of transmission after the motor generates power: belt transmission, transmission chain transmission and transmission shaft transmission. Belt transmission relies on the friction between belt and pulley for power transmission. In contrast, belt transmission has the lowest cost and is very simple to install and maintain, but the belt must be tensioned during transmission. Otherwise, it is easy to slip and affect the transmission effect. The transmission shaft has high transmission efficiency, stable and reliable performance and large power transmission. It is mostly used in heavy-duty vehicles, but there are installation angle requirements in practical use.

Chain transmission is widely used. The same transmission efficiency is high, maintenance is simple, transmission is more accurate, and can adapt to humid, dusty and other harsh service environments. Due to the limitation of installation space and cost, the way of chain transmission is selected in this subject. The driving system uses battery power to drive the motor to generate power, and the power is transmitted to the driving wheel by chain transmission and deceleration to drive the vehicle.

The maximum total mass of the whole vehicle is 1500kg (sum of equipment weight and loading weight), the friction coefficient of most brick factory pavement is taken as 0.025[25], The design speed is 2m/s. According to the design requirements and mechanical design manual, the chain transmission efficiency is set as 0.96, overload factor is set as 1.5.

$$\mathrm{F} = \mu \mathrm{mg} = 375\mathrm{N} \tag{12}$$

$$\mathrm{P} = \mathrm{FV} = 750\mathrm{w} \tag{13}$$

$$P_N = 750 \times \frac{1.5}{0.96} = 1172\mathrm{w} \tag{14}$$

The motor power is bigger than P_N, A DC series excitation reduction motor with self- cooling is chosen and the horizontal foot is installed. Rated voltage is 60V, Rated power is 1300W, reduction ratio is 5.2:1, rated speed of the motor is $3200\,r/\min$, Output speed is $625\,r/\min$, Rated torque is $3.8N \cdot m$, Output torque $19.76N \cdot m$.The flowchart of driving system design process is as shown in Figure 9.

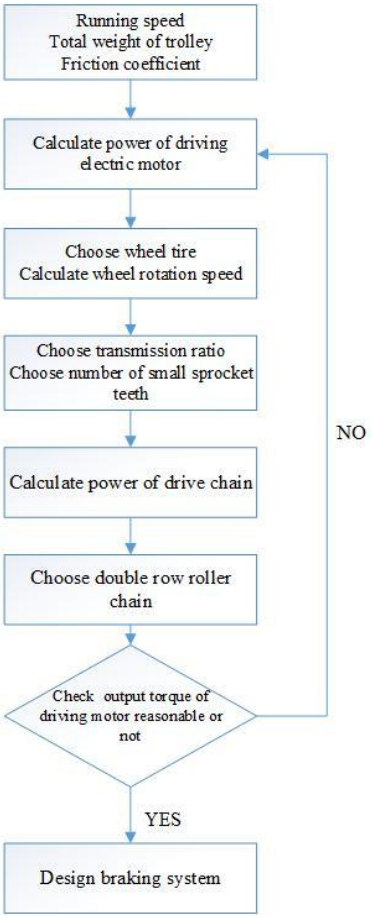


Fig. 9 - Flowchart of driving system design process

The driving motor of the brick transport trolley drives the rear wheel through chain drive. According to the weight of the whole vehicle and referring to the road conditions of most brick factories, it is proposed to select 4.5 R12 radial steel wire tire, which has a section width of 114mm, a diameter of 545mm and a circumference of 1.7m. Tire pressure: 600kpa, normal use; Tire pressure 650kpa, rated load 0.8t; Tire pressure 700KPA, rated load 1.0T. According to the design speed $2m/s$, tire circumference 1.7m, Available wheel speed $1.18r/s = 70.59r/\min$, determine the transmission ratio $615/70.59 = 8.71$ according to the speed of the driving motor and the driving wheel, transmission ratio is set as 9, Set the number of pinion teeth as Z_1=9, so the number of teeth of large sprocket is Z_2=81, according to the formula:

$$P_C = \frac{K_A P}{k_z k_p} \le P_0 \tag{15}$$

In the formula, P_C means calculated power of chain drive, P_0 means rated power, *P* means nominal transmission power, the power of lifting motor is set as 2500W, K_A means working condition coefficient, it is set as 1.0 from table 2, k_Z means small sprocket number factor, it is set as 0.446 from table 3, k_p means row number coefficient, it is set as 1.7 from table 4.

From the calculation, we get $P_0 \ge 2229W$, together with $n_1 = 615r/\min$, By look-up table ,08A type double row roller chain is chosen as transmission chain with the pitch $p = 12.7mm$.

Diameter of indexing circle of two sprockets according to formula:

$$\mathrm{d} = \frac{P}{\sin(180°/z)} \tag{16}$$

From the calculation, we can get $d_1 = 37.1$, $d_2 = 325.6$, Torque check according to formula

$$T = \frac{FR}{i\eta} \tag{17}$$

The drive motor requires the least torque $T_1 = 11.83N \cdot m$, the rated torque of the drive motor is $T_2 = 19.76N \cdot m$, so the motor meets the requirements.

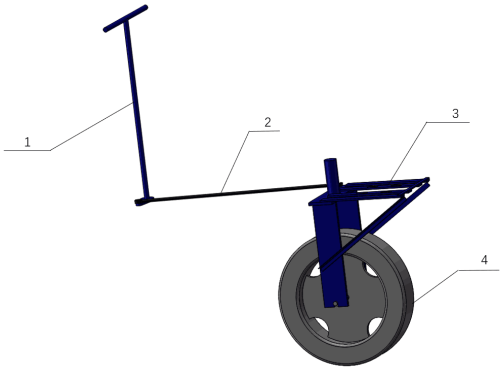
In order to realize the forward and backward of the brick conveying trolley, it is necessary to connect the reverse forward switch, speed regulating handle and motor controller in the driving circuit to control the forward and reverse rotation of the driving motor. Similarly, in order to prevent the motor from blocking and damaging the motor due to the failure of the transmission mechanism, it is also necessary to connect the thermal relay. All the chains used in the bricks

transportation car are shown in Figure 10.

Fig. 10 - All the chains used in the bricks transportation car

Design of steering system

In this design, the rear single wheel is the steering wheel, and the load is mainly in front of the vehicle. Considering the economic and simple and reliable practical requirements, the brick conveying trolley adopts mechanical steering [26]. The steering control device is directly hinged with the transmission device without a steering gear, that is, the rigid structure of the fixed steering wheel is hinged with the steering handle through the pull rod, so as to realize the driver's function of controlling the forward direction of the vehicle, as is shown in Figure 11. The steering handle and the shaft in the rigid structure of the steering are connected with the main frame through bearings. The mechanical steering system is simple and reliable, easy to maintain, and is more suitable for the service conditions of unfired brick plants.



1- Steering handle, 2 - Steering tie rod, 3- Steering rigid structure, 4- Steering wheel
Fig. - 11 Steering system schematic

Design of braking system

The belt brake is composed of a brake drum and a brake belt that can rub with the circumferential surface of the brake drum. When the vehicle needs braking, the brake belt is stretched and contracted to contact the brake drum to generate friction and produce braking

effect. It can be divided into simple belt brake, differential belt brake and comprehensive belt brake. These three types have simple and compact structure. The utility model has the advantages of easy loading, unloading and maintenance and large braking torque. However, its heat dissipation is poor, and the rotation direction of the brake drum will affect the braking force generated by the simple type and differential belt type, which limits its application range. Belt brakes are mostly used in occasions requiring compact structure [27]. The action diagram of integrated belt brake is shown in Figure 12.

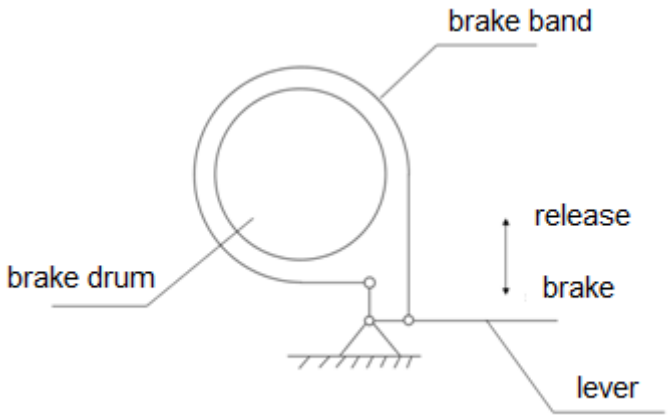


Fig. 12 - Working principle diagram of belt brake

In this design, the design speed of the brick conveying trolley is 2m/s, which belongs to low-speed operation and requires less braking force. Therefore, the requirements for the braking device are low and limited by the size of the installation space. In order to achieve the characteristics of energy conservation, environmental protection, durability and simple operation, this design selects the comprehensive belt brake and manual braking system. The brake lever in the integrated belt brake is hinged with the brake pedal through the pull rod, and the driver can control the braking of the vehicle through the pedal.

FINITE ELEMENT ANALYSIS OF BEARING PARTS

In order to check bearing capacity of the loading carriage and main frame, check the strength of the part, verify the structure design is reasonable or not, the deformation process is simulated and the parameters are obtained with the help of finite element analysis software ANSYS. The load curve of the loading carriage, the deformation process of main frame, the stress field, the strain field, and velocity field can be analyzed and summarized, through which the deformation principles can be known. The reaction force of the brick plates and loading carriage, the stress distribution of each part of main frame can be calculated.

Finite element analysis method

The basic steps of finite element problem solving can be divided into: firstly, the physical properties and solving region of the solving model are defined according to the actual problem.

Then the solution model is discretized, that is, the finite element mesh of the solution model is divided [28]. Obviously, the more detailed the mesh is, the closer the approximate solution of the discrete model is to the exact solution, and the more accurate the solution of the model is. At the same time, it brings the disadvantage of increasing the amount of calculation. Finite element mesh generation plays an extremely important role in finite element analysis. The next step is to determine the control method and state variables.

A physical problem to be solved can generally be expressed by a set of equations containing the boundary conditions of the state variables of the physical problem. Then, the element derivation is carried out, and an appropriate approximate solution is set for a certain element, that is, the formulation of the finite element is derived. Then, the final assembly solution, that is, all finite element final assembly forms the total matrix joint equations of the discrete model. The last step is to solve the simultaneous matrix equations and explain the results.

Finite element analysis can be divided into three basic stages: pre-processing, General Assembly solution and post-processing. The pre-processing is to establish the solution model and mesh it. The post-processing is to collect the solution and analyze and evaluate it, so that users can easily extract the obtained information and understand the calculation results more intuitively.

Finite element analysis results

In the finite element analysis, it is necessary to select the materials of the main bearing components, import the assembled assembly into ANSYS, and then mesh the whole assembly. In this process, it is necessary to select the appropriate mesh size to ensure the accuracy of the analysis results. Then add loads and constraints to the assembly to ensure that the loads and constraints are added correctly, and then conduct finite element analysis of the assembly.

As follows, Table 5 shows the names of the materials selected for the structure, and Table 6 shows the load constraints imposed on the bearing structure and the properties of the table. Figure 13 is the schematic diagram of meshing, Figure 14 is the stress diagram in the analysis results.

Tab. 5: Selected material properties

Material name	Q345
Material density	7.85E+03kg/m³
Elastic modulus	2.06E+11N/m³
Poisson's ratio	0.280
yield strength	345Mpa

Tab. 6 - Loads, constraints and attributes

Load type	Force
Load value	8000N
Number of constraint faces	5

Grid size	20mm
Number of grids	72429

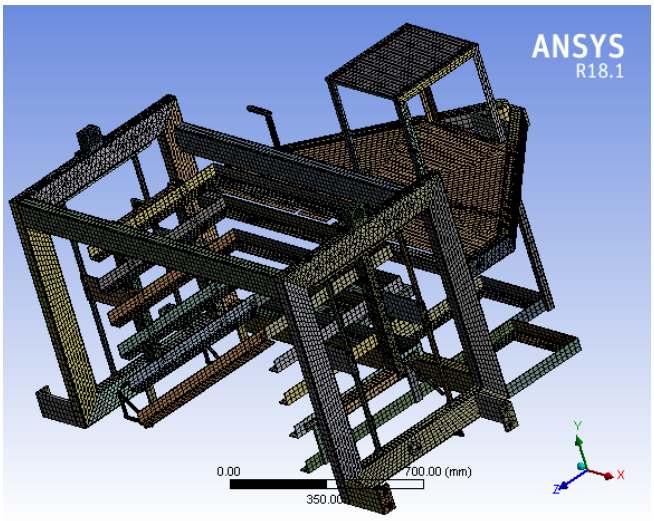


Fig. 13 - Meshing of the loading carriage

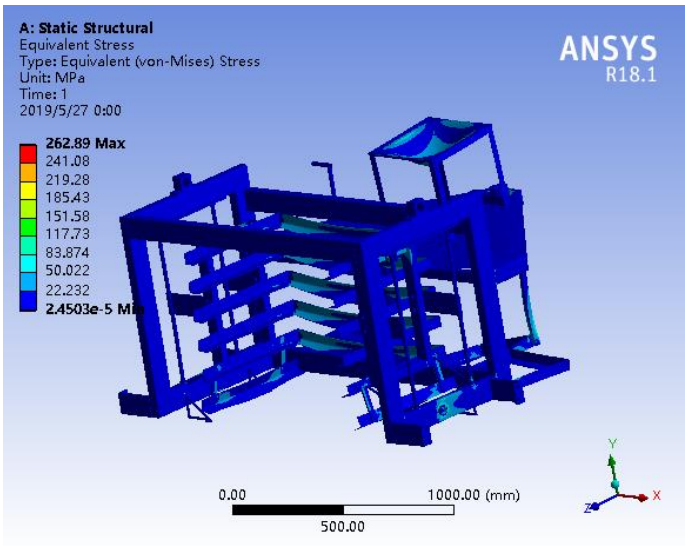


Fig. 14 - Stress contour of the loading carriage

The finite element analysis results show that the deformation and stress of the support beam of the loading car are large, max stress 241.08MPa, meet design requirements.

CONCLUSION

The designed brick conveying trolley is fully electric. The power consumption is as low as 5-7 KW·h. It takes 8-10 hours to get the battery full charge. There is a gap between the upper and lower layers when conveying bricks, the vibration amplitude is small. Therefore there will be few brick breaking problems. Loading capacity reaches 4-5 boards continuous working 14-16

hours after full charge. It reduces brick breaking rate and conveying cost than common diesel brick truck.

With the advantages of simple operation, little noise, energy saving and simple structure. One person can drive the trolley easily, which greatly reduces labor force, labor intensity and production cost, improves production efficiency and increases brick factory profit. It is an excellent ideal equipment for unfired brick factory which is suitable for various types of unfired brick types for integrating the work of the stacking machine and the forklift. It is suitable for different brick machines and brick plates of different sizes for users to choose. If there are brick machines and brick plates of special sizes, the factory only needs to change the loading carriage.

The characteristics of the brick conveying trolley are as follows:

(1) No damage to the quality of brick blank: the set of equipment automatically palletizes and lifts. During operation, each brick has a gap, which does not press, squeeze, lean or twist, and does not damage the brick.

(2) Green environmental protection: the trolley is driven by electric energy, without noise, vibration, oil pollution and carbon dioxide emission.

(3) Simple operation, The operation of brick conveying trolley has been simplified to the operation of the steering wheel, lever and button, and one person can complete the work task very easily.

(4) Stable power output, reliable performance and longer service life.

(5) Simple control system: it adopts continuously speed change, handle throttle control, brake power-off protection device.

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REFERENCES

[1] Chen, Y., Du, W., Zhuo, S., Liu, W., Liu, Y., Shen, G., Wu, S.,Li,J., Zhou,B., Wang,G., Zeng,E., Cheng,H., Liu,W., Tao,S., Stack and fugitive emissions of major air pollutants from typical brick kilns in China. Environmental Pollution 224(2017)421-429. http://dx.doi.org/10.1016/j.envpol.2017.02.022

[2] Zheng Juaner, Wu Cifang. Research on the current situation, potential and policy design of building energy conservation in China[J]. Chinese Soft Science, 2005(5): 64,76-80.

[3] Zhao,P., Zhang,X., Qin,L., Zhang,Y., Zhou,L., Conservation of disappearing traditional manufacturing process for Chinese grey brick: Field survey and laboratory study. Construction and Building Materials 212(2019)531-540.
https://doi.org/10.1016/j.conbuildmat.2019.03.317

[4] Ganzone,G., Frano,R., Sumini,M., Troiani,F., Dismantling of the graphite pile of Latina NPP: Characterization and handling/removal equipment for single brick or multi-bricks. Progress in Nuclear Energy 93(2016)146-154.

http://dx.doi.org/10.1016/j.pnucene.2016.08.010

[5] Taurino,R., Ferretti,D., Gattani,L., Bozzoli,F., Bondioli,F., Lightweight clay bricks manufactured by using locally available wine industry waste, Journal of Building Engineering 26(2019)100892. https://doi.org/10.1016/j.jobe.2019.100892

[6] S. Elavarasan, A.K. Priya, V.Kavin Kumar, Manufacturing fired clay brick using fly ash and M-Sand, Materials Today: Proceedings 37(2021)872-876.
https://doi.org/10.1016/j.matpr.2020.06.042

[7] Lan,J., Zhang,S., Mei,T., Dong Y., Hou,H., Mechanochemical modification of electrolytic manganese residue: Ammonium nitrogen recycling, heavy metal solidification, and baking-free brick preparation, Journal of Cleaner Production 329(2021)129727. https://doi.org/10.1016/j.jclepro.2021.129727

[8] Liu,L., Cheng,X., Miao,X., Shi Y., Zhang,M., Guo,M., Cheng,F., Zhang,M., Preparation and characterization of majority solid waste based eco-unburned permeable bricks, Construction and Building Materials 259(2020)120400.
https://doi.org/10.1016/j.conbuildmat.2020.120400

[9] Zhao,Y., Liang,N., Chen,H., Li,Y., Preparation and properties of sintering red mud unburned road brick using orthogonal experiments, Construction and Building Materials 238(2020)117739. https://doi.org/10.1016/j.conbuildmat.2019.117739

[10] A.Seco, J.Omer, S.Marcelino, S.Espuelas, E.Prieto, Sustainable unfired bricks manufacturing from construction and demolition wastes, Construction and Building Materials 167(2018)154-165. https://doi.org/10.1016/j.conbuildmat.2018.02.026

[11] Wang,W., Gan,Y., Kang,X., Synthesis and characterization of sustainable eco-friendly unburned bricks from slate tailings, Journal of Materials Research and Technology 2021;14:1697-1708. https://doi.org/10.1016/j.jmrt.2021.07.071

[12] Peng,Y., Peng,X., Yang,M., Shi,H., Wang,W., Tang,X., Wu,Y, The performances of the baking-free bricks of non-sintered wrap-shell lightweight aggregates from dredged sediments, Construction and Building Materials 238(2020)117587.
https://doi.org/10.1016/j.conbuildmat.2019.117587

[13] Zhao,H., Gou,H., Unfired bricks prepared with red mud and calcium sulfoaluminate cement: Properties and environmental impact, Journal of Building Engineering 38(2021)102238. https://doi.org/10.1016/j.jobe.2021.102238

[14] V. Gupta, H. K. Chai, Y. Lu, S. Chaudhary, A state of the art review to enhance the industrial scale waste utilization in sustainable unfired bricks, Construction and Building Materials 254(2020)119220.
https://doi.org/10.1016/j.conbuildmat.2020.119220

[15] D. E. Quesada, M. A. Felipe, M. J. Fuentes, Biomass bottom ash waste and by-products of the acetylene industry as raw materials for unfired bricks, Journal of Building Engineering 38(2021)102191. https://doi.org/10.1016/j.jobe.2021.102191

[16] Li, X., Gu, H., Huang, A., Fu, L, Bonding mechanism and performance of rectorite/ball clay bonded unfired high alumina bricks, Ceramics International 47(2021)10749-10763. https://doi.org/10.1016/j.ceramint.2020.12.191

[17] S, Masuka., W, Gwenzi., T, Rukuni., Development, engineering properties and potential applications of unfired earth bricks reinforced by coal fly ash, lime and wood aggregates, Journal of

Building Engineering 18(2018)312-320, https://doi.org/10.1016/j.jobe.2018.03.010

[18] L, Lang., B, Chen., Y, Pan., Engineering properties evaluation of unfired sludge bricks solidified by cement-fly ash-lime admixed nano-SiO_2 under compaction forming technology, Construction and Building Materials 259(2020)119879.
https://doi.org/10.1016/j.conbuildmat.2020.119879

[19] D. Muheise, S. Pavia, Properties of unfired, illitic-clay bricks for sustainable construction, Construction and Building Materials 268(2021)121118.
https://doi.org/10.1016/j.conbuildmat.2020.121118

[20] J.E. Oti, J. M. Kinuthia, Stabilised unfired clay bricks for environmental and sustainable use, Applied Clay Science 58(2012)52-59. doi:10.1016/j.clay.2012.01.011

[21] H. A. Gawwad, A. M. Rashad, M.S. Mohammed, T. A. Tawfik, The potential application of cement kiln dust-red clay brick waste-silica fume composites as unfired building bricks with outstanding properties and high ability to CO_2-Capture, Journal of Building Engineering 42(2021)102479. https://doi.org/10.1016/j.jobe.2021.102479

[22] Si Jingping. Refitting analysis and design key points of special purpose vehicle sub frame [J]. Inner Mongolia Highway and transportation, 1997 (1): 28-29.

[23] Wu Xingmin. New energy vehicle[M]. Beijing: Beijing University of Technology Press, 2018,14.

[24] Rubal Dua, Kenneth White, Rebecca Lindland. Understanding potential for battery electric vehicle adoption using large-scale consumer profile data[J]. Energy Reports,2019,5.

[25] Qiu Xuanhuai. Mechanical design[M]. Fourth Edition. Beijing: Higher Education Press, 2011,280.

[26] Shi Wenku. Automobile structure[M]. Sixth Edition. Beijing: People's Communications Press,2013, 291.

[27] Wang Wangyu. Automobile design[M]. Beijing: Machinery Industry Press, 2004, 219.

[28] Hu Fucai, Zhou Yong. Finite element analysis and experimental study of belt brake[J]. Hoisting and transportation machinery, 2007(8): 80-82.