Analysis and improvement measures of defective coal gangue fired brick

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Abstract. According to the phenomenon of the accident of defective products of finished bricks, combined with fuzzy mathematics and fault tree analysis theory, the causes of the accident are studied. Firstly, the downward method is used to analysis the structure of fault tree and the influence degree of each basic event on the defective top event of finished brick is sorted. Secondly, the trigonometric fuzzy function is used to normalize the probability value of the basic event collected and the probability value of the basic event without statistical data obtained by the expert scoring. The importance of the processed triangular fuzzy probability is quantitatively analyzed and compared and the main factors affecting the top event are obtained. Finally, specific and targeted suggestions are put forward according to the factors causing the top event.

1. Introduction
As a new modern wall material, coal gangue fired brick is widely concerned by people. Using coal gangue as the raw material for producing sintered brick can not only reduce the damage of coal gangue to the environment but also solve the problem of using a lot of land for brick making, realizing "No coal is used to burn bricks and soil is not used to make bricks ". Many coal companies rely on their own companies to build coal gangue brick factories nearby, hoping to consume coal gangue and bring more benefits to the company. However, due to the immaturity of technology and management defects, defective products will appear in the process of producing sintered bricks. Defective products will not only affect the quality level of the assessed product, but also affect the sales of the product.

2. Overview of coal gangue fired brick
Coal gangue fired porous brick and hollow brick are new energy-saving wall materials. Through the analysis of the chemical composition of coal gangue, it is found that the coal gangue fired brick can completely replace the solid brick made of clay, which greatly reduces the environmental damage. Coal gangue brick not only saves land space, but also consumes mine waste [1]. It is a low-carbon building material which is conducive to environmental protection. Gangue brick has a broad market, it has unique performance advantages:
(1) Good fireproof, sound insulation and dimensional stability
(2) Low energy consumption, excellent quality
(3) Increase the use area of building
3. Establishment of fault tree model for defective bricks

According to the needs of production management, the whole process of coal gangue fired brick can be divided into three processes, namely raw material crushing, brick blank forming and product firing. Due to the complexity of the process, there are many factors causing the quality problems of coal gangue fired brick, so comprehensive analysis is needed. According to the traditional fault tree analysis theory, combined with the technological process of making fired brick, the fault tree analysis model with the defective products as the top event was established [2].

The top event was selected as the defective product of fired brick. 18 factors were found in the production process as the bottom event of the fault tree [3], As shown in Table 1.

According to the theory of deductive analysis and logical reasoning, starting from the top event, looking down the various causes of the top event, and finally drawing the inverted logic tree diagram, As shown in Figure 1.

| Event number | Event name                                      |
|--------------|-------------------------------------------------|
| X_1          | Aging without ingredients                       |
| X_2          | The calorific value is not up to standard       |
| X_3          | The content of chemical composition does not meet the requirements of Standard brick |
| X_4          | Poor plasticity                                 |
| X_5          | The particle gradation is unreasonable          |
| X_6          | Uneven cloth                                    |
| X_7          | Device mismatch                                 |
| X_8          | The pressure is not suitable when forming       |
| X_9          | Unreasonable installation and use of equipment  |
| X_10         | Abnormal lubrication                            |
| X_11         | The billet is not qualified                     |
| X_12         | The molding operation is not standardized       |
| X_13         | Rush to dry                                      |
| X_14         | Condensation                                    |
| X_15         | Block fracturing                                |
| X_16         | Pent-up anxiety                                 |
| X_17         | Cooling too fast                                |
| X_18         | Too high temperature of kiln truck table        |
Figure 1. Fault tree of defective finished brick

4. Fault tree analysis of defective brick

4.1. Qualitative analysis of fault tree

4.1.1. Minimum cut set solution. Through the downward method, the Boolean algorithm is used to solve the minimum cut set as follows:

\[ T = M_1 + M_2 + M_3 \]
\[ = X_1X_4 + X_5X_6 + X_9X_{10}X_{11}X_{13} + M_2 + M_3 + M_6 \]
\[ = X_1X_2 + X_3X_4 + X_5X_6X_9X_{10}X_{11}X_{13} + X_{13}X_{14}X_{15}X_{18} \]
\[ = X_1X_2X_3X_4X_5X_6X_9X_{10}X_{11}X_{13}X_{14}X_{15}X_{18} \]

According to the calculation, there are 14 minimum cut sets in the defective products of gangue bricks, which indicates that there are 14 ways to cause defective products.

4.1.2. Solving the structural importance of fault tree. According to the minimum cut set of fault tree, the importance of each event structure is judged. The cut set is the smallest:

\[ I(X_{i_1}) = \sum_{x_{i_2}} \frac{1}{2^{n-1}} \]

According to the formula, the structural importance coefficient of the basic event is solved as follows:

\[ I(X_1) = I(X_{17}) = I(X_{16}) = \frac{1}{2^{2-1}} + \frac{1}{2^{2-1}} + \frac{1}{2^{2-1}} = 2 \]
\[ I(X_2) = I(X_3) = I(X_4) = I(X_5) = \frac{1}{2^{2^1}} = \frac{1}{2} \]  
\[ I(X_6) = I(X_8) = I(X_{10}) = I(X_{11}) = \frac{1}{2^{2^2}} + \frac{1}{2^{2^1}} = \frac{1}{16} \]  
\[ I(X_7) = I(X_{12}) = \frac{1}{2^{6^1}} = \frac{1}{32} \]  
\[ I(X_{13}) = I(X_{14}) = I(X_{15}) = I(X_{18}) = \frac{1}{2^{2^3}} + \frac{1}{2^{2^1}} = 1 \]  

According to the above basic events, the order of structural importance is as follows:

\[ I(X_{17}) = I(X_{16}) = I(X_1) = I(X_{14}) = I(X_{12}) = I(X_{13}) = I(X_2) = I(X_4) = I(X_3) = I(X_2) = I(X_{11}) = I(X_{10}) \]
\[ = I(X_5) = I(X_8) = I(X_6) = I(X_{12}) = I(X_7) \]  

According to the order of structure importance, it can be concluded that the cooling is too fast, the aging is not enough, and the emergency fire has the greatest impact on the defective products of fired bricks. Therefore, it is necessary to strengthen the control and management of these events [4].

4.2. Quantitative analysis of fault tree

4.2.1. Normalization of basic time probability.

4.2.1.1 Data processing with exact statistical data. According to the collected data, the basic events of probability statistics are as follows:

\[ x_2, x_3, x_5, x_8, x_{10}, x_{11}, x_{15}, x_{18} \]  

The basic events without statistics are:

\[ x_1, x_4, x_6, x_{7}, x_{9}, x_{12}, x_{13}, x_{14}, x_{16}, x_{17} \]  

Basic events with accurate probability and statistics: \( x_2, x_3, x_5, x_8, x_{10}, x_{11}, x_{15}, x_{18} \) the probability values are: \( q_2=0.0049, q_3=0.0002, q_5=0.00035, q_8=0.0065, q_{10}=0.00017, q_{11}=0.0098, q_{15}=0.077, q_{18}=0.0082 \). Affected by external conditions, these seemingly accurate data still have fluctuation range. In order to describe more accurately, three experienced experts are asked to score and give the fluctuation range [5]. The triangular fuzzy probability \( \tilde{q} = (a, m, b) \) is obtained by normalizing the fluctuation value and its precise value, where \( a \) is the lower limit of the fluctuation value scored by the expert, and \( b \) is the upper limit of the fluctuation value scored by the expert. As shown in Table 2.
Table 2. Triangular fuzzy probability of basic events with statistical data

| Event number | Event name                                      | $\tilde{q} = (a, m, b)$    |
|--------------|------------------------------------------------|-----------------------------|
| X2           | Calorific value does not meet the requirements | (0.0002, 0.0049, 0.0003)    |
| X3           | The chemical composition content does not meet the requirements of standard brick | (0.00004, 0.00023, 0.00001) |
| X5           | The particle gradation is unreasonable         | (0.00007, 0.00035, 0.00005) |
| X8           | The pressure is not suitable when forming      | (0.00018, 0.0065, 0.00012)  |
| X10          | Abnormal lubrication                           | (0.00002, 0.00017, 0.00006) |
| X11          | The billet is not qualified                    | (0.00023, 0.0098, 0.00045)  |
| X15          | Block fracturing                               | (0.0019, 0.077, 0.0011)     |
| X18          | Too high temperature of kiln truck table       | (0.0005, 0.0082, 0.0008)    |

4.2.1.2 Data processing without accurate statistics. There is no exact statistical data for the remaining basic events, and the probability value of such events can be obtained by the $3\sigma$ characterization method. Three experts are invited to evaluate the basic probability events. The mean value of the evaluation value is taken as the $m$, and the standard deviation is taken as $\sigma$. It is assumed that the evaluation value follows the normal distribution [6]. According to the $3\sigma$ principle, the possibility of the value of the evaluation value in the interval is 99.7%. Therefore, $a = b = 3\sigma$, it is required to normalize the data without exact statistics, and the data obtained is shown in Table 3.

Table 3. Triangular fuzzy probability of basic events without statistical data

| Event number | Event name                                      | Expert 1 | Expert 2 | Expert 3 | $m$ | $3\sigma$ | $\tilde{q}=(a,m,b)$ |
|--------------|------------------------------------------------|----------|----------|----------|-----|-----------|---------------------|
| X1           | Aging without ingredients                      | 0.0005   | 0.0007   | 0.0006   | 0.0006 | 0.0002    | (0.00028, 0.00065, 0.00028) |
| X4           | Poor plasticity                                | 0.0045   | 0.0048   | 0.0051   | 0.0018 | 0.0018    | (0.0018, 0.0051, 0.0018)  |
| X6           | Uneven cloth                                   | 0.0075   | 0.0071   | 0.0075   | 0.0099 | 0.0099    | (0.00098, 0.0075, 0.00098) |
| X7           | Device mismatch                                | 0.0003   | 0.0004   | 0.0003   | 0.0002 | 0.0002    | (0.00021, 0.00037, 0.00021) |
| X9           | Unreasonable installation and use of equipment | 0.061    | 0.067    | 0.065    | 0.0093 | 0.0093    | (0.0093, 0.065, 0.0093)   |
| X12          | The molding operation is not standardized       | 0.0043   | 0.0052   | 0.0054   | 0.0028 | 0.0028    | (0.0028, 0.0054, 0.0028)  |
| X13          | Rush to dry                                    | 0.049    | 0.038    | 0.045    | 0.016  | 0.016     | (0.016, 0.045, 0.016)     |
| X14          | Condensation
tent-up anxiety                 | 0.012    | 0.024    | 0.024    | 0.031  | 0.031     | (0.031, 0.024, 0.031)     |
| X16          | Cooling too fast                               | 0.0061   | 0.0071   | 0.0066   | 0.0012 | 0.0012    | (0.0012, 0.0066, 0.0012)  |
| X17          |                                              | 0.37     | 0.23     | 0.27     | 0.21   | 0.21      | (0.21, 0.27, 0.21)        |
4.2.2. importance analysis of basic events. The influence degree of top event by basic event can be described by fuzzy importance and the fuzzy importance of basic event is positively correlated with the impact on the system, so improving the event with higher fuzzy importance can effectively improve the system reliability. In this paper, triangular fuzzy numbers are selected, 

\[ A_1 = \int_{m-a}^{m} Y(x) \, dx \quad A_2 = \int_{m}^{m+b} Y(x) \, dx \quad A = A_1 + A_2 \]  

When \( A_1, A_2 \) represents the area of two small triangles respectively, suppose there is a point \( Z \), so that the two parts of the area under the fuzzy curve can be divided equally through the boundary of the point, Then this point \( Z \) is the median of triangular fuzzy number, and the value of point \( Z \) can be calculated according to the following formula:

\[ b < a, \int_{m-a}^{z} \frac{x-m+a}{a} \, dx + \int_{Z}^{m} \frac{x-m+a}{a} \, dx + \int_{m}^{b+m-b-x} \frac{b-m-b-x}{b} \, dx, T_{iz}^I = m-\sqrt{a^2-ba} \]  

\[ b > a, \int_{m-a}^{z} \frac{x-m+a}{a} \, dx + \int_{Z}^{m} \frac{x-m+a}{a} \, dx = \int_{m}^{b+m-b-x} \frac{b-m-b-x}{b} \, dx, T_{iz}^I = m+\sqrt{b^2-ba} \]  

\[ b = a, T_{iz}^I = m \]  

The evaluation method is as follows: 

The first case: for those with exact statistical data, it can be obtained according to formula (12), (13). 

The second case: if there is no exact statistical data, the median is determined by the score of experts, which is obtained by equation (14).

According to the above formula, the fuzzy probability of each basic event is calculated:

\[ T_{iz}^I = 0.00065 \]  

\[ T_{2z}^I = 0.0049+\sqrt{0.0003^2-0.0002\times0.0003} = 0.0051 \]  

\[ T_{3z}^I = 0.0023+\sqrt{0.00004^2-0.00004\times0.00001} = 0.0021 \]  

\[ T_{4z}^I = 0.0051 \]  

\[ T_{5z}^I = 0.0035+\sqrt{0.00007^2-0.00007\times0.00005} = 0.0031 \]  

\[ T_{6z}^I = 0.0075 \quad T_{7z}^I = 0.0037 \]  

\[ T_{8z}^I = 0.0065+\sqrt{0.00018^2-0.00018\times0.00012} = 0.0064 \]  

\[ T_{9z}^I = 0.0065 \]  

\[ T_{10z}^I = 0.00017+\sqrt{0.00006^2-0.00006\times0.00002} = 0.00022 \]
\[ T'_{11z} = 0.0098 + \sqrt{0.00045^2 - 0.00045 \times 0.00023} = 0.01 \] (24)

\[ T'_{12z} = 0.0054 \quad T'_{13z} = 0.045 \quad T'_{14z} = 0.024 \] (25)

\[ T'_{15z} = 0.077 \sqrt{0.00019^2 - 0.00019 \times 0.00011} = 0.076 \] (26)

\[ T'_{16z} = 0.0066 \quad T'_{17z} = 0.27 \] (27)

\[ T'_{18z} = 0.0082 + \sqrt{0.0008^2 - 0.0008 \times 0.0005} = 0.0087 \] (28)

The fuzzy importance of the basic event \( X_i \) is: \( S_i = T'_{iz} \), the fuzzy probability value of the top event is the same, Therefore, the fuzzy importance of basic events can only be compared with \( T'_{iz} \). The larger \( T'_{iz} \) is, the smaller \( S_i \) is, the greater the impact on the top event. According to the calculated results, the order of the results is as follows:

\[ T'_{17z} > T'_{15z} > T'_{12z} > T'_{14z} > T'_{11z} > T'_{18z} > T'_{6z} > T'_{8z} > T'_{16z} > T'_{2z} = T'_{4z} > T'_{1z} > T'_{7z} > T'_{5z} > T'_{10z} > T'_{3z}. \] (29)

Therefore, the fuzzy importance of basic event \( X_i \) is ranked as follows:

\[ S_{17} < S_{15} < S_6 < S_{13} < S_{14} < S_{18} < S_6 < S_{18} < S_{18} < S_{13} < S_2 = S_4 < S_1 < S_7 < S_5 < S_{10} < S_3 \] (30)

According to the ranking of the above fuzzy importance, it can be seen that the chemical composition content does not meet the requirements of the standard brick, the lubrication is not normal, the particle grading is unreasonable, the equipment is not matched, and the aging is not sufficient, to strengthen the control of these factors, we can effectively reduce the occurrence of defective product accidents [7]. Among them, insufficient aging is very high in the analysis of structural importance and fuzzy importance, that is to say, it has a great impact on the top event, so it is necessary to focus on monitoring this basic event in the normal production process.

5. Measures to prevent defective products of coal gangue fired brick

5.1. raw material crushing

The ball mill is installed in the raw material crushing system to overcome the hard and hard to break material on the screen by hammer. The returned material is ground into powder by ball mill and added into the raw material, and the raw material particles after ball milling are no longer angular, which increases the plasticity of raw material; A stone remover is added at the entrance of raw materials to prevent iron nails, iron sheets, welding rod heads, large stones, broken mixer cutters, etc. from entering the extruder, increasing the wear of bearings.

Due to the high moisture content of coal gangue discharged from underground coal mine or washing plant, it is easy to stick and block crushing, crushing and screening equipment, so it is necessary to store gangue in advance to reduce the moisture content of raw materials. Reasonable control of particle gradation, particle composition ratio are: particle size less than 0.05mm content of 33%~52%; particle size of 0.05mm~1.3mm content of 22%~66%; particle size of 1.3mm~2mm content of less than 30%, to ensure reasonable particle gradation, through the control of particle size to reduce the damage caused by limestone particles [8]. Reasonable aging can improve the plasticity of raw materials and the strength
of green bodies. Therefore, it is necessary to ensure that the aging time is more than 3 days. The temperature should be kept above 10 °C and the moisture content should be controlled at 11%~13%.

5.2. brick forming stage
The air content should be controlled at 10%~12% (volume ratio) before brick forming. When excess air is found, vacuum pump should be used to extract air before molding. The formed brick is mainly composed of raw materials, air and water. The cracks can be eliminated by mixing evenly with a mixer to keep the slurry homogenized.

In order to prevent the core frame from cracking, the extruder head and mouth adopt the structure of equal speed extrusion with low stress, and the length of the die is controlled within 0.6~0.7 times of the first section of cutter. The head and mouth of the machine should be equipped with lubrication structure to reduce the resistance during extrusion, so as to solve the problem of speed difference of mud stick, and save about 20% of electric energy. Since the cost of electric energy accounts for a large proportion in the production cost, this method should be paid attention to. When the surface of the core head is too rough or there are impurities which lead to fish scale in the hole, the surface of the core head should be polished, the design scheme should be optimized, the molding moisture should be increased and the impurities should be removed [9].

5.3. product firing
Because the drying speed and shrinkage speed of the green body are always fast outside and slow inside, the shrinkage should be controlled less than the elastic coefficient (1%~2%) of the slurry to prevent the occurrence of network cracks. The air supply temperature is not easy to be too high during drying and should be controlled between 105 °C and 130 °C. Because the hollow brick wall is thin, the rib is thin, the strength is low, the crack resistance is weak, and it is not resistant to high temperature. Therefore, the hot air temperature of the air inlet of the artificial drying chamber should be 30%~50% lower than that of drying solid brick under the same conditions.

The strength of hollow brick is low, and it is easy to collapse due to moisture. Therefore, it is necessary to check the moisture discharge hole frequently, discharge the moisture with relative humidity greater than 95% in time, improve the baking level, fully preheat the body, slowly dehydrate, and steadily raise the temperature, so as to avoid moisture absorption collapse. In order to prevent hairy cracks, the cooling should be slow after high-temperature roasting, the fire eye cover should be kept closed in the negative pressure area, and the kiln door should not be opened too early or too close [10]. The temperature of kiln car table should not be too high. Refractory materials with good thermal insulation effect should be used on the table surface. The length of empty car line should be extended and the cooling time should be increased.

6. Conclusion
With the continuous development of China's gangue brick industry and policy guidance, the use of coal gangue to produce sintered brick has attracted more and more attention. In this paper, the fuzzy fault tree analysis method is used to analyze the accidents that lead to the defective products of finished coal gangue bricks in the production process. Through effective measures to reduce the occurrence rate of defective products accidents, in order to reduce the comprehensive cost of gangue bricks, it provides reference data for the future brick industry and promotes the circular development of enterprise economy.

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