Effect of density on smoldering rate of cotton bale

Zheng Wang*, Wanfu Liu, Zhaopeng Ni and Wuqin Qi

Dept. of Mechanical Engineering, Tianjin University of Commerce, 300134, Tianjin, China

*Corresponding author’s e-mail: wz1016522064@163.com

Abstract. Cotton is an important economic crop, which plays an irreplaceable role in national production and life. With the economic development of society, the demand for cotton is also growing, which means that a lot of transportation and storage are needed. Cotton has the characteristics of smoldering, so in the process of transportation and storage, we should pay attention to the management of cotton. Open fire can cause the smoldering of cotton. In the wet environment, it is beneficial to the reproduction of microbes. If the heat can’t be released in time, it will also cause the smoldering. The density of cotton bags is different, and the porosity is different. The oxygen content in the cotton bag changes, which has an impact on the combustion state. Therefore, in this experiment, the test phenomena, quality changes and temperature changes after burning are studied for different density of cotton samples.

1. Introduction
With China's accession to the WTO and the opening of the cotton market, China's textile industry has developed rapidly [1], so cotton is an important economic crop in China, as an important raw material of the textile industry, and an indispensable necessity in people's life. At the same time, cotton also plays an important role in medicine, chemical industry, military and other aspects, and is an important material for China's economic and social development [2].

The storage and circulation of cotton is an important part of cotton market, which plays an important role in ensuring the stable operation of cotton market and people's life and work. In order to adjust the demand of cotton, China has set up many cotton warehouses in Hebei, Shandong, Shanxi and other places. In the process of storage and transportation of cotton, there are often various influencing factors, especially for cotton, a flammable substance, which is easy to cause a major loss of cotton fire [3].

Cotton has three main characteristics: 1. Cotton and open fire contact will burn, and the more loose cotton fiber, the drier, the faster the burning rate. 2. When cotton is stained with oil (vegetable oil and animal oil), it will be oxidized and burned. Because cotton fiber is very thin, heat is not easy to be emitted. In this case, the cotton fiber is prone to spontaneous combustion. 3. When cotton is affected by rain, moisture or large water content, microorganisms will grow and propagate, causing cotton fiber tissue to rot and heat. If the heat cannot be emitted, it will also spontaneous combustion [4].

The bales are wrapped in cotton linen and bound with steel wire or PET tape [5-6], and then hundreds of compressed bales are stacked in the open yard in the form of pile [7]. It can be seen from the characteristics of cotton that the fiber structure of cotton, that is, the porosity of cotton bale, has a certain impact on the combustion of cotton. Therefore, the density of cotton bale has a certain impact on the internal oxygen content, which leads to different changes in the combustion rate of cotton bale due to the different oxygen content during the fire combustion of cotton bale. Therefore, this paper
explores the influence of the density of cotton bale on the combustion of cotton. The effect of burning rate on the study of cotton fire is significant.

2. Sample selection and test method
The sample of the scale cotton bag shall be made by referring to the national standard “cotton lint cotton” (GB 1103-2007). The size of the scale cotton bag is 260mm×105mm×100mm. In the experiment, two kinds of shrinkage pack density were made, 100 kg/m³ and 50 kg/m³ respectively.

In this test, a 6m ×2.5m ×3m closed iron container is used as the test room, and the sample of the reduced cotton bag is placed in the middle of the test room for test. The layout of the test device is shown in Figure 1. An electronic scale is placed under the sample of the scale bale to weigh and record the weight change of the bale during the test. A monitoring camera is used to collect the test image inside the container.

Figure 1. Layout of test device.

In this test, the lighter is used to ignite the shrunk cotton bag on one side, and the thermocouple is inserted in the center of the shrunk cotton bag. A total of 3 thermocouples are arranged every 65mm. The ignition source is near the T1 end, as shown in Figure 2.

Figure 2. Schematic diagram of temperature measuring points.

3. Experimental phenomena
Figure 3 and Figure 4 are combustion test phenomena of 50 kg/m³ and 100 kg/m³ scale bales respectively. When the lighter is taken away, the loose cotton on the outer surface of the scale bale will burn with flame, but it will turn to full smoldering immediately after the duration of less than 1 min, the smoke emitted from the surface of the bale will gradually increase with the test time. The surface of the scale bales gradually turns from yellow to black. The outer surface of the 50kg/m³ bales is completely carbonized and black at 15min, and the outer surface of the 100kg/m³ bales is
completely black at 41min. When the thermocouple measurement temperature drops to room
temperature, the test is stopped. The test end time of 50kg/m$^3$ cotton bag is 61min, and that of
100kg/m$^3$ cotton bag is 135min.

![0min, 1min, 15min, 60min](image1)

Figure 3. Test phenomenon of 50kg/m$^3$ reduced cotton bale.

![0min, 11min, 41min, 135min](image2)

Figure 4. Test phenomenon of 100kg/m$^3$ reduced cotton bale.

4. Analysis of test results

4.1 Analysis of quality change results

Figure 5 shows the results of mass change of combustion of different density scale bales. At the
beginning of the experiment, the two density bales experienced a slow dehydration process, and the
mass loss rate was the same. With the development of the experiment, the time to reach the quality
stability of the bale with small density is about 52 minutes, while the time to reach the quality stability
of the bale with large density is about 101 minutes. Although the density is different, the mass of the
two bales is different at the beginning of the test, but the residual mass is the same at the end of the
test, both of them are 10.09kg. At this time, the loss of big density bale is 0.24kg, and that of small
density bale is 0.10kg.

![Mass change process](image3)

Figure 5. Mass change process of different density cotton bales during combustion
4.2 Analysis of temperature change results

The temperature changes of the different density scale bales burning test are shown in Figures 6 and 7, respectively. When the density of the shrunk bale is 50 kg/m$^3$, the burning time of the shrunk bale is about 61 min. In the initial stage of the test, the temperature rising rate of T1 and T3 measuring points near the side of the cotton bale was relatively fast, and the time needed for T2 measuring point in the center to reach the highest temperature was relatively long. The highest temperature of T2 in the center was the highest among the three measuring points, reaching 555 °C, and it experienced a smooth peak period of 12 minutes, and then rapidly dropped to room temperature. The difference between the maximum temperature of T1 and T2 near the ignition source is 25 °C. During the process of falling to room temperature, the temperature has experienced two stages: first slow decline and then sharp decline. The distance between temperature measuring points T3 and T2 is the same as that between T1 and T2, but because they are far away from the ignition source, the maximum temperature is only 430 °C, which is 125 °C and 100 °C different from the maximum temperature of temperature measuring points T1 and T2 respectively.

When the density of the shrunk bale is 100 kg/m$^3$, the burning time of the shrunk bale is about 135 min. At the beginning of the test, the temperature of each measuring point of the cotton bag increased slowly, and it began to rise sharply after about 26 minutes. The time for T1 and T3 to reach the highest temperature is shorter than that for T2, which indicates that the combustion process of cotton bales develops from the outside to the inside. After reaching the highest temperature, the three temperature measuring points of 100 kg/m$^3$ scale cotton bag have an obvious relatively flat peak, indicating that the three measuring points are in a relatively stable smoldering state, among which T2 temperature measuring point in the center has the longest flat peak, maintaining 42 minutes. Different from the 50 kg/m$^3$ cotton bag, the highest temperature of the three measuring points is very close, about 552 °C. After the gentle peak, the temperature of the three temperature measuring points decreased sharply, T2 temperature measuring point decreased the fastest, T1 and T3 temperature measuring points experienced the process of fast first and then slow down.

![Figure 6. Temperature change process of 50 kg/m$^3$ cotton bales.](image)

![Figure 7. Temperature change process of 100 kg/m$^3$ cotton bales.](image)

According to the above analysis, the increase of density will slow down the heating rate in the early stage, maintain stable smoldering in the middle stage and speed up the cooling rate in the later stage. With the increase of density, the porosity and oxygen content of cotton bales decrease. In the early stage of smoldering combustion, due to the lack of oxygen supply, combustion is difficult to enter the interior, so the initial heating rate is obviously slow. With the extension of the test time, the inner heat of the cotton bale is stored, the outer combustion causes the structure to loosen gradually, the oxygen permeability to increase, the smoldering rate to speed up, and the temperature to increase significantly. After continuous steady-state smoldering, the combustible material decreases and the temperature drops rapidly.
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