Foaming effect influence of PBT / ABS resin as a reducing agent in foamed asphalt

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Abstract. Foamed asphalt provides good environmental protection characteristics and economy. The utilization rate of old materials in foam asphalt recycling technology is higher than that of emulsified asphalt. Due to the lack of performance, the application scope of foam asphalt recycling technology is limited. In order to maintain high utilization rate of recycled asphalt concrete and improve the performance of foamed asphalt mixture, it will be the focus of research. In recent studies, adding a reducing agent into the regeneration process of foamed asphalt is a new technology. According to the test results of reduction performance of asphalt SARA four components, the PBT/ABS resin (Acrylonitrile butadiene styrene modified by Polybutylene Terephthalate) has excellent asphalt reduction effect, and PBT/ABS resin has good compatibility with emulsified asphalt after emulsification. Therefore, based on the existing foaming theory, the influence of asphalt temperature and water consumption on asphalt foaming with PBT / ABS resin reducing agent was designed. The influence of asphalt temperature and water consumption on foamed asphalt modified by PBT / ABS resin reducing agent was discussed. The results show that the PBT/ABS resin has larger foam volume than ordinary foam asphalt, but the average diameter of foam is slightly smaller. Similar to ordinary foamed asphalt, expansion rate and half-life are opposite to that of water consumption. Water consumption and asphalt temperature have significant effects on foaming effect. At the same temperature, with the increase of water consumption, the expansion rate increases and the half-life decreases. Under the same water consumption, the higher the foaming temperature, the greater the expansion rate. However, when the temperature reaches 160 ℃, the expansion rate of asphalt does not vary with the temperature. With the increase of temperature, asphalt with different temperature has different optimal foaming water consumption. Finally, the optimum foaming conditions of PBT/ABS resin foam are given as follows: the best foaming temperature is 140 C, the water consumption is 3.8%, the ultimate expansion rate is 21.5%, and the half-life is 22.5s.
1. Introduction
At present, the development of road engineering has generally transited from the early construction stage to the current construction and maintenance stage. Therefore, from the perspective of economic and environmental benefits, in order to protect the environment and avoid the waste of resources, the recycling techniques of reclaimed asphalt pavement materials are gradually increasing[1]. Among them, cold recycling of foamed asphalt is the most economical method, and therefore widely concerned by researchers for its high RAP content ratio and rapid construction speed[2,3].

This research is based on the test section of a field construction. A lot of pre-research indicated that, the current aging degree of the binder in RAP, cannot be applied to the upper layer by ordinary foam regeneration technology. In order to use all recycled materials as much as possible, increasing the recycling rate becomes the path that must be passed [4,5]. PBT / ABS resin has become a potential good choice and entered the field of vision of researchers in this study.

PBT / ABS resin foam is made of PBT / ABS resin reductant, asphalt, water and compressed air. It is the same as ordinary foam asphalt. Asphalt is coated with steam bubbles, which causes asphalt to expand and increase the belly area of asphalt. During the process of asphalt foaming, the volume expands, and the asphalt has undergone obvious physical deformation. Aiming at the role of raw asphalt, the PBT / ABS resin reductant has increased the penetration rate and increased the content of flexible phenol [6-8]. Because there are few earlier stage studies on the foaming effect of foam asphalt added with special reducing agent, this study will mainly explore the temperature and utilization of content of water based on the existing foaming theory, at the same time, this study will provide some reference for the foam asphalt technology incorporating the reducing agent. The influence of water content on the foaming of asphalt with PBT / ABS resin reductant was emphasized, as well as the law of the change of expansion rate and half-life. This study selects the foaming index of PBT / ABS resin expansion foam and the half-life varying curves to comprehensively evaluate the foaming effect of asphalt, to determine the best foaming conditions.

2. Materials and experimental

2.1. Materials
PBT(Poly Butylene Terephthalate) was used to modify the conventional ABS(acrylonitrile butadiene styrene) to obtain PBT / ABS resin with good toughness. More importantly, its gum component can supplement the aged asphalt. The appearance of PBT / ABS resin is shown in Figure 1, and the appearance after shearing, dispersing and emulsifying is shown in Figure 2. The production method is not detailed, for it involves the unpublished patent and technical protection.

![Figure 1. Appearance of PBT / ABS resins.](image1)

![Figure 2. Emulsified resin reducing agent.](image2)

The principle of asphalt component test comes from liquid-solid adsorption chromatography. Adsorption is the accumulation of liquid molecules on the solid surface due to the attraction of unbalanced force. According to the different adsorption capacity of substances on the adsorbent, the
separation effectives achieve. Generally, the substances with high polarity are easy to be adsorbed by the adsorbent, and the substances with weak polarity are not easy to be adsorbed by the adsorbent, so the components of asphalt can be separated. According to the China guideline JTGE-20-2011 “Standard Test Methods of Asphalt and Bituminous mixture for Highway Engineering” [9]. The asphalt was separated by n-heptane, toluene and ethanol.

Three groups of experiments were conducted and the mean value was taken. The four component test results (SARA: S(saturate), A(aromatic), R(resin), A(asphaltene)) are shown in Table 1.

| Item       | Fresh asphalt | Aged asphalt | Reduced asphalt | Coefficient of Variation 1 (%) | Coefficient of Variation 2 (%) |
|------------|---------------|--------------|-----------------|--------------------------------|-------------------------------|
| Asphaltene (%) | 14.6          | 44.5         | 18.3           | 204.7945                       | 25.34247                     |
| Resin (%)    | 28.8          | 23.3         | 26.5           | 19.09722                       | 7.9861111                    |
| Saturate (%)  | 30.6          | 18.8         | 31.2           | 38.56209                       | 1.960784                     |
| Aromatic (%)  | 26            | 13.4         | 24             | 48.46154                       | 7.692308                     |

Where, Coefficient of Variation 1 refers to the difference of components between aged asphalt and fresh asphalt, and Coefficient of Variation 2 (%) refers to the condition after reduction.

Calculation method of Coefficient of Variation, see formula 1:

\[ CV = \left| \frac{A - A_0}{A_0} \right| \times 100\% \]  

(1)

2.2. Test method

Previous studies have shown that foamed asphalt has adopted the established index system, that is, Expansion ratio (ERm) and half-life (Half-life, 1/2) [10]. The ratio of the maximum volume to the original volume in the process of asphalt foaming is defined as the expansion rate. As the foamed asphalt is prepared as the process of the edge foaming edge decay, the measured expansion rate is slightly smaller than the true value. Under certain conditions, the larger the expansion area of the foamed asphalt, the better the dispersion of aggregates in asphalt. The half-life refers to the time it takes for the volume of the foamed asphalt to decrease to half of the maximum volume (with an accuracy of 0.1s). The longer the half-life, the slower the foam decay rate, that is, the half-life characterizes the relative stability of the foamed asphalt, so there is more time for mixing with mineral materials, effectively improving the performance of the mixture[11]. It will comprehensively consider the expansion rate and half-life to analyze the test results of PBT / ABS resin reduced asphalt foaming.

The expansion rate and half-life of the foam show the opposite trend with the change of water consumption. At the same time, the expansion rate and half-life have the lowest numerical limit. The best foaming condition should be determined according to the lowest numerical limit of the two. The middle value in the range should be selected as the best foaming condition at this temperature [12,13].

In addition, there is a fixed relationship between expansion rate and half-life. Foamed asphalt foaming is the process of edge foaming decay. Before measuring the expansion rate, the asphalt starts to burst [14], so we know that the maximum expansion rate is not the true expansion rate. Therefore, Jenkins uses differential method to get the general solution of ERa formula 2.

\[ ER_a = ER_m t_s (\ln 2) / \tau_{1/2} \left[ 1 - \exp \left( -\frac{\ln 2}{\tau_{1/2}} t_s \right) \right] \]  

(2)

Where: \( ER_m \) - expansion rate measured by test;  
\( \tau_{1/2} \) — The half-life measured by the test;  
\( t_s \) — The asphalt spraying time is 5s The amount of foaming test is generally 500g, and the spraying rate is about 100g / s, then 5s is taken.
In view of this, by studying the decay curves of foamed asphalt, the foaming index (Foaming index, FI) shown in formula 3 is used to evaluate the foaming properties of asphalt. Therefore, the expansion rate, half-life and foaming index are used to evaluate the foaming characteristics of asphalt.

\[
FI = -\tau_{1/2}[4 - ER_m - 4 \ln(4/ER_m)]/ \ln 2 + (1 + c)ER_m t_0/2
\]  

(3)

Where: \(-\tau_{1/2}\) asphalt spraying time 5s;

\(C\) -- ratio of expansion value test value to true value.

Figure 3 shows the indoor foam asphalt testing machine chosen for this study. It is characterized by precise control and can adjust water volume, temperature and pressure.

The addition of reducing agent affects the foaming degree and half-life. For decreasing uncertainty during the physical reactions, the emulsification of PBT / ABS resin is required to be very uniform. In addition, the steps of adding PBT / ABS resin and foam spray reducer should be early. In this test, a spray port was added. While fresh asphalt was added, the emulsified PBT / ABS resin was added into it. The amount of PBT / ABS resin reductant is 15wt% of total asphalt (fresh asphalt and recyclable effective asphalt). The foaming states of PBT / ABS resin foam are as Figure 4 and 5:

![Figure 4. Appearance of common foamed asphalt](image)

![Figure 5. Appearance of PBT / ABS resin reduced asphalt.](image)

It can be seen from the appearance that the average diameter of foam is smaller than that of ordinary asphalt, but the amount of foaming is larger. Its binding effect needs to be further verified.

It is noteworthy that before the foaming test, the standard asphalt dosage is 500g, and the scale is erected on the side of the barrel. During the test, observe and record the maximum volume of asphalt expansion and the time when the volume is reduced to half of the maximum volume, namely the expansion rate and half-life respectively. Due to the greater influence of human factors in the experiment, each group conducted three parallel experiments. During data processing, error analysis is performed, and the test results with larger errors are discarded and the average value is taken.
2.3. Experimental design
Asphalt foaming is affected by water pressure, air pressure, asphalt type, asphalt temperature and water consumption [15]. In this test, the water pressure is set to 5bar, and the air pressure is set to 4bar. The rest will be studied as variables. After PBT / ABS resin reductant is added, the asphalt is not suitable for foaming below 130 ℃, and above 170 ℃, it is easy to cause reductant failure and further aging of asphalt. Therefore, in this test, the optional values of temperature as a variable are 130 ℃, 140 ℃, 150 ℃, 160 ℃ and 170 ℃. Based on the previous experimental experience and literature research[16], the available variables of water consumption are determined to be 2%, 2.5%, 3%, 3.5% and 4%. The orthogonal experimental design is shown in Table 2:

| Table 2. Orthogonal experimental design |
|----------------------------------------|
| Influencing factors (variable indicators) | Temperature / ℃ | 130  | 140  | 150  | 160  | 170 |
| Water consumption | 2%     | 2.50% | 3%   | 3.50% | 4%   |

In order to control error, all the above data have been tested in parallel for three times. In case of abnormal data, it is necessary to remove and conduct supplementary test. All the above test values are the average of the parallel test data obtained after removing the abnormal data and supplementary test. In the following sections, the data will be analyzed in detail through the trend chart.

3. Test results and analysis

3.1. Effect of asphalt temperature on foaming effect
The curves are drawn and studied for that the expansion rate and half-life will reach a value as large as possible[17]. According to the test plan in Table 2, the influence of asphalt temperature on the expansion rate and half-life are respectively plotted, as shown in Figure 6 and 7:

**Figure 6.** Expansion rate of foamed asphalt.

**Figure 7.** Half-life of foamed asphalt.

It can be seen from Figure 6 that the expansion rate of different water consumption systems of the pitch increases with the rise of temperature at early stage, and then decreases with the rise of temperature, with a critical value of 160°C. The main reason for the increase of temperature before 160°C is that the increase of temperature accelerates the vaporization of water and promotes the formation of foamed asphalt[18]. When the temperature is too high, the asphalt will gradually move from non-Newtonian fluid into Newtonian fluid, resulting in the decrease of the surface tension of asphalt and the rapid loss of foam asphalt, resulting in poor effect of asphalt foaming. If the temperature exceeds 180°C, the asphalt may occur varying degrees aging, so the foaming temperature should be lower than 180°C. As shown in Figure 7, the half-life decreases with the increase of temperature, showing a rule different from the expansion rate. Therefore, the evaluation index of single expansion rate or half-life cannot be used to evaluate the effect of asphalt foaming comprehensively.
3.2. Effect of water consumption on foaming effect
According to Figure 6 and 7, that the expansion rate of asphalt and the half-life of asphalt show the opposite rule in the range of 2% to 4% water consumption. The expansion rate of asphalt increases with the temperature, and the increase is less than 18%. The half-life decreases with the increase of temperature, and the overall decrease is less than 20%. It proved that the increase of water consumption promotes the burst of foamed asphalt and reduces the stability of foamed asphalt.

3.3. Determination of foaming conditions
From the above, it can be concluded that after the volume expansion of asphalt, the thickness of asphalt film turns thinner, which decreases of asphalt stability and half-life. The two trends are opposite. Therefore, the intersection method analyze the best water consumption under two variable conditions more intuitively and accurately, it’s adopted it to determine the expansion rate and half-life of asphalt foaming, and quantitatively analyze the best conditions of asphalt foaming. The change of expansion rate and half-life with water consumption is shown in Figure 8:

![Figure 8. Relationship between water consumption, expansion rate and half-life.](image)

According to the optimal design method, the curve intersection point data reflects the optimization. At the same temperature, when the half-life and the expansion rate reach the maximum at the same time, it is the optimal value. Therefore, the foaming effect of 140°C, 3.8% water consumption is the optimal choice, which is the best foaming condition for PBT / ABS resin reduced foam asphalt.

4. Conclusions
By altering the asphalt temperature and foaming water consumption in preparation of PBT / ABS resin foam asphalt, based on the existing foaming equipment and methods, the influence of water consumption and asphalt temperature on asphalt foaming is explored, and the optimum expansion parts are determined by expansion ratio, half-life and foaming index. The main conclusions are as follows:

1. The expansion rate, half-life and foaming index effectively evaluate the foaming effect of asphalt. The expansion rate and half-life perform the opposite trend with the water consumption. Only by the foaming conditions with larger expansion rate and half-life achieve the best foaming conditions, it shows that the water consumption and asphalt temperature impacts on the foaming effect markedly.

2. At the same temperature, the increase of water consumption increases the expansion rate of asphalt and decreases the half-life. When the water consumption is the same, the higher the temperature is, the greater the expansion rate is. But when the temperature reaches 160°C, the expansion rate does not increase with the increase of the asphalt temperature, and the asphalt with different temperature corresponds to different optimal foaming water consumption.

3. Considering the comprehensive expansion rate, half-life and foaming index, the optimum foaming conditions of the foamed asphalt are that the temperature of the asphalt is 140°C and the water consumption is 3.8%. The expansion rate of the foamed asphalt is 21.3 and the half-life is 22.5s.
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