Evaluation and Optimization Strategies of Environmental Protection Performance for Passenger Seats of EMU

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Abstract. Passenger seats of Electric multiple-unit (EMU) influence environmental performance. Formaldehyde and other volatile organic compounds in the nonmetallic material of the seat is volatilized. Toxic gas is produced by seat material combustion. This study chooses a typical passenger seat and proposes optimization strategies based on the experiment. First, the source of seat formaldehyde and volatile organic compounds is determined through a test. Four optimization strategies, including foaming pretreatment, foaming formula improvement, binder optimization, and bioenzyme spraying, are proposed. Second, the source of toxic gases in the seat is determined through a combustion test on the seat and its nonmetallic materials. Moreover, the optimization strategy for controlling the material of seat fabric is formulated.

Keywords: Passenger seat, Environmental protection performance, Optimizing strategy

1. Introduction

With the rapid development of rail transit, passengers demand for environmentally friendly vehicles. Researchers have gradually extended their attention from the functional indicators of products to the environmental indicators of passengers. Increasing interest has been recently focused on the environmental performance of vehicles. In the past two years, the emergence of several vehicle air quality complaints has led to the proposal of strict requirements for the environmental protection of rail vehicles. On this basis, domestic researchers have conducted substantial research on the environmental performance of vehicles [1-5]. At present, scholars concentrate on the analysis of research status, research of measurement methods, suggestions of management and control, and suggestions of standard setting. Neither evaluation of the environmental protection performance of specific components nor specific optimization strategies have been formulated to improve environmental protection, whose aspects are difficult to control.

In a typical rail transit vehicle, the passenger seat is an important part of interior decoration equipment and considerably affects the environmental performance of an EMU. On the one hand, seats occupy a large proportion of space in EMUs and are mostly made of nonmetallic materials [6]. The formaldehyde and other volatile organic compound contents in nonmetallic materials determine the environmental protection performance of EMUs to a certain extent. On the other hand, several nonmetallic materials in seats are prone to fire [6]. Toxic smoke from fire also affects the environmental performance of EMUs. Considering these aspects, the present study aims to test the typical passenger seat to enhance the environmental protection performance from the nonmetallic
materials that make up the seats. An optimization strategy is proposed on the basis of the test results of formaldehyde, volatile organic compounds, and combustion toxic substances.

2. Seat Composition Material

Fig. 1 shows that EMU seats are usually divided into three types: first-class two-person seat, second-class two-person seat, and second-class three-person seat. The material choices for the three types of seat structures are all comparatively similar. Common nonmetallic materials used in seats are foam, adhesives, masks, PC/ABS plastics, flame retardant felt, rubber, white flannel, and powder coating. Table 1 shows the composition and use position of various nonmetallic materials, whereas Table 2 exhibits the dosage.

![Figure 1. Passenger seat](image)

**Table 1.** Composition and Use Position of Non-metallic Material

| Material          | Component                  | Use location                                                                 |
|-------------------|----------------------------|-------------------------------------------------------------------------------|
| foaming polyurethane | Backrest, cushion          |                                                                               |
| Adhesive Neoprene water | Between Foaming and White Fine Cloth |                                                                               |
| Seat cover Flame retardant polyester fiber | Mid-armrest support plate, cover plate, shell adhesive, rear pedal, backrest |                                                                               |
| PC/ABS plastics Flame retardant, PC+ABS | Decorative cover, clasp, shock absorber, outer cover |                                                                               |
| Flame retardant felt Carbon fiber cotton | Compound cushion and back foam front | Sheath, rubber brace, shock absorber, block assembly |
| Rubber Flame Retardant and EPDM Rubber | Compartmentalization |                                                                               |
| White cloth Fuzz fabric | Foaming of backrest and cushion |                                                                               |
| Coating Plastic powder | Surface of chassis and turntable |                                                                               |
| PA plastics Flame retardant, PA+15%Glass fiber | Nylon retaining rings, drums, sliders, liners, bushes |                                                                               |

**Table 2.** Quantity of Nonmetallic Materials for Seats of Various Types

| Material          | first class two-person seat(g) | second class two-person seat(g) | second class three-person seat(g) |
|-------------------|--------------------------------|---------------------------------|----------------------------------|
| foaming           | 6225                           | 4041                            | 6136                             |
| Adhesive          | 2720                           | 1460                            | 2190                             |
| Seat cover        | 2647                           | 1270                            | 1906                             |
| PC/ABS plastics   | 1145                           | 1545                            | 1886                             |
| Flame retardant felt rubber | 1083                  | 512                             | 659                              |
| White cloth       | 1021                           | 250                             | 346                              |
| Coating           | 455                            | 172                             | 265                              |
| PA plastics       | 277                            | 134                             | 260                              |
| Total             | 15765                          | 9577                            | 13910                            |
3. Seat Volatile Species Material Testing and Optimization Strategy

Under normal use, seats release formaldehyde and volatile organic compounds. Consequently, the environmental performance of EMU is reduced, thus affecting passengers’ health. At present, China’s EMU industry implements standard TB_T 3139-2006, which stipulates that formaldehyde content should be <0.10 mg/m³, and total volatile organic compound (TVOC) content should be <0.60 mg/m³.[7] However, no separate control index for seats is available in the industry and thus inconvenient for detail control. Therefore, this study aims to improve this situation.

3.1. Testing of Seat Volatile Species Compounds

3.1.1 Test mode

The sampling bag method was used in the experiment (Fig. 2). The main testing processes of the sampling bag method are as follows: cleaning the sampling bag and conduit with nitrogen, loading seat in the sampling bag, holding the temperature for a certain time in the thermostat, opening the valve and collecting gas (DNPH tube collecting formaldehyde, Tenax tube collecting VOC), and using a detection instrument to measure gas emissions. When the EMU is under normal operation, the indoor temperature is between 23 °C and 25 °C. On this basis, the test temperature was set to 25 °C. The test time adhered to GB/T 18883, and the holding time was set to 16h [8]. The other test conditions are listed in Table 3.

![Sampling bag method sketch](image1)
![Testing instrument](image2)
![Sampling bag](image3)

Figure 2. Sampling bag method

Table 3. Test conditions

| Sampling bag specification(L) | 2000 | Capture velocity (mL/min) | 200 |
|-------------------------------|------|---------------------------|-----|
| Nitrogen Filling Volume(L)    | 1000 | Trapping volume (L)       | 3   |
| Constant temperature(℃)      | 25   | Capture velocity(mL/min)  | 800 |
| Constant time(h)              | 16   | Trapping volume (L)       | 12  |

In consideration of practicability, the volatilization of passenger seat formaldehyde and volatile organic compounds was observed via natural placement, air blowing, and air drying.

3.1.2. Test result

This study only tested the seats of first-class two-person and second-class two-person seats due to the small size of the sampling bag.

(1) Natural placement

The study was conducted in a storehouse under natural conditions. Table 4 and Fig. 3 demonstrate the results of formaldehyde and volatile matter emissions of the seats after different storage times.
Table 4. Test results of formaldehyde and volatile substances in natural storage

| Seat type               | Time (day) | Formaldehyde (mg/m³) | TVOC (mg/m³) |
|-------------------------|------------|----------------------|--------------|
| second class two-person seat | 4          | 0.480                | 1.959        |
| first class two-person seat   | 4          | 0.403                | 1.030        |
| second class two-person seat | 30         | 0.297                | 0.701        |
| first class two-person seat   | 30         | 0.277                | 0.606        |
| second class two-person seat | 90         | 0.107                | 0.244        |
| first class two-person seat   | 90         | 0.115                | 0.223        |

Figure 3. Test results of formaldehyde and volatile matter in natural storage

(2) Blowing and sunshine

The materials used for the various seats were basically the same. Hence, the second-class two-person seat was taken as an example. Table 5 shows the test results of formaldehyde and volatile substances in the seats under blowing and sunshine exposure conditions in the open air in summer.

Table 5. Test results of formaldehyde and volatile substances under blowing and sunshine exposure conditions

| Seat type               | mode | Time day | Formaldehyde mg/m³ | TVOC mg/m³ |
|-------------------------|------|----------|--------------------|------------|
| second class two-person seat | Blowing | 14       | 0.230              | 0.252      |
| second class two-person seat | Sunshine | 14       | 0.474              | 4.098      |

3.1.3. Result analysis

Table 4 shows that formaldehyde and volatile organic compounds naturally volatilized and decreased with time. The concentrations of formaldehyde and TVOC measured four days after the construction of a new seat were high. After 30 days, the TVOC concentration dropped to a barely acceptable value. By contrast, formaldehyde could not reach an acceptable value until 90 days later. However, 90 days of natural storage is unrealistic in actual production. A reasonable treatment must be adopted to accelerate the volatilization of formaldehyde and TVOC. Table 5 exhibits that the formaldehyde value can reach a natural placement effect for 30 days after 14 days of blowing. On the contrary, the TVOC value could even reach the natural placement effect after 90 days. Therefore, blowing could greatly accelerate the volatilization of formaldehyde and TVOC. Solar treatment was counterproductive. Solar exposure to a certain extent intensified formaldehyde and volatile organic compound production, which is undesirable.

3.2. Testing of Volatile Materials

The formaldehyde and volatile substances in different materials were measured under the corresponding standards to analyse the influence of different materials on the formaldehyde and volatile substance contents. Tables 6 and 2 show that the formaldehyde in EMU seats comes from inside the foaming, whereas the volatile organic compounds originate from adhesives.
Table 6. Test results of volatile substances in major non-metallic materials

| Material          | formaldehyde | Volatile Organic Compounds | Testing standard |
|-------------------|--------------|----------------------------|------------------|
| foaming           | 9g/kg        | 4.4g/kg                    | GB 18586         |
| Seat cover        | —            | —                          | GB 18401         |
| Adhesive coating  | 0.08g/kg     | 563g/L                     | GB 18583         |
| Flame retardant felt | —         | —                          | GB 18401         |
| rubber            | —            | 3g/kg                      | GB 18586         |
| PC+ABS            | —            | —                          | GB 18581         |
| PA                | —            | —                          | GB 18581         |

“—”Show that it has not been detected or is below the detection limit.

According to Table 6 and Table 2, it can be concluded that the formaldehyde in EMU seats mainly comes from inside the foaming, whilst the volatile organic compounds mainly come from adhesives.

3.3. Seat Environmental Performance Optimization Strategy
Blowing can effectively and rapidly reduce the formaldehyde content of seats. However, the implementation of blowing treatment for numerous seats is difficult. Thus, a rapid and economical solution is needed. The mentioned analysis indicates that the initial content of formaldehyde in seats could be reduced by improving the foaming formula. The initial content of organic volatile substances could be reduced by a careful selection of adhesives.

3.3.1 Foaming pretreatment
The seat foam cushion material is polyurethane foam, which is composed of flame-retardant polyether, isocyanate, catalyst, and water flame retardant. Formaldehyde and volatile substances come from inadequate reaction. Only the foam could ripen because the reaction process is difficult to control, that is, the pretreatment has to occur before the seat is installed. Fig. 4 shows the flow chart. First, the gas inside the foam was discharged by roll-in pressing. Second, the foam was baked for 6 h at 50°C~70°C. Lastly, the natural ventilation period lasted for 3~4 days.

![Foaming Pretreatment Process](image)

**Figure 4. Foaming Pretreatment Process**

The pretreated foams were placed on the chair for 4 days. The formaldehyde and volatile gas contents were measured (Table 7). The formaldehyde and volatile gas contents in seats considerably decreased. The formaldehyde tended to be placed in the natural place for 90 days, and TVOC reached the natural place for 30 days.

Table 7. Measurement results using pre-treated foaming

| Seat type                  | Storage time day | Formaldehyde mg/m³ | TVOC mg/m³ |
|----------------------------|------------------|--------------------|------------|
| second class two-person seat | 4                | 0.123              | 0.607      |
| first class two-person seat  | 4                | 0.141              | 0.672      |
3.3.2 Improvement of the foaming formula

Polyurethane foaming is produced by mixing polyether and isocyanate. The raw material of isocyanate is one of the main sources of formaldehyde and VOC.[9] The raw and processed material formula before improvement is as follows: Polyether mixtures used polyether 1618 and polyether. Isocyanate used MR-200, TDI, MDI5005, and an MDI modified 2082. The improved formula is as follows: Polyether mixtures used polyether 330D, polyether3630D, whereas isocyanate used a modified MDI8598.

The foam of the improved formula was mounted on the chair. The changes of the formaldehyde and volatile gas content with time were measured (Table 8). The TVOC and formaldehyde gas releases were remarkably reduced, and less formaldehyde was remarkable. Under this basic value, the formaldehyde content slightly changed with time.

**Table 8.** Test results after the foaming formula for seats is improved

| Seat type              | Type condition   | Test time h | Formaldehyde mg/m$^3$ | TVOC mg/m$^3$ |
|------------------------|------------------|-------------|------------------------|---------------|
| second class two-person seat | Ventilation and airing | 24          | 0.08                   | 0.39          |
|                        |                  | 48          | 0.05                   | 0.36          |
|                        |                  | 72          | 0.06                   | 0.36          |
|                        |                  | 96          | 0.06                   | 0.35          |
|                        |                  | 120         | 0.06                   | 0.33          |
|                        |                  | 144         | 0.06                   | 0.30          |

![Figure 5. Foaming Treatment](image)

3.3.3. Optimizing adhesive

On the basis of improving foaming, chloroprene rubber was further changed into hot melt adhesive using low formaldehyde and VOC. The test results after the chair optimization was 0.060 and 0.224 mg/m$^3$ for formaldehyde and TVOC, respectively. The adhesive optimization had a significant effect on TVOC content reduction.

3.3.4. Spraying bioenzymes

Approximately 40mL of bioenzymes was sprayed on the second-class two-person seats with unoptimized foam and adhesive. Table 9 shows the results of formaldehyde and volatile matter measurement before and after spraying for seats without optimized foaming and adhesives. Table 10 shows the measurement results of formaldehyde and volatile substances before and after spraying for seats with optimized foaming and adhesives.

**Table 9.** Testing results of bio-enzymes for seat spraying with unoptimized materials

| Seat type                | Storage time(day) | formaldehyde(mg/m$^3$) | TVOC(mg/m$^3$) |
|--------------------------|-------------------|------------------------|---------------|
| second class two-person seat | Before spraying    | 0.15                   | 0.55          |
|                          | After spraying     | 0.08                   | 0.38          |
### Table 10. Testing results of bio-enzymes for seat spraying with optimized materials

| Seat type                      | Type time(day)               | formaldehyde (mg/m³) | TVOC (mg/m³) |
|-------------------------------|------------------------------|----------------------|--------------|
| second class two-person seat  | Before spraying Airing for 6h| 0.06                 | 0.35         |
|                               | After spraying Airing for 3 hours | 0.02                 | 0.15         |
|                               | After spraying Airing for 15h | 0.02                 | 0.15         |
|                               | After spraying Airing for 63h | 0.02                 | 0.15         |

Tables 9 and 10 show that bioenzymes could effectively reduce the release of formaldehyde and volatile organic compounds. Spraying for nonoptimized seats could reach the level of optimized foaming and adhesives. However, this process had no evident effect on the optimized seats. The effect of spraying a bioenzymatic agent on the optimized seat was evident and stable over a certain period of time.

### 4. Seat Toxicity Testing and Optimization Strategy

The ignition and combustion of EMU seats produce numerous toxic gases because of the large amount of nonmetallic materials. Consequently, the EMU environmental protection is seriously affected, and the lives of passengers are at risk. Therefore, improvement measures for seat materials should be proposed to reduce toxic gases during seat combustion.

#### 4.1 Toxicity smoke test of nonmetallic materials

The standard TB/T 3237-2011 measurement method can determine the source of toxic gases in seat combustion [10]. Combustion tests were performed on the nonmetallic materials constituting the seat, and combustion gases were detected.

### Table 11. Toxic components of nonmetallic materials

| toxicity gas | Standard requirements ppm | polyurethane foam ppm | Adhesive /ppm | First-class seats cover ppm | Second-class seats cover ppm | PC/ppm | Flame retardant felt ppm | Rubber ppm | Powder coating ppm | PA ppm |
|---------------|---------------------------|-----------------------|---------------|------------------------------|-------------------------------|--------|--------------------------|------------|------------------|--------|
| CO            | 3500                      | 417                   | 152           | 20.5                         | 252                           | 2107   | 115                      | 1153       | 126              | 1186   |
| CO2           | 50000                     | 6956                  | 3353          | 2509                         | 9509                          | 6551   | 2654                     | 9218       | 3420             | 6785   |
| HF            | 100                       | -                     | -             | -                            | -                             | -      | -                        | -          | -                | -      |
| HBr           | 100                       | -                     | 3.6           | -                            | -                             | 14     | 5.9                      | -          | 4.9              | 13.1   |
| HLC           | 100                       | -                     | 14.5          | -                            | -                             | 6.9    | 18.6                     | -          | 19.5             | 21     |
| NO2           | 100                       | -                     | -             | 2.6                          | 8                             | -      | 9                        | -          | -                | -      |
| SO2           | 100                       | -                     | -             | -                            | 4.1                           | 60     | -                        | -          | -                | -      |
| HCN           | 100                       | 41                    | -             | -                            | 22.5                          | 30.7   | 2                        | -          | 23               | -      |

"-"Show that it has not been detected or is below the detection limit.

#### 4.2. Whole chair toxicity smoke test

Seat surface combustion was simulated in accordance with the DIN5510 standard to determine the smoke composition of the actual seat combustion.[11] Fig. 7 demonstrates that during the combustion process, only masks and flame retardant felt were damaged. The foaming of the lower layer was
unaffected. The smoke components at four minutes and eight minutes of combustion were detected; the results are recorded in Table 12.

Figure 7. Seat and Chair Surface Combustion Test

Table 12. Tobacco poisoning of nonmetallic materials

| Toxicity gas | Concentration benchmark (mg/m³) | First-class two-person seat four minutes | Second-class two-person seat four minutes | First-class two-person seat eight minutes | Second-class two-person seat eight minutes |
|--------------|---------------------------------|----------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|
| CO           | 1380                            | 5.4                                    | 151.4                                    | 8.6                                      | 227.0                                    |
| CO₂          | 72000                           | 2378.4                                 | 29050.2                                  | 4417.0                                   | 41395.1                                  |
| HF           | 25                              | -                                      | -                                        | -                                        | -                                        |
| HBr          | 99                              | -                                      | -                                        | -                                        | -                                        |
| HCL          | 75                              | -                                      | -                                        | -                                        | -                                        |
| NO₂          | 38                              | 3.6                                    | 19.5                                     | 3.6                                      | 30.2                                     |
| SO₂          | 262                             | -                                      | -                                        | -                                        | -                                        |
| HCN          | 55                              | -                                      | -                                        | -                                        | -                                        |

"-"Show that it has not been detected or is below the detection limit.

4.3. Seat optimization strategy

The analytical results of the above-mentioned experiments indicate that the masked cloth and flame-retardant felt are the main combustion factors in the whole chair combustion because the foam of composite flame-retardant felt is under the cover cloth of the chair. Therefore, if we want to control the smoke of the whole chair in the fire, then the first task would be to control the smoke output of the masks and fire-retardant felt.

5. Conclusions

The conclusions are drawn as follows:

(1) Long-term natural storage can effectively reduce formaldehyde and volatile organic compounds, but the cycle is long. Blowing can accelerate the volatilization of formaldehyde and volatile organic compounds, especially for TVOC. Sunlight not only cannot reduce volatile substances, but can promote their formation.

(2) Formaldehyde in EMU seats comes from foaming, and volatile organic compounds originate from adhesives.

(3) The effective methods to reduce formaldehyde and volatile substances are foaming pretreatment, foaming formula improvement, binder optimization, and bioenzyme spraying. The treatment effects of different strategies are different. The volatilization of formaldehyde after foaming by roller pressure tends to the level of 90 days after natural storage. The TVOC levels reach the level of 30 days after natural storage. Optimizing foaming and adhesives can drastically reduce formaldehyde and volatile organic compound releases. Bio-enzymatic treatment is more direct and rapid than other methods, but the cost is higher.
(4) Combustion tests of the seat’s nonmetallic materials show that the amount of smoke produced by different materials varies. The combustion test of the whole chair shows that the smoke comes from the masks and fire-retardant felt. The proportion of toxic gases produced by the combustion of different seats is closely related to the materials. Controlling the seat fabric material is an effective means to reduce the emission of toxic gases.

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