Study of material strength properties for horizontal road marking using innovation equipment

V I Bochkarev\textsuperscript{1}, E V Zhustareva\textsuperscript{1}, S V Fedorov\textsuperscript{1}

\textsuperscript{1}Moscow Automobile and road construction state technical university (MADI), Moscow, Russia

E-mail: joustareva@mail.ru

Abstract. The article deals with the study of strength properties of materials used for horizontal road marking. The investigations were carried out on the basis of the chair “Construction and Maintenance of Roads” of MADI and NTTs “Katafot”. The tests were performed on marking materials that are most common and frequently used in the Russian Federation. Thermoplastics and cold plastics were selected for research. For the tests, up-to-date high-precision equipment (AMPT / SPT installation) was used, which made it possible to take measurements in automatic mode as well as to save and process data. During the experiments, the dependences of the dynamic modulus of thermoplastics and cold plastics on the frequency of load application (loading frequency) and temperature were investigated. The researches resulted in recommendations for the use of materials to arrange the horizontal road marking under various operating conditions. The aim of the study is to improve the quality and durability of road markings as well as to ensure road traffic safety. The current scientific work has relevance to the implementation of the national project "Safe and High-Quality Roads".

1. Introduction

At present, the national project "Safe and High-Quality Roads" is being implemented. The completion date of the project is 2024. The project includes four federal projects: "Road network", "System-wide measures for the development of road sector", "Traffic safety" and "Highways of the Russian Ministry of Defense". One of the main objectives of the federal projects "Road Network" and "System-Wide Measures for the Development of the Road Sector" is to decrease the number of places, where traffic accidents (TA) are concentrated, as well as the number of federal and regional roads at heavy traffic.

To resolve these tasks there is continuous effort to improve the methods and means of traffic organization. Road marking is one of three kinds of technical means to organize information traffic. World experience shows that the cost of road marking is at least an order of magnitude lower than the damage caused by traffic accidents.

In recent years in Russia, the areas of thermoplastic and cold plastic markings on the federal public road network have dramatically increased [1]. As a rule, thermoplastics are used for applying longitudinal lines of road markings. In so doing, marking machines to apply materials by a mechanized mode are used. From a technological point of view, cold plastic is traditionally a more convenient material for performing "manual works", i.e., applying "symbolic" markings using the scotch-stencil method. However, recently, the technologies for cold plastic longitudinal marking by a mechanized mode, which use special aggregates incorporated in marking machines, have been intensively developed.

In spite of the fact that the cost of 1 kg of cold plastic is approximately 3 times higher than the cost of thermoplastic, the share of the cold plastic road marking is increasing. Nevertheless, even if taking into account the facts cited, the cost of material per unit of the marking area for cold plastic is 1.3-2.0 times higher as compared with that of thermoplastic.

In foreign countries, cold plastic is believed to be a high-quality material for road marking. Firstly, cold plastic is a more stable and durable material; secondly, its physical and mechanical features do not
depend on temperature. The Federal Road Agency also agrees with this point of view, considering that the use of more durable, but more expensive types of materials will be economically beneficial. The scientific and normative literature, however, does not provide sufficient information about strength indices of these materials, as well as about the change in these indices depending on temperature. Data on comparative tests of thermoplastics and cold plastics are utterly lacking. So, there is a need to carry out researches on changes in strength properties of marking materials. Reliable information allows selecting properly these materials for the use under different operating conditions. Thus, this will provide durability of road marking and, as a result, highway traffic safety as well.

2. Materials and methods
Comparative tests of thermoplastics and cold plastics were performed on the basis of the MADI chair “Construction and Maintenance of Road” and NTTs “Katafot”. Following tasks were set:

- to measure the strength of thermoplastics and cold plastics used for road marking depending on temperature;
- to define the field of application and to give recommendations for using these materials under different operating conditions.

The methods to estimate and compare strength characteristics of thermoplastics and cold plastics for road marking are lacking both in domestic and foreign standard test methodologies [2, 3, 4].

The AMPT/SPT (Asphalt Mixture Performance Tester) plant that is usually applied for asphalt concrete testing under various temperature conditions was used for tests. Thermoplastics and cold plastics are elastic-viscous-plastic materials, so the plant in question was used as a system that made it possible to determine similar properties of materials.

The AMPT/SPT plant (Figure 1) takes measurements of the dynamic modulus that characterizes a material hardness [5].

Three labels of thermoplastics and two labels of cold plastics, which are widely applied for road marking in Moscow as well as on Russian federal roads, were selected for experimental studies. Each material was assigned its code in order to avoid advertising - anti-advertising of manufacturers:

- thermoplastics TP 1, TP 2, TP 3;
- cold plastics CP 1, CP 2.

The AMPT / SPT test requires cylindrical samples 100 mm in diameter and 150 mm in height (Figure 2).

Thermoplastics were heated to the operating temperature advised by the material manufacturer. The material was stirred at operating temperature within the time also recommended by the manufacturer. To avoid strong deformation of samples owing to thermal shrinkage during cooling, the mold was poured layer-by-layer. The pouring was performed in three steps, until each layer cooled down to a temperature of 60-80 °C.

During making cold plastic samples the ratio of the base material to the hardener advised by the manufacture was strictly observed. The material was thoroughly stirred and poured into forms before hardening.

Figure 1. General view of AMPT/SPT plant.

Figure 2. Test samples.
3. Sample testing

Before testing, 6 anchors were glued on the sample to set sensors for reading the sample deformation during loading. Then the sample was placed in a climatic chamber (Figure 3), where it was kept for two hours at different temperatures (+ 4 °C, + 10 °C, + 20 °C, + 30 °C, + 35 °C). After that, the dynamic loading process was started (Figure 4). The test was performed in automatic mode. The sample was loaded at different frequencies (from 0.1 to 25 Hz). Upon completion of the tests, a summarized table with the results of measured values was displayed on the computer. The process was repeated for each temperature level.

The tests resulted in obtaining the values of the dynamic modulus at various temperatures and loading frequencies. Figures 5-7 show the data for thermoplastics. Figures 8-9 demonstrate the data for cold plastics.

![Figure 3. Placing of the sample into a climatic chamber.](image1)

![Figure 4. Startup of the test program.](image2)

| Temperature (°C) | Frequency (Hz) | Dynamic Modulus (MPa) |
|-----------------|---------------|-----------------------|
| 4°C             | 0.1           | 12065                 |
|                 | 0.2           | 11872                 |
|                 | 0.5           | 11320                 |
|                 | 1             | 10719                 |
|                 | 2              | 9888                  |
|                 | 5              | 9195                  |
|                 | 10             | 8490                  |
|                 | 20             | 7501                  |
|                 | 25             | 6745                  |
| 10°C            | 0.1           | 10399                 |
|                 | 0.2           | 10156                 |
|                 | 0.5           | 9482                  |
|                 | 1             | 8762                  |
|                 | 2              | 7775                  |
|                 | 5              | 6990                  |
|                 | 10             | 6179                  |
|                 | 20             | 5085                  |
|                 | 25             | 4271                  |
| 20°C            | 0.1           | 8309                  |
|                 | 0.2           | 8035                  |
|                 | 0.5           | 7250                  |
|                 | 1             | 6425                  |
|                 | 2              | 5301                  |
|                 | 5              | 4434                  |
|                 | 10             | 3582                  |
|                 | 20             | 2509                  |
|                 | 25             | 1771                  |
| 30°C            | 0.1           | 4311                  |
|                 | 0.2           | 4042                  |
|                 | 0.5           | 3237                  |
|                 | 1             | 2462                  |
|                 | 2              | 1553                  |
|                 | 5              | 1003                  |
|                 | 10             | 609                   |
|                 | 20             | 296                   |
|                 | 25             | 167                   |
| 35°C            | 0.1           | 2215                  |
|                 | 0.2           | 1993                  |
|                 | 0.5           | 1364                  |
|                 | 1             | 869                   |
|                 | 2              | 441                   |
|                 | 5              | 256                   |
|                 | 10             | 151                   |
|                 | 20             | 76                    |
|                 | 25             | 45                    |

Frequency, Hz

Figure 5. Diagram of the dynamic modulus change in TP 1.
Figure 6. Diagram of the dynamic modulus change in TP 2.

Figure 7. Diagram of the dynamic modulus change in TP 3.
4. Analysis of test results

The analysis of diagrams of changes in the dynamic modulus depending on loading frequency showed that thermoplastics and cold plastics had the properties of classic elastic-viscous-plastic materials. The
values of the dynamic modulus of such materials depended on the frequency of loading impact: the more frequent the load is, the higher the values of the dynamic modulus will be.

To compare and analyze the properties of test materials the diagrams of the dynamic modulus changes depending on the temperature at a frequency of 10 Hz, which corresponded to the duration of a single load of 0.1 s, were plotted (Figure 10). According to the diagrams, some thermoplastics showed higher values of the dynamic modulus than cold plastics. Thus, it cannot be argued that cold plastics have higher strength properties than thermoplastics.

The tests have demonstrated that there was a significant decrease in the values of the dynamic modulus with the increase in temperature both for cold plastics and thermoplastics. Thus, a generally accepted statement that thermoplastics and cold plastics have a different nature of changes in the strength properties at temperature change has not been confirmed.

| Temperature, °C | Dynamic modulus, MPa |
|----------------|-----------------------|
| 4              | 5937                  |
| 10             | 4611                  |
| 20             | 2633                  |
| 30             | 1183                  |
| 35             | 589                   |

| Temperature, °C | Dynamic modulus, MPa |
|----------------|-----------------------|
| 4              | 6467                  |
| 10             | 4868                  |
| 20             | 2589                  |
| 30             | 1171                  |
| 35             | 656                   |

| Temperature, °C | Dynamic modulus, MPa |
|----------------|-----------------------|
| 4              | 11320                 |
| 10             | 9482                  |
| 20             | 7250                  |
| 30             | 3237                  |
| 35             | 1364                  |

| Temperature, °C | Dynamic modulus, MPa |
|----------------|-----------------------|
| 4              | 10323                 |
| 10             | 8934                  |
| 20             | 6098                  |
| 30             | 2762                  |
| 35             | 1364                  |

| Temperature, °C | Dynamic modulus, MPa |
|----------------|-----------------------|
| 4              | 5069                  |
| 10             | 3919                  |
| 20             | 1500                  |
| 30             | 527                   |
| 35             | 285                   |

Figure 10. Cumulative diagram of test results at 10 Hz loading frequency.

5. Conclusion

Researches resulted in the following conclusions:

1) there is no significant difference between the properties of cold plastics and thermoplastics under short-term loading of the samples (determination of the dynamic modulus);
2) contrary to well-established opinion, the properties of cold plastics change at temperature change as well: the dynamic modulus decreases 5 times when the temperature changes from +10 to +30°C;
3) if there is no difference in the properties of materials studied under short-term loading, it makes no sense to use more expensive cold plastic for those lines of road marking where continuous static loads or significant shear loads are hardly probable.

References

[1] ODM 218.6.020-2016 Guidelines for road marking (Moscow: Rosavtodor [Federal road agency]), 2016
[2] GOST 32829-2014 Automobile roads of general use. Road marking materials. Methods of testing (Moscow: Standartinform), 2015
[3] GOST R 52576-2006 General use highways. Road marking materials. Test methods (Moscow: Standartinform), 2007
[4] EN 1871:2000 *Road Marking materials. Physical properties* (Brussels: European Committee for Standardization), 2012

[5] AASHTO T 378 *Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)* (Washington: American Association of State Highway and Transportation Officials), 2017