WEP Warwick Evans Publishing

International Journal of Natural Resources and Environmental Studies

ISSN: 3006-2012 (Print), ISSN: 3006-0834 (Online) | Volume 8, Number 3, Year 2026
DOI: https://doi.org/10.62051/ijnres.v8n3.03
Journal homepage: https://wepub.org/index.php/IJNRES/index

Research Status of Composite Thin Spray Materials

Yulong Han*

Henan Polytechnic University, Jiaozuo, Henan, 454003, China
*Corresponding Author: Yulong Han (2410384654@qq.com)

ABSTRACT

In order to adapt to the development of The Times, reduce the construction amount of workers and meet the requirements of intelligent roadway construction, there is an urgent need for a new material to solve the existing problems of the existing support materials. Thin spray material is a kind of polymer cement based material, which has the effect of preventing weathering of surrounding rock, spontaneous combustion of coal seam, harmful gas sealing, preventing corrosion of metal support and supporting of surrounding rock. This paper mainly summarizes the research progress of thin spray materials in recent years and the mechanical properties and sealing properties of thin spray materials, finds the problems of existing thin spray materials in the market and puts forward their own views, and finally prospects the future of thin spray materials.

KEYWORDS

Thin spray material; Mechanical properties; Cement-based material.

1. INTRODUCTION

Bolt-mesh-shotcrete support is the predominant support method in coal mine roadways [1]. "Bolting" involves installing rock bolts into the deep surrounding rock to prevent its deformation and mobilize the self-bearing capacity of the rock mass. "Mesh" refers to the wire mesh placed on the roadway surface and connected to the bolts, which prevents the detachment of small, loose rock blocks between bolts, thereby maintaining the stability of the integrated support system and the surrounding rock. "Shotcreting" is the application of a concrete layer onto the surrounding rock surface, providing continuous support and sealing the rock to prevent weathering and corrosion. While bolt installation has largely been mechanized, mesh installation remains labor-intensive with a low level of mechanization, presenting challenges to support efficiency and safety. Furthermore, the difficulty in achieving a smooth roadway surface often results in poor contact between the mesh and the rock, delaying the mobilization of support capacity. Shotcrete is a brittle material that is prone to failure under the significant tensile stresses induced by the large deformations common in coal mine roadways during construction. Additionally, its application is associated with drawbacks such as high dust generation and heavy workload. In contrast, tough thin spray-on materials (TSMs) offer advantages including an effective sealing capability, a thin application layer, low workload, and high spraying efficiency, making them a promising direction for future research and development.

2. MATERIAL PROPERTIES AND SUPPORTING MECHANISMS

Thin spray material is a high-performance composite material possessing high flexural and shear strength. It exhibits excellent film-forming properties, ductility, flame retardancy, airtightness, flexibility, and environmental friendliness. Based on the theory and practice of bolt-shotcrete support, the thin spray material product series utilizes high-performance composites to replace traditional shotcrete for achieving surrounding rock sealing and auxiliary support. It can effectively address the persistent drawbacks of shotcrete: dirtiness, labor-intensiveness, brittleness, and high cost.

The support mechanism of thin spray materials for support primarily includes the load-bearing layer effect, the bonding effect, and the wedging effect [2]. The load-bearing layer effect mainly refers to the ability of the sprayed shell to bear external stress through its own compressive and flexural strength. The bonding effect is achieved through the adhesion between the sprayed layer and the underlying rock surface (see Figure 1). The wedging effect occurs when the spray material penetrates and bonds within the fractures of the surrounding rock, preventing rock blocks from falling due to insufficient space for dilation and shear (see Figure 2). Through the bonding and wedging effects, fragmented rock is consolidated into an interlocked rock mass, preventing loosening and detachment, thereby enhancing the integrity and stability of the surrounding rock.

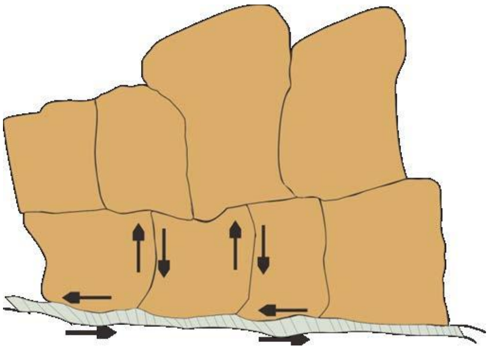

Figure 1 Bonding effect with the rock surface

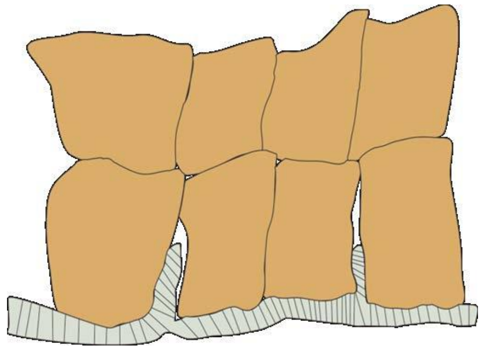

Figure 2 Bonding effect penetrating fractures in the surrounding rock

3. CURRENT RESEARCH STATUS

Support-oriented thin spray materials evolved from sealing-type thin spray materials. Currently, foreign sealing-type thin spray material technology has matured, with dozens of products available, such as BASF's Masterseal series. These are widely used in roadway sealing projects, either replacing shotcrete or being used in conjunction with it, representing a new type of roadway surface support material. In China, research on sealing-type thin spray materials began in the 1990s and has since been widely applied in engineering fields such as waterproofing, anti-weathering, and air leakage prevention. After years of development, sealing-type thin spray materials have laid the foundation for support-oriented thin spray materials.

3.1 International Research Progress

Research Progress on Tensile Properties. The tensile strength test for thin spray materials is generally based on the ASTM D638 standard (The Standard Test Method for Tensile Properties of Plastics), using dumbbell-shaped specimens. YILMAZ [3] conducted tensile strength tests on 35 spray membrane products available on the market (all but three, which were polyurethane-based, were polymer-cement-based materials) under different curing periods, with tensile strengths ranging from 0.5 to 7.5 MPa. Guner and Ozturk [4] investigated the effect of curing time on the tensile properties of two thin spray materials. The thin spray material specimens were processed into dog-bone specimens and cured for 1, 7, 14, 21, and 28 days, respectively. The tensile strength, Young's modulus, and elongation at break of the materials were calculated from the tensile test data. The results showed that with increasing curing time, the tensile strength and Young's modulus of the materials increased, while the elongation at break decreased. Notably, the most significant changes in these three mechanical parameters of the thin spray materials occurred when the curing time increased from 1 day to 7 days. Mpunzi et al. [5] tested the reinforcing effect of sprayed flexible membranes on the tensile strength of rock and concrete using the Brazilian splitting test and the three-point bending test. It was found that for a high-strength, brittle rock, the tensile strength could be increased by approximately 30%, and for concrete, by 40%. However, for a porous sandstone, the strength decreased, which may be attributed to the weakening effect of water absorption by the sandstone.

Research Progress on Bonding Performance. Yilmiz [6] conducted a study on the 1 to 28-day tensile bond performance of 20 thin spray materials, and the results indicated that the tensile bond strength of most thin spray materials increased over time. Ozturk et al. [7] applied TSL materials onto different substrates (concrete, granite, and sandstone matrices) and bonded them with metal pull-heads, calculating the tensile bond strength from the pull-off load and bonded area. The results showed that the bond strengths of the developed support-oriented thin spray material on sandstone and granite were 11.4 MPa and 10.4 MPa, respectively, which were significantly higher than the bond strength on concrete (3.7 MPa). Additionally, the study investigated the effect of loading rate on tensile bond strength and found that the effect of loading rate was considered negligible. Ozturk [8] found that thin spray materials can achieve good bonding performance with the substrate only when their tensile strength exceeds 2 MPa, and identified bonding performance as a critical performance indicator affecting the application of thin spray materials. Based on experiments, it was suggested that the spraying thickness of thin spray materials should not be less than 4 mm. Li et al. [9] discovered through experiments that higher strength and greater surface roughness of the rock substrate lead to better bonding performance between the thin spray material and the substrate. Yilmaz [10] introduced the direct pull-off test method for measuring the tensile bond strength between thin spray materials and the substrate, and based on this experimental method, tested the bonding performance of different thin spray materials with the substrate.

Research Progress on Shear Performance. Tanant [11] suggested that the support capacity of thin spray materials primarily relies on their bonding, shear, and tensile properties, noting that research on the shear performance of these materials is relatively limited. Hadjigeorgiou and Grenon [12] proposed that the shear strength of thin spray materials is almost equivalent to their tensile strength. Qiao et al. [13] conducted tests on the shear strength of spray membrane materials and various substrates, including dry coal, wet coal, coarse sandstone, and fine sandstone, using different methods such as double-sided shear, full ring, and partial ring tests. A stamping method was employed to test the shear strength of glass fiber-reinforced spray membrane materials. The results indicated that glass fiber reinforcement imparted higher shear strength and increased the ductility of the thin spray material specimens. Qiuqiu Qiao [14] proposed a segmented ring shear test, a method that minimizes the influence of shrinkage-induced normal stress on shear bond strength, thereby improving the accuracy of evaluating the shear bond strength of thin spray materials.

Research Progress on Load-Bearing Capacity. Load-bearing capacity is a crucial indicator for evaluating the support performance of thin spray materials, as it directly affects the stability of roadway surrounding rock and the safety of the support structure. International scholars have relatively early conducted research on the support mechanism and mechanical properties of thin spray materials. It is believed that after being sprayed onto the surrounding rock surface, thin spray materials can fill fractures and enhance interfacial bonding, thereby improving the integrity of the surrounding rock. Together with the rock, they form a load-bearing system similar to a "thin-shell structure," effectively sharing the rock load and inhibiting rock deformation [15]. Furthermore, studies indicate that the support function of thin spray materials is mainly manifested in aspects such as bonding reinforcement effects, confinement effects, and thin-shell load-bearing effects. During the development of surrounding rock deformation, they can gradually form an integral stress structure, enhancing the overall load-bearing capacity of the support system [16]. In recent years, international research has also analyzed the mechanical properties of fiber-reinforced thin spray materials through experiments and numerical simulations. The results show that the incorporation of fibers can significantly improve the tensile strength, toughness, and load-bearing capacity of the material, thereby enhancing the stability of roadway support structures. Stacey [17] proposed that good bonding between the spray membrane structure and the rock can reduce stress and strain caused by deformation, inhibit rock movement and rotation, and thereby play a role in controlling the detachment of hazardous rock blocks. Shan et al. [18] conducted large-scale comparative experiments and found that, compared with welded mesh, simulated rock specimens reinforced with spray membranes exhibited higher peak strength. They also simulated the support effect of a spray material on the buckling failure of roof rock, discovering that the spray material can bond with the rock to form a composite thin layer, enhancing the specimen's resistance to surface failure.

3.2 Domestic Research Status

Compared with foreign countries, domestic research on thin spray materials started relatively late and has yielded relatively fewer achievements. Wei Qun [19] discovered through experiments that thin spray materials have a minor effect on the strength of dense rock but a significant effect on the strength of loose rock. The study showed that the material can enhance the confined compressive strength of the substrate by forming a complete bonded structure of a certain thickness with it, thereby improving its load-bearing capacity. Furthermore, Brazilian splitting test results indicated that thin spray materials help maintain the integrity of the rock surface layer, demonstrating their good surface protection performance.

In terms of material development, Li Hongxian et al. [20] developed a thin spray material primarily composed of "VAE emulsion with a fixed water-cement ratio of 50% and a polymer-cement ratio of 15%," supplemented with components such as light calcium carbonate, cellulose, and accelerators. The spraying parameters were optimized through a series of experiments. Engineering applications showed that when the maximum roof displacement reached 380 mm and the maximum rib displacement reached 91 mm, the sprayed layer remained intact. After roadway spraying, the air leakage rate decreased significantly, and as the spraying range expanded, the CO volume fraction in the goaf near the final mining line continuously decreased and remained at a low level, effectively mitigating the risk of spontaneous combustion of residual coal. Similarly, Li Xuebin et al. [21] developed a new type of polymer spray material, achieving good support effects in weakly cemented soft rock roadways.

To further elucidate the support performance of thin spray materials, Zhang Nong et al. [22] systematically measured their mechanical properties and conducted comparisons with steel mesh and shotcrete in terms of timeliness of load-bearing, load-bearing capacity, deformation adaptability, conformity to the surrounding rock surface, and construction technology. The results indicated that although thin spray materials can achieve timely load-bearing, their load-bearing capacity is weaker than that of shotcrete and steel mesh, and they cannot play a structural support role. However, they exhibit significant advantages in construction adaptability and conformity to uneven rock surfaces. Chen Qingfa et al. [23] investigated the influence of the water-cement ratio on the tensile strength of the material from a microstructural perspective through macroscopic tensile tests and pore analysis. They found that an increase in the water-cement ratio leads to larger pore sizes, but an excessively low water-cement ratio can deteriorate the long-term pore structure, affecting material stability.

In terms of material modification and ratio optimization, Zheng Diantao et al. [24] focused on improving the strength, toughness, and deformation adaptability of cement-based thin spray materials, exploring their reinforcement mechanism, and providing a theoretical basis for the application of thin spray materials in coal mine roadways. Chen Lianjun et al. [25] conducted tensile bond strength tests based on different lithological substrates and spray layer thicknesses, finding that the bond strength of support-oriented materials with coal substrates is significantly influenced by the tensile strength of the substrate itself, and that the bond strength becomes more stable when the spray layer thickness reaches 5 mm. He Yudi et al. [26-27] further studied the shear characteristics of waterproof layers and interfaces, summarizing three failure modes: interfacial shear failure, cohesive failure within the waterproof layer, and substrate shear failure, with interfacial failure and interfacial-cohesive mixed failure being the predominant forms.

Domestic scholars' research on shotcrete and thin spray materials has mainly focused on mechanical properties, failure mechanisms, and load-bearing support characteristics. Existing experiments have shown that shotcrete can form a load-bearing layer of a certain thickness on the surrounding rock surface and can work synergistically with components such as anchor bolts to form a composite support system, thereby enhancing the overall load-bearing capacity of the roadway [28]. At the same time, laboratory tests and field monitoring results also indicate that the cooperative deformation of the thin spray layer and the surrounding rock can form a shell-like load-bearing structure, helping to improve the load-bearing performance of the support system at the peak stage [29]. In general, load-bearing capacity is widely regarded as a core indicator for evaluating the support performance of thin spray materials. Its magnitude is not only constrained by the material's own strength characteristics but also closely related to factors such as fiber content, interfacial bonding performance, and the synergistic effect with the surrounding rock [30].

4. CONCLUSIONS

As a novel material with broad application prospects, thin spray materials have achieved remarkable research progress. Both laboratory experiments and field trials have demonstrated their favorable support performance. However, due to their significantly thinner application layer compared to concrete and their pronounced ductile behavior, the support effectiveness of spray membranes remains questionable. Furthermore, when applied to mine support, there is a lack of widely accepted standards for testing, design, and construction. Under coal mine conditions, application cases and fundamental research on their use as a support method, in particular, remain relatively scarce.

In response to these issues, further optimization of the material formulation is required to enhance the performance of thin spray materials. Extensive application in mine support construction should be undertaken to establish comprehensive field construction data, thereby providing a foundation for the development of new thin spray materials. The application of thin spray materials in underground coal mines should follow the principle of gradual progression. Initially, they can be used to replace shotcrete in scenarios where a structural role is not required, or to partially replace mesh under favorable geological conditions. Additionally, spray membranes can be used in combination with existing surface protection methods.

Thin spray materials, which are flame-retardant, sealing, and reinforcement materials for underground coal mine applications, are of great significance for mine safety. Future research and development of thin spray materials will place greater emphasis on environmental friendliness and efficiency. As societal attention on environmental protection and safety in production intensifies, the demands for the eco-friendliness and high efficiency of mining materials will continue to increase. Moreover, with the advancement of digitalization and intelligence, the construction processes for thin spray materials are likely to become more intelligent and automated. The future prospects for thin spray materials will focus more on environmental sustainability, high efficiency, intelligence, and customization. Although future developments still hold uncertainties, it is anticipated that thin spray materials will play an increasingly significant role in future applications.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

[1] Wei Jingyun. Application of Polyurethane Materials in Coal Mine Production[J]. Coal Mining Technology, 1994, 3: 10-14.

[2] Shi Ling. Research Progress on Shotcrete Layer Support Mechanism in Underground Engineering[J]. Chinese Journal of Underground Space and Engineering, 2011, 7(04): 759-763.

[3] YILMAZ Halil. Tensile strength testing of thin spray-on liner products (TSLs) and shotcrete [J].The Journal of Southern African Institute of Mining and Metallurgy,2010,110:559-569.

[4] Guner D, Ozturk H. Experimental and Numerical Analysis of the Effects of Curing Time on Tensile Mechanical Properties of Thin Spray-on Liners[J]. Rock Mechanics & Rock Engineering, 2016, 49(8): 3205- 3222.

[5] Mpunzi P, Masethe R, Rizwan M, et al. Enhancement of the tensile strengths of rock and shotcrete by thin spray-on liners[J]. Tunnelling and Underground Space Technology, 2015(49): 369-375.

[6] Yilmaz,H.2007 . Shear-bond strength testing of thin spray-on liners . J. S. Afr. Inst. Min. Metallurgy, 107:519-530 .

[7] Ozturk H, Tannant D. Thin spray-on liner adhesive strength test method and effect of liner thickness on adhesion[J]. International Journal of Rock Mechanics and Mining Sciences, 2010, 47(5): 808-15.

[8] OZTURK H. Work of adhesion of thin spray-on liners[J].Rock Mechanics and Rock Engineering,2012,45(6):1095-1102.

[9] LI Zecheng,NOCELLI Benjamin,SAYDAM Serkan.Effect of rock strength and surface roughness on adhesion strength of thin spray- on liners[J]. International Journal of Rock Mechanics and Mining Sciences,2017,91:195-202.

[10] YILMAZ Halil. Comparison of tensile bond strength of thin spray on liners[J]. International Journal of Mining, Reclamation and En- vironment,2012,27(1):56-71.

[11] Tannant D. Thin spray-on liners for underground rock support[C]// 17th International Mining Congress and Exhibition of Turkey (IMCET 2001), Ankara, 2001.

[12] [12].Hadjigeorgiou J, Grenon M. Towards a rational design methodology for thin sprayed on liners[C]// Proceedings of 2nd International Seminar on Surface Support Liners, South Africa, 2002: 1-16.

[13] Qiao Q, Nemcik J, Porter I. A new approach for determination of the shear bond strength of thin spray-on liners[J]. International Journal of Rock Mechanics and Mining Sciences, 2015(73): 54-61.

[14] QIAO Qiuqiu, NEMCIKJan, PORTER Ian. A new approach for determination of the shear bond strength of thin spray-on liners[J].International Journal of Rock Mechanic sand Mining Sci- ences,2015(73):54-61.

[15] Liang, H., Zhang, Z., Shi, Y. et al. Experimental study on surface protection support that uses polymer thin spray-on layer. Sci Rep 15, 29027 (2025). https://doi.org/10.1038/s41598-025-14618-4

[16] Zhang, J. et al. Study on antiweathering support technology of thin spray-on liners in shallowly buried coal seam roadway under corrosion condition. Shock Vib. 2022 (7065650). https://doi.org/10.1155/2022/7065650 (2022).

[17] STACEY Thomas. Review of membrane support mechanisms , loa- ding mechanisms, desired membrane performance,and appropriate test methods[J]. The Journal of the South African Institute of Mining and Metallurgy,2001,101(7):343-351.

[18] SHAN Zhenjun,IAN Porter,JANNemcik,etal. Comparing the reinforcement capacity of welded steel mesh and a thin spray -on liner using large scale laboratory tests[J]. International Journal of Mining Science and Technology,2014,24(3):373-377.

[19] Wei Qun. Study on the Mechanism of Sprayed Flexible Membrane in Bolt Support[D]. China University of Mining and Technology, 2021. DOI: 10.27623/d.cnki.gzkyu.2020.000868.

[20] Li Hongxian, Xu Shurong, Lu Anchen, et al. Application of New Thin Spray-on Material in Grouting for Fire Prevention at Final Mining Line of Retained Roadway[J]. Mining Safety & Environmental Protection, 2022, 49(04): 199-204. DOI: 10.19835/j.issn.1008-4495.2022.04.028.

[21] Li Xuebin, Yang Chunman, Wang Bo, et al. Study on New Polymer Spray Layer Support for Weakly Cemented Soft Rock Roadway in Western China[J]. Coal Science and Technology, 2017, 45(12): 76-80. DOI: 10.13199/j.cnki.cst.2017.12.014.

[22] Zhang Nong, Wei Qun, Wu Jiansheng. Technology and Applicability of Sprayed Flexible Membrane in Coal Mine Roadways[J]. Coal Science and Technology, 2022, 50(01): 78-85.

[23] Chen Qingfa, Yang Wenxiong, Wu Jiayou, et al. Macro-Micro Experimental Study on the Effect of Water-Cement Ratio on Tensile Properties of Thin Spray-on Liner Materials[J]. Materials Reports, 2024, 38(08): 281-287.

[24] Zheng D, Chen X, Jiao H, Yang L, Liu X, Han Y, Liu Z. Research on the Mechanical Properties and Modification Mechanisms of Orthogonal Optimization Composite Cement-Based Thin Spray On-Liner. Materials (Basel). 2025 Apr 17;18(8):1837. doi: 10.3390/ma18081837. PMID: 40333501; PMCID: PMC12028695.

[25] Chen L, Zhou Z, Liu G, et al. Effects of substrate materials and liner thickness on the adhesive strength of the novel thin spray-on liner[J]. Advances in Mechanical Engineering, 2020, 12(2): 1-13.

[26] He Yudi. Study on Bond-Slip Characteristics of Interlayer Interface of Sprayed Membrane Waterproof Lining Structure in Tunnels[D]. Southwest Jiaotong University, 2020. DOI: 10.27414/d.cnki.gxnju.2019.000732.

[27] Jiang Yajun, Zhao Jumei, He Yudi, et al. Discussion on Mechanical Characteristics of Interlayer Interface of Double-Sided Bonded Sprayed Membrane Waterproof Lining for Tunnels[J]. Tunnel Construction, 2023, 43(06): 1003-1010.

[28] Bai Jinchao, Cheng Yunhai, Zheng Qiangqiang, et al. Mechanical Characteristics and Failure Mechanism of Dry-Mix and Wet-Mix Shotcrete Under Load[J]. Journal of China Coal Society, 2020, 45(8): 2777-2786. DOI: 10.13225/j.cnki.jccs.2019.0686.

[29] Liang Han, Zhang Zedi, Bai Zihan, et al. Experimental Study on Surface Protection Support of Polymer-Based Thin Spray-on Layer for Mining Applications[J]. Coal Science and Technology, 2026, 54(3): 1-12. DOI: 10.12438/cst.2025-0408.

[30] Wu Peng, Chen Jian, Cui Lan, Xu Chen. Model Tests and Load-Bearing Characteristics of Composite Lining Tunnels[J]. Chinese Journal of Geotechnical Engineering, 2024, 46(S1): 102-106. DOI: 10.11779/CJGE2024S10019.