Research Status of Mechanical Properties of Metal-faced Sandwich Panels for Building Construction

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Abstract. This paper describes the classification and mechanical characteristics of metal-faced sandwich panels for construction, the research methods of mechanical properties of metal-faced sandwich panels, and the research status of bending bearing capacity, wind load resistance and impact resistance of metal-faced sandwich panels. It can be seen from this that the research on mechanical properties of metal-faced sandwich panels has been relatively mature at present. In order to make the metal-faced sandwich panel more widely used, further research is needed on the incomplete bonding between layers and the mechanical properties of the metal-faced sandwich panel under special circumstances such as fire and low temperature.

1. Introduction
As early as the sixties and seventies of the last century, researchers around the world began to study the mechanical properties of metal-faced sandwich panels for construction, the research methods of mechanical properties of metal-faced sandwich panels, and the research status of bending bearing capacity, wind load resistance and impact resistance of metal-faced sandwich panels. It can be seen from this that the research on mechanical properties of metal-faced sandwich panels has been relatively mature at present. In order to make the metal-faced sandwich panel more widely used, further research is needed on the incomplete bonding between layers and the mechanical properties of the metal-faced sandwich panel under special circumstances such as fire and low temperature.

2. Bending Capacity of Metal-faced Sandwich Panels
At present, there is much research on the flexural capacity of metal-faced sandwich panels. However, in the early days, there was not much systematic research on metal-faced sandwich panels used in the
construction field. Most of the designs were based on engineering experience, lacking unified design equations and accurate scientific theoretical basis.

Yu Min, Zha Xiaoxiong et al. [5, 6] studied the flexural capacity of metal-faced sandwich panels through mechanical analysis, finite element simulation and experimental verification. In this study, the mechanical deformation mechanism of metal-faced sandwich panels is analyzed, and the design calculation equations of various types of metal-faced sandwich panels are obtained, and the correctness of the equations is verified by experiments.

According to the finite element analysis and test results, Song Ruiqiang et al. [7] put forward the design equation of bearing capacity of metal-faced rock wool sandwich panels, and applied it to the design of single-span and multi-span panels, and listed the load-span selection tables of metal-faced sandwich roofing panels and wall panels with panel thicknesses of 50mm, 80mm and 100mm, so as to simplify the design process.

Through a large number of experiments, theoretical analysis and finite element simulation analysis, Song Xinwu [8] deduced the bending bearing capacity equation of metal-faced sandwich panels. By introducing a COHESIVE bonding element, the influence of bonding damage of a roofing panel model on the bending capacity of metal-faced sandwich panels is illustrated.

Fan Yong [9] established the discrete element model of the metal-faced sandwich panel by using the discrete element method and simulated the bearing capacity and failure mode of the sandwich panel. The discrete element contact constitutive theory based on PFC2D is studied, and three discrete element contact models for sandwich panels are proposed, as shown in Figure 1. The parallel bonding model and contact bonding model are more accurate and reasonable.

![Figure 1. PFC2D Model of Metal-faced Sandwich Panel](image)

Wu Ye et al. [10] proposed a numerical model for the buckling behavior of polyurethane elastomer sandwich panels by analyzing the failure modes of polyurethane sandwich panels. The analysis shows that the failure mode of a polyurethane sandwich panel is mainly integral buckling.

Metal-faced sandwich panels are often affected by external environmental factors (temperature, humidity) in the use of construction projects. Therefore, the influence of various environmental factors on the mechanical properties of metal-faced sandwich panels cannot be ignored.

Li Wenliang [11] indirectly illustrates the influence law of long-term environmental factors on the bending bearing capacity of metal-faced sandwich panels by explaining the influence of long-term environmental factors (temperature and humidity) on the tensile strength of the core materials and proposing the relationship between the bending bearing capacity of metal-faced sandwich panels and the tensile strength of the core materials.

In order to meet the needs of architectural functions, metal-faced sandwich panels will inevitably need openings in actual construction projects. Before and after the opening, the bending bearing capacity of metal-faced sandwich panels have been weakened to some extent.

In order to solve this problem, Li Linsheng [12] has carried out relevant research on flexural capacity of metal-faced sandwich panels with openings. In this study, open-hole sandwich panels are divided into two situations: large open hole and small open hole, as shown in Figure 2.
According to the form of opening, Li Linsheng used finite element analysis to revise the calculation equation of the deflection and bearing capacity of the sandwich panel. The results show that the sandwich panels with large openings cannot bear the load alone, and the adjacent sandwich panels shall share the load. In addition, according to the deformation coordination principle, the strength calculation equation of sandwich panel joints is given, as shown in Table 1.

Table 1. Strength Calculation Equation for Sandwich Panel Joints [12]

| Node connection strength | Connection strength corresponding to failure mode | Static load calculation equation | Failure diagram |
|--------------------------|--------------------------------------------------|---------------------------------|-----------------|
| Tensile strength of joint connection | Pull through strength of panel | $F_p = \alpha d_u f_u$ | ![failure diagram] |
| | Pull-out strength of connector | $F_u = \phi d_u f_{uc}$ | ![failure diagram] |
| | Tensile fracture strength of connector | $F_t = \frac{\pi d_u^2}{4} f_t^b$ | ![failure diagram] |
| Shear strength of joint connection | Shear strength of panel | $F_s = \eta d_v f_u$ | ![failure diagram] |
| | Tear strength of panel | $F_v = A_v f_u$ | ![failure diagram] |
| | Shear strength of connector | $F_v = n \frac{\pi d_v^2}{4} f_v^b$ | ![failure diagram] |

The research on the mechanical properties of metal-faced sandwich panels with openings complements the theoretical research on metal-faced sandwich panels and provides a design basis for the application of metal-faced sandwich panels in practical engineering.

In practical engineering applications, metal-faced sandwich panels will not only be subjected to axial pressure, uniformly distributed load and concentrated load, but will also be subjected to the combined action of axial pressure, uniformly distributed load and concentrated load. Zha Xiaoxiong et al. [13] obtained the unified expression of deflection of metal-faced sandwich panel under single load and combined load by using the method of energy method to obtain the stationary value of potential energy, and compared it with the results of finite element simulation analysis, proving the correctness and rationality of the equation.

Most of the research objects on mechanical properties of metal-faced sandwich panels are single-span sandwich panels. With the use of long-span sandwich panels, multi-span sandwich panels have been applied in engineering practice, and related research on multi-span sandwich panels is also in progress.

Based on the mathematical distribution function, Zhu Yongwei [14] deduced the deformation expression of multi-span metal-faced sandwich panel under the combined action of uniformly distributed load, temperature load and intermediate supporting counterforce. It is found that the increase of core thickness and shear modulus of multi-span thin metal-faced sandwich panels can effectively reduce the deformation of the panel, and the temperature load has a great influence on the panel, which shall not be ignored in design.
3. Wind Load Resistance of Metal-faced Sandwich Panels

In recent years, metal-faced sandwich panels are commonly used in large-span roof structures, and more and more accidents occur under wind load. Therefore, more and more research has been made on their resistance to wind load.

Huang Li, Deng Hua et al. [15, 16] established an eight-node rectangular sandwich panel element on the middle surface of the core layer by applying the Hoff type sandwich panel theory. In addition, the reaction time history and power spectrum of three models with different stiffness and damping (undamped rigid panel, low damping flexible panel and high damping flexible panel) are compared, and the results are shown in Figures 3 and 4. The results show that the damping of sandwich panels has a significant effect on the wind-induced vibration of large-rigidity roof structures.

Wang Chen [17] studied the wind-induced damping property of a rock wool sandwich roofing panel with metal surface. The results show that both rock wool material and metal surface rock wool sandwich roofing panel have high loss factors, with the highest loss factor reaching 0.5. In other words, the metal surface rock wool sandwich roofing panel has better damping property.

Zhou Zesheng [18] studied the influence of metal-faced polyurethane sandwich roofing panel and metal rock wool sandwich roofing panel on the wind-induced vibration response of the main building structure. The results show that the main factor affecting the bearing reaction characteristics of roofing panel is the loss factor of core layer.

At present, the connection between metal-faced sandwich wall panels has been changed from a penetrating self-tapping nail connection to a concealed nail connection, as shown in Figure 5. The concealed nail connection method can effectively prevent the corrosion of wall panels caused by rainwater and the like, and also prevent infiltration of water. However, the connection mode of concealed nails is also easy to cause wind damage of the enclosure system.

Tang Chao et al. [19] analyzed the wind resistance of a metal-faced sandwich wall panel enclosure system. The study pointed out that due to the difference of force transmission methods, the bearing capacity and deformation of metal-faced sandwich panels subjected to wind pressure can be checked according to the code [20], but when subjected to negative wind pressure, its wind resistance property...
mainly depends on the connection bearing capacity of sandwich panel connectors. Similarly, Zhao Wenzhan [21] obtained that the failure of the sandwich panel under negative wind pressure is the strength failure at the plug-in joint through the wind-resistant uncovering test of the aluminum magnesium manganese rock wool sandwich panel, as shown in Figure 6.

### 4. Impact Resistance of Metal-faced Sandwich Panels

As the outer protection structure of the building, the metal-faced sandwich panel bears the protection function of the building space, so it is necessary to study its mechanical properties against external impact.

Through experiments by Wang Hongxin [22] et al., it can be seen that under the action of low-speed impact, the damage of metal-faced sandwich panels is mainly caused by local depression deformation, cracking and overall deformation of the sandwich panels, as shown in Figure 7. Based on the principle of stationary potential energy and taking the tensile fracture of the panel as the failure condition, the relationship between the concentrated force and the local deformation of the metal-faced sandwich panel is obtained, and the impact force equation for cracking of the sandwich panel is deduced.

![Figure 7. Low-speed Impact Failure of Metal-faced Sandwich Panels](image)

(a) Local sag deformation of panel  
(b) Panel cracking  
(c) Overall deformation of sandwich panel

Finite element analysis and theoretical analysis show that the increase of surface layer thickness, panel strength, drop hammer radius and cracking strain will increase the cracking impact force of metal-faced sandwich panels, while the drop hammer quality, core material strength and sandwich layer thickness have only minor influence on the cracking impact force.

Deng Lei et al. [23] analyzed the deformation characteristics of sandwich panels under the action of Hopkinson pressure bar device. The post-buckling problems of sandwich panels in displacement, stress and strain are emphatically analyzed. The dynamic buckling and propagation characteristics of sandwich panels under the action of elastic-plastic compression wave, the interaction between compression wave and buckling deformation and the development law of large plastic post-buckling deformation are pointed out.

Due to the increase of explosion accidents in recent years, the anti-explosion property of metal-faced sandwich panels has been paid close attention to. Wang Hong Xin et al. [24] conducted relevant studies for the dynamic response of metal-faced sandwich panels under explosion based on the principle of energy balance. According to the failure characteristics of sandwich panels under explosion, the deformation process is divided into four stages: bending shear deformation, elastic tensile deformation, plastic tensile deformation and tensile fracture. The deformation equation for the whole process of sandwich panel and the values of tensile explosion load, yield explosion load and fracture explosion load in the deformation process are given.

### 5. Conclusion

At present, research on the mechanical properties of metal-faced sandwich panels is based on the premise of firm adhesion and cooperative work between metal panels and core materials. However, in actual engineering, the interlayer of a metal-faced sandwich panel is not completely bonded firmly. During long-term use, the bonding force between the layers gradually decreases, which has an important impact on the mechanical properties of the metal-faced sandwich panel and the safety of the
enclosure structure. Therefore, the mechanical properties of the metal-faced sandwich panels with different bonding degrees can be studied.

With the improvement of building fire prevention requirements and consideration of building envelope safety during and after fire, it is necessary to further study the mechanical properties of metal-faced sandwich panels under fire and residual mechanical properties after fire.

Metal-faced sandwich panels are favored by engineers because of their non-wet operation and short construction period, thus being popularized and applied in various places. In order to satisfy the safe use of metal-faced sandwich panels in fabricated building projects in severe cold areas or even extremely cold areas, it is necessary to further study the mechanical properties of metal-faced sandwich panels under low temperature conditions.

Acknowledgments
This work was supported by Science and Technology Project of State Grid Corporation of China (Research on Deepening Design Technology and Construction Effectiveness System in the Modular Construction of 35-220kV Substations,5200-202055134A-0-0-00).

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