International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I4P108

Volume 72 Issue 4, 74-80, April 2024

Original Article

A Review of Trends in Truss Materials Used in the Construction Industry

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Received: 10 October 2023 Revised: 21 February 2024 Accepted: 01 April 2024 Published: 24 April 2024

Abstract - *As the number of houses is increasing worldwide there is a growing challenge of trusses failure. Trusses made of wood provide tiles with leverage to exert more weight on the truss itself and cause the roof to deform and collapse in due time gradually. This review paper discusses the effectiveness of the different types of roof trusses in use. This paper reviews the mechanical properties of timber trusses, steel trusses, concrete trusses, composite trusses, and plastic trusses, and possible solutions to eliminate the failure of trusses are discussed. Steel trusses are more enduring than timber trusses; even so, steel trusses are more expensive than any other type. In addition, steel trusses are more susceptible to corrosion and rusting than any other type. Furthermore, steel is a good conductor, posing hazards of electrical shock to any human in contact. Developments have been made for concrete trusses; however, concrete remains a challenge since it has low tensile strength, allowing chipping and cracking. Plastic trusses have been in use; however, plastic trusses have limited strength and lifespan compared to wood, steel, and concrete, resulting in limited use in larger structures. However, the utilization of fiberglass and epoxy has been introduced to replace the trusses in use since they have a high strength-to ratio, which means they can support heavy loads without adding any weight to the structure. Ultimately there is still a need for further research to come up with optimized composite trusses that can have enhanced mechanical properties, resistance to termites, and moisture.*

Keywords - *Composite, Mechanical properties, Truss.*

1. Introduction

A Truss is a structure consisting of numerous members interconnected together at their ends so they configure a firm body [1]. They are commonly used to reach substantial distances and to bear sizeable loads that can be effectively done by a columnar single beam [2]. Trusses are frequently used to create bridges and support roofs. Essentially, roof trusses are a triangulated system, as shown in Figure 1, typically consisting of straight structural elements interconnected together [3].

In roof trusses, elongation and shortening of members of the truss cause a bending action, which further results in deflection [4]. The bending of the truss is quite a noticeable firm bending of the beam. To reduce excessive deflection, a sag-tie member is installed to support the long horizontal member at the bottom chord of a truss that is normally in tension [5] [3]. The members of the trusses are classified as main members and secondary members [6]. Wood trusses are widely used; however, these trusses are limited by the mechanical properties of wood, as shown in Table 1 [7]. Furthermore, wood tends to absorb moisture, which weakens the truss. Wood is also susceptible to termite attack which can result in its premature failure [8]. The chemical composition of wood is organic, containing mainly hydrogen and carbon, which are combustible, posing a fire hazard [9].

Table 1. Depicts mechanical comparisons between wood, steel and concrete [7]

Material	E/GPa	μ	$\alpha/10^{-5}{}^{\circ}\mathrm{C}^{-1}$
Concrete	30.0	0.2	1.0
Steel	210.0	0.3	1.2
Wood	10.0	0.1	0.8

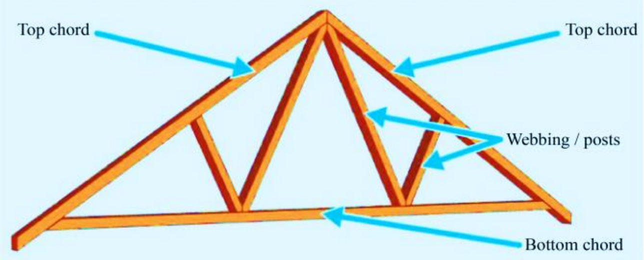

Fig. 1 Layout of a truss [1]

Concrete trusses have found some use due to their high compressional strength and resistance to fire and water absorption. However, concrete has a very low tensile strength, which results in it forming a weaker truss that is susceptible to damage. The low tensile strength serves as a limitation in the weight that the concrete truss can support [10]. Steel trusses are dominating the industry due to their durability and ability to sustain heavier loads. However, steel is expensive and also requires more skilled labour to machine it appropriately [11]. Steel is affected by temperature differentials, and it is a conductor of electricity, which can pose a hazard. Furthermore, steel tends to corrode if not treated accordingly [2]. Plastic trusses have found some limited market share. Plastic trusses have limited strength and lifespan compared to wood, steel, and concrete, resulting in limited use in larger structures. Furthermore, plastic trusses are generally not fire-resistant, which can pose a fire risk to the building [4].

2. Types of Trusses

The roof trusses that are used in the construction industry are mainly wood trusses, steel trusses, concrete trusses, plastic trusses, and composite trusses. The failure mechanisms of trusses and their mechanical are reviewed in the successive subsections.

2.1. Wood Trusses

Wooden trusses have been considered effective and cost-efficient in the construction industry. However, wooden trusses tend to absorb moisture. Moisture has a negative effect on the wood properties. Moisture causes the wood to swell and then shrink when it dries out, affecting its durability. Furthermore, wood has very low resistance to insects and fungal decay [12]. Moisture contributes over time to softening the wood, causing it to have reduced mechanical properties and be susceptible to fungus attack [13]. To increase the resistance of wood to fungi attack it is necessary to use chemicals to treat it. However, these chemicals are costly and not environmentally friendly [3].

Fig. 2 Termite attack

Wood trusses tend to harbour termites which feed on the wood from the inside out, which can cause undetectable damage on the trusses until it is extensively damaged, as shown in Figure 2 [14]. When termite damage is visible the damage will generally already be extensive [15] [12]. The properties of wooden trusses, which include thermal, electrical, and mechanical properties, make them useful for trusses [16].

2.2. Steel Trusses

Steel is a versatile material enabling it to be easily fabricated into various shapes and geometries. However, steel tends to corrode easily [17]. Steel trusses have the advantage of resistance to heat over wooden trusses, which are easily combustible, as shown in Table 2 [18]. It takes much higher temperatures to compromise the integrity of steel trusses making these trusses safer than with the ones made of wood since they are deemed to be fire resistant [19].

Furthermore, steel has a good high strength-to-weight ratio, enabling it to be ideal for large buildings requiring trusses [20]. Deflection of trusses is a huge challenge that most researchers have encountered, as shown in Figure 3. However, steel can make a very durable and safe roof framing or truss without weighing down the structures [21].

Table 2. Shows the comparison of thermal conductivity between steel and other materials

Material	Thermal conductivity (W/Mk)
Aluminum	214
Steel (carbon 1%)	43
Concrete, dense	1.3
Bricks	0.73
Water (20°C)	0.60
Sand (Dry)	0.30
Wood (oak)	0.17
Glass fiber quilt	0.035
Air	0.024

Fig. 3 Steel truss failure [5]

A big disadvantage of steel is that steel needs to be corrosion-protected by either galvanizing it or coating it [22]. The galvanizing of the steel can be effective, but it has been shown that if the coating is scratched, the steel becomes exposed and becomes susceptible to corrosion [23]. Steel is a very good electrical conductor, with trusses made of steel posing an electrical risk due to the possibility of conducting electricity, as shown in [24]. Lastly steel trusses are generally more expensive compared to other trusses [26].

2.3. Concrete Trusses

Concrete has also not been a viable alternative for roof truss applications as a result of the complexity of concrete components construction and its heavy weight [27]. However, some of the disadvantages of structural steel roof truss systems, such as susceptibility to corrosion, high maintenance cost, and the rising prices of steel [28], can be overcome by the use of concrete trusses [29].

However, the heavy weight of concrete trusses is a hindrance to their wide application [30]. Furthermore, when concrete cracks or chips, as shown in Figure 4, it tends to lose its strength and compromise the structural integrity of the truss [31]. Concrete has a very low tensile strength compared to compressive strength, as shown in Table 3.

3. Polycarbonate Plastic Trusses

Polycarbonate plastic is a very common material that is now widely used in the construction industry. Plastic tends to be light in weight and has low density [34]. However, polycarbonate plastic is composed of polymer chemicals which are non-biodegradable [35].

Polycarbonate plastic degrades its mechanical strength under the action of direct sunlight and is flammable unless treated [36]. In the design of trusses, their reaction to temperature is an important parameter [37]. With sufficiently high temperatures, plastic trusses tend to soften, which can lead to failure of the plastic truss [38].

Other researchers have attempted to design trusses using polycarbonate plastics since it has low production cost, resistance to corrosion, are lightweight, and, most importantly, are a poor conductor of heat and electricity [34]. However, plastic trusses have limited strength and lifespan compared to wood, steel, and concrete, resulting in limited use in larger structures. Furthermore, polycarbonate plastic trusses are non-resistant to fire, which can increase the risks of fire damage in a building [2]. Researchers have attempted to create various hybrid composite materials with plastics, steel, and concrete materials with marginal success [40]. Polycarbonate plastic trusses are susceptible to fire unless treated, which tends to lower their modulus of elasticity, making them highly unsuitable for load-bearing applications[41].

Table 3. Shows the mechanical properties of concrete [32] [33]

Properties	Values
Compressive strength	31.2 MPa
Density	2400 kg/m^3
Modulus of elasticity	26.3 GPa
Poisson's ratio	0.2
Tensile strength	2.07 MPa
Fracture energy/ unit area	73.6 N/m
Strain at peak compressive stress	0.0022

Table 4. Properties of polycarbonate plastic material [42]

Properties	Values
Density	1200 kg/m^3
Modulus of elasticity	2.3 GPa
Tensile strength	68 MPa
Elongation	130
Poisson ratio	0.35%
Stress-optical constant	7 N/mm/fringe

Fig. 4 Cracks on concrete structure

Polycarbonate plastic tends to undergo plastic deformation over time, which lowers its durability compared to metal, wood, and or concrete trusses. The workability of plastic is also a challenge compared to other materials. It is harder to screw, nail, and drill plastic compared to wood [43]. However, most of these structural constraints can be overcome by mixing other materials with plastics to form composite building materials [44].

4. Composite Trusses

Composite materials are manipulated or natural materials developed from two or more materials[45]. Composites are the most considered advanced materials for hybrid applications. [46] Composite materials are classified as polymer matrix composite, ceramic matrix composite, and metal matrix composite [47]. In the design of composite roof trusses, polymer matrix composite materials are utilized, which are inclusive of Carbon fiber composites[48]. Carbon Fiber composites are exceptionally strong and lightweight but extremely costly to produce due to the requirement of advanced technical equipment, as discussed in Figure 5 [49].

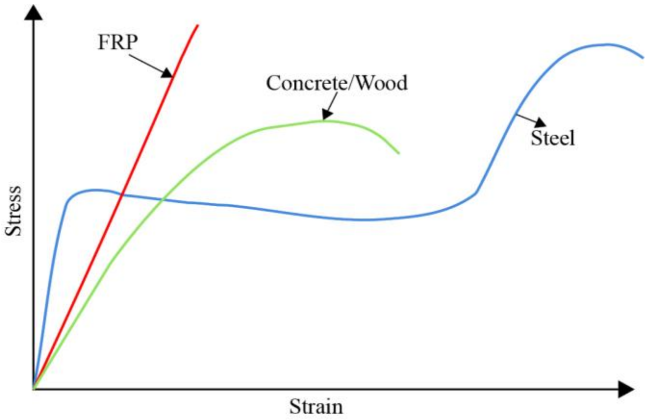

Fig. 5 Stress vs. strain graph showing the behavior comparisons between different materials

Table 5. Properties of Glass Fiber Reinforced Polymer and Carbon Fiber Reinforced Polymer [53].

Properties	GFRP	CFRP
Longitudinal elastic modulus, E_1	7 GPa	17.5 GPa
Transverse elastic modulus, E_2	7 GPa	17.5 GPa
Thickness elastic modulus, E_3	1 GPa	5 GPa
In-plane Poisson's ratio, v_{12}	0.22	0.24
Thickness Poisson's ratio, v_{13}, v_{23}	0.22	0.24
In-plane shear modulus, G_{12}	1 GPa	2 GPa
Thickness shear modulus, G_{13}	2.5 GPa	10.5 GPa
Tensile strength, σ_{ut}	138.1 MPa	262.6MPa

Table 6. Durability and reasons for failure of trusses

Types of trusses	Life span	Causes of failure	Reference
Wood trusses	Over 30 years	Termite attack, fire, and moisture	[55]
Steel trusses	50 years	Fatigue and corrosion failure	[56][57][58]
Concrete trusses	50 years	Cracking	[29][59]
Plastic trusses	20 years	Humidity	[35][60]

Composite materials have high strength, enabling them to support heavy loads while remaining lightweight [51]. Composite material comprises stiffness properties, durability, and high corrosion resistance when compared with bulk materials, allowing for a weight reduction in the trusses [52]. The properties of the most common composites are discussed above: Nevertheless, carbon fiber composites also come with limitations of high costs to manufacture and repair, brittleness, and recycling challenges. [54]

5. Conclusion

Due to the heaviness of the tiles used for roofing purposes, the trusses experience stress, which leads to the whole truss being gradually deformed, resulting in unsafe buildings. Therefore, it is very important to safely design and simulate the roofing trusses to ensure they are durable and can withstand normal operational forces.Timber trusses have been widely used; however, timber trusses are sensitive to moisture and degrade significantly if wet resulting in the loss of structural strength whilst subjected to termites' attack. In addition, timber is lightweight, causing a direct advantage of more sensitivity to lateral loads. Steel trusses are more enduring than timber trusses; even so, steel trusses are more expensive than any other type. In addition, steel trusses are more susceptible to corrosion and rusting than any other type. Steel is a good conductor, posing hazards of electrical shock to any human touching it. Concrete trusses are marginally used due to their low tensile strength allowing chipping and cracking. Plastic trusses have also found some limited use; however, plastic trusses have limited strength and lifespan compared to wood, steel, and concrete, resulting in limited use in larger structures. Furthermore, plastic trusses are non-resistant to fire, which can increase the risks of fire damage in a building.

Acknowledgement

This research was supported by the Vaal University of Technology. The authors wish to thank the Department of Mechanical Engineering at Vaal University of Technology for facilitating this work.

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