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A Review of The Effectiveness of Different Types of Railway Sleepers

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***Abstract** - The railway structural material often suffers from aggressive loading and vibration in the locomotive industry. The durability of the sleepers currently in use and their vibration properties are not sufficiently resilient to vibration, and this can lead to premature failure such as cracking in the mid-span of concrete sleepers and on the rail seat due to impact loading. This review paper discusses the effectiveness of the different types of railway sleepers that are currently in use. This paper reviews the mechanical properties of a composite sleeper, timber sleeper, concrete sleeper, and steel sleeper, and possible solutions to eliminate failure of sleepers are discussed. Timber sleepers historically were the most widely used in the railway industry. However, termite, end splitting, and fungal decay susceptibility have been known as the root reason for timber failure. On the other hand, steel sleepers have a threat of fatigue cracking and corrosion. A concrete sleeper possesses great compression strength. However, they have low ductility and elasticity. This results in cracking the mid-span of the concrete sleeper. The composite sleeper has been introduced to replace sleepers that are in use. Composite sleepers have great mechanical strength. However, the composite sleeper has low hydrophilicity, and this can cause weak bonds between resin and filler. There is still a need for further research to come up with optimized composite sleepers that can have enhanced vibration properties and great mechanical strength.*

***Keywords** - Sleeper, Mechanical properties, vibrational analysis, railway line*

I. INTRODUCTION

The railway sleeper is a crucial part of the structure of the track system in the railway. Basically, sleepers are beams placed between the railway track and ballast supports [1]. The main function of the sleepers is to maintain the rail gauge, distribute and transfer the transported rail load to ballast or other supported components. Furthermore, the railway sleeper prevents abrading actions, cutting of the bearing plates, and protects ballasts material. Sleepers play an important role in resisting longitudinal and lateral movement of the railway track system [2].

There are different brands of sleepers that are used in the railway structure. The railway sleepers in common use are Timber sleeper, Steel sleeper, Composite sleeper, and Concrete sleeper[3]. The Timber sleeper has been widely used over centuries as it met the quality requirement at the time. However, with recent developments in train technology, the railway track has to be able to sustain trains that move at high speeds; thus, the demands on the sleeper material properties have increased. Timber sleepers are not suited to high-speed trains that carry ever-increasing payload weight [4]. Figure 1 shows the layout of the railway.

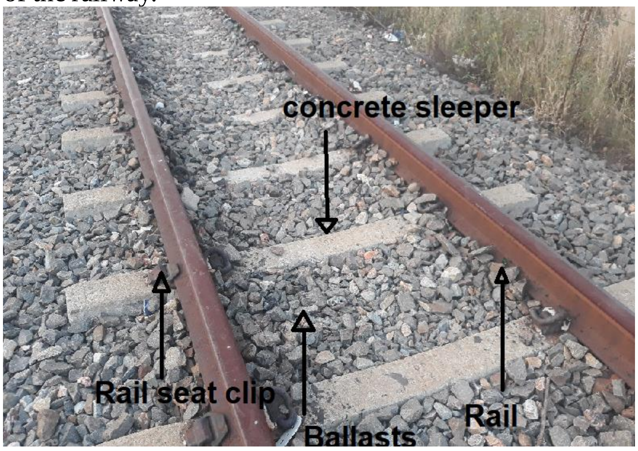

Figure 1- Layout of railway

The concrete sleeper was introduced to meet the needs of recent developments in train technology. However, the concrete sleeper has a significant flaw in that rail abrasion takes place, ultimately resulting in a mode failure [5]. Rail abrasion is a loss of concrete material due to high vibration that is caused by heavily loaded trains. In addition, the damage of concrete material underneath the rail seat can further compromise the durability of the concrete sleeper [5].

II. Types of Sleepers

The railway sleepers that are used in the railway industry are Timber sleeper, Steel sleeper, Composite sleeper, and Concrete sleeper [3]. Mechanical properties of different types of sleepers and the failure of sleepers that are currently in use are deliberated in the subsequent subsections.

A. Timber sleeper

Timber sleepers have a good past of reliable performance and are effective in the railway industry [6]. Furthermore, Timber sleepers have a major advantage in that they are simple to assemble, replace, work with, handle, and can be installed in almost all kinds of railway track structures [4]. Though, the main weakness with timber sleepers is that

they are susceptible to mechanical and biological degradation. Fungal decay is also a noticeable problem that causes failure in timber sleepers [7].
Due to the outlined shortcomings of the timber sleeper, several alternatives were found, which included concrete and steel sleepers

Timber sleeper is biodegradable since it is an organic material. Timber sleepers absorb moisture during the rainy season, making them susceptible to fungus decay. Furthermore, the fungus decay can easily spread from timber to another timber through rail or non-nutritional surfaces [8,9]. End splitting in timber sleeper is another challenge that has been identified due to aggressive traverse shear loading [4,10]. Termite attack has also been identified as the root cause of timber sleeper failure. Figure 2 shows the effect of termites attack on timber sleeper, and Termites consumes cellulose-containing materials causing permanent damage to the timber sleeper [11].

Figure 2 - Termite attack

Invasion of termites has been located in cracked sleeper's pouches even when it was cured with creosote, as shown in Figure 2 [12]
Australian railway maintenance requires approximately 2.5 million timber sleepers to do their maintenance on the railway system [13]. The United States of America uses 2% out of 700 million timber sleepers for replacement and for maintenance [14]. Germany is in demand of 11 million sleepers for maintenance and replacement [14]. Australian railway industry uses about 25-35% of their yearly budget to do the maintenance of their railway structure [15]. Replacement of the timber sleeper is very costly, and the United States railway industry uses more than 1 billion US dollars annually to do replacement of railway sleepers [16]

a) Softwood timber

Softwood sleeper timber has a poor mechanical strength resistance compared with hardwood sleeper, and it has a tendency for spike hole enlargement as well as gauge spreading [17]. Hardwood timber has the ability to transmit the load to ballast, whereas softwood sleepers are notability of transferring the load weight to the ballasts. Therefore, softwood sleeper timber and hardwood timber should not be mixed on the railway line [4].

b) Measures to minimize timber failure Synthetic Chemical

To impregnate timber sleepers with synthetic chemical and biological treatment is the method that is commonly used to protect timber sleepers from termite attack and fungal decay [18]. A toxic chemical that is used to abolish damaging plants in sleeper timber sleepers has been implemented for over and above 200 ages due to their low cost. However, environmental organizations are currently troubled about the synthetic chemicals used to impregnate timber of sleeper and the method of disposal of the sleeper after they are removed from railway [18,19]. A natural way of controlling timber quality and stability can stay effective as chemical safety and placing selected micro-organisms doesn't affect the mechanical properties of the sleeper [20].

c) End splitting solution

Splitting at the end of the sleeper can be averted or minimized by the use of an endplate mounted in the last part of the wooden sleeper [8,21]. Figure 3 illustrates the timber sleeper splitting end look because the endplate is separated. However, this technic has limitations; the splitting width and length must be smaller than 20mm and 250 mm.

Figure 3- End plate used to prevent the splitting end

Splitting end accepted limited range width should be 3 to 6mm, for length 100 mm.

B. Steel sleeper

Steel sleepers have superior mechanical strength compared to concrete and timber sleepers [22]. Sleepers made of steel have less weight compared to timber and concrete; this makes it easier to work with and handle. Steel sleeper has a working life expectancy of 50 years [4]. The steel sleeper can only accommodate lightly loaded trains and goods. Furthermore, it is suitable for trains traveling at speeds less than 160km/hr [23]. Steel sleepers are expensive and not widely used due to their susceptibility to corrosion [22]. Fatigue cracking is also a major challenge in the fastening holes of steel sleepers [24].
Steel sleepers do offer high mechanical strength compared to concrete and timber. However, the steel sleeper is more expensive [22]. Steel sleeper corrosion is caused by the rich, salty element that supports steel sleepers, such as ballasts and soil.

Risks of railway steel sleeper corrosion are much higher compared with steel rail, even though both rail and sleeper are made of steel. Sleepers generally come to interact with different types of salts from soil, combinations, water which comes from the ground that can react with steel sleeper and cause early failure of a sleeper because of corrosion. Metal slag-ballast, frequently moist surroundings, and the presence of corrosive materials can improve deterioration in steel sleepers [25].

Fatigue cracking catastrophe happens in the rail-way structure as a result of constant strain enforced by repeated loaded trains. The rail seat is exposed to a weighty continuous shear load, making it exposed to fatigue cracking. While trains are moving on a rail, a sleeper experiences both traverse and longitudinal stress originating from its rail seat position, which is generally on its upper surface. This can result in fatigue cracking [26].

a) Steel sleeper

Y shape sleeper was designed and developed to substitute the traditional steel sleeper that was in use [14]. Y steel sleeper is designed like a Y in its level arrangement. Y steel sleeper possesses higher resistance to line compared to other sleepers due to its design of the y fork. The y fork contains a large number of ballasts; this makes the y steel sleeper have greater resistance to the line of the sleepers. However, it is impossible to pull or adjust the y steel sleeper in the ballast by means of a modest positioning method. Furthermore, because of the y shape, the laying of sleepers should follow strict guidelines [27]. Another challenge with steel sleepers is train vibrations that cause fatigue cracking in the holes of the steel sleepers [13].

C. Concrete sleeper

Concrete sleepers have the ability to gauge holding characteristics and deliver a better line than timber sleepers. Yet, concrete sleepers tend to be heavy and expensive, as well as being incapable of providing service life beyond 50 years [28].

Figure 6 shows the failure mode of concrete sleepers through cracking that occurs at mid-span and at the end of the upper side of the sleeper.

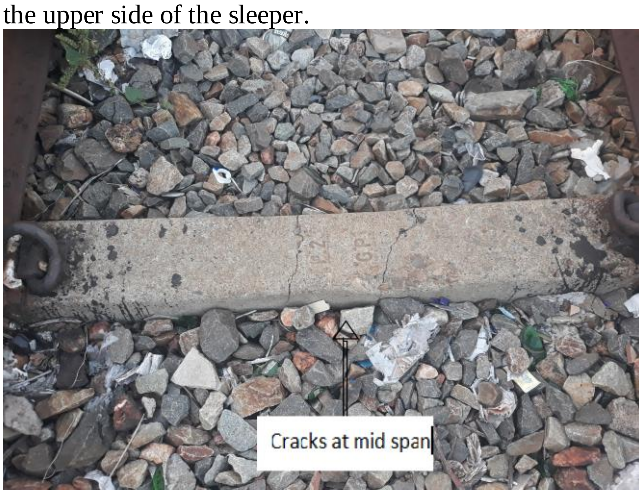

Figure 6 - Cracks of concrete sleeper

Figure 6 shows the failure mode that is commonly in concrete sleepers. The failure can be classified under three categories, namely, rail fastener failure, rail seal abrasion, and flexural cracking [29]. The cracking occurs at the mid-span and in the rail seat because of impact loading [30]. Due to higher stiffness or low ductility of the concrete sleeper, this could result in a faster rate of deterioration leading to global failure due to flexural cracks [4]. Mixing concrete with rubber particles to overcome the cracking has been implemented [31]. However, this leads to a reduction of compression strength[32].

a) Rail seat deterioration

Rail seat abrasion is a common type of failure in the prestressed concrete sleeper in the railway industry. The root cause of this is rail seat abrasion, hydraulic pressure cracking, hydro abrasion erosion, chemical deterioration, and freeze-thaw cracking [33]. Rail seat abrasion is the damage of concrete underneath the rail seat, and this factor can decrease the life span of concrete sleepers [5]. Severe abrasion can result in rail tipping, loss of clip toe load, gauge widening, and these can fault can result in train derailment [34]. It has been observed that when a heavier and faster train travels, it makes the ballasts deteriorate progressively, and this can lead to the formation of voids and pockets between ballasts and sleepers. Since the structure of the track system is subjected to vibration, this could lead to the concrete sleepers cracking and suffering structural damage [35].

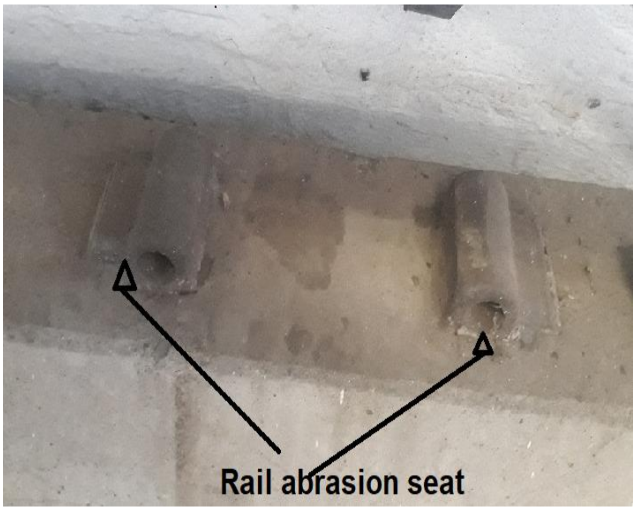

Figure 7 - Rail seat abrasion

Factors that contribute to the failure of rail seat abrasion are heavyweight axle masses, the letdown of clasps, the presence of water, sleeper pads with curves greater than two degrees [26,30]. Wheels transmit loads from sleeper-pad to sleepers over the rail, a shear force takes place at the rail-pad boundary, and when sheer force goes beyond the motionless friction force stuck between the bottommost of the pad and rail seat, slip-up happens, and the strain is transmitted to concrete. After some time, the minute this straining overpowers the tiredness boundary, concrete begins to deteriorate under the rail seat.

Derailment due to sleeper defects commonly occurs due to faulty installation of sleepers and impermissible defects in the railway track [37]. Ground water, soil, and aggregates that contain magnesium, calcium, potassium, sulfates of sodium when added existing in a solution, respond through the calcium hydroxide or tricalcium aluminate elements of the cement adhesive, such kind of reactions is the origins source of spreading out and this results to cracking of concrete sleepers [32,33].

Although the alkali in Portland cement is the main source of concrete sometimes, an added source is un-washed sand which contains sodium chloride. Furthermore, admixtures such as superplasticizers and mixing water are likewise deliberated potential sources of alkali [39]. Silica containing aggregates such as quartzite, chert, strained quartz crystals, and opal may perhaps be influenced by means of hydroxyl ions in alkaline types of cement solution to expansion as shown in equations 1, 2 and 3

Reactive silica +Alkali=Alkali-silica gel...equation 1

$Si0_2$ $+Ca(OH)_2$ $+H_20=CaH_2Si0_42H_20$ (Alkali-silica gel)…….equation 2

Alkali-silica gel + water = expansion, which is the root cause of cracking ……equation 3

D. Composite sleeper

Development and innovative methods have shown that composite materials mixed with fiber composites could improve both mechanical and physical properties of railway sleepers [40]. South Africa has adopted the method of using polymer sleepers to support underground railway layouts [4].

a) Polyethylene foam and glass fiber

Composite sleepers made of glass fiber and polyethylene foam are unique development [41]. This sleeper is expected to have a long service life of more than 60 years while maintaining its physical properties [36,37].

b) Sleeper plastics

A composite sleeper that are made of recycled plastic materials and fibre possess greater strength, lower weight when compared to similar grade timber sleepers. Furthermore composite sleepers are more durable and have adequate mechanical and physical properties [43]. The damping impact loads, sound absorption and lateral stability properties if composite sleepers are similar to timber sleeper. The railway sleeper made of recycled plastic was first developed in the United States of America [4,41].

Composite sleeper can be made of thermoplastic materials which can be re-hardened when cooled and softened by heating, this is a reversible process which however, can have influence on the mechanical properties of sleeper [44].Challenges with in the use of recycled plastic composite sleepers possess low stiffness, low strength , little resistance ability of sustains screws, development of empty space in the sleeper ,insufficient lateral resistance and permanent distortion as result of creep and temperature differences [32].

c) Urethane foam and glass fibre

Composite sleepers made of foam urethane and glass fibre can be machined and fastened together using conventional woodworking tools [14]. This sleeper has greater compression strength and it also gives better resistance of the removal of screw spikes. Furthermore, the sleeper shows stiffness that is similar to timber sleeper [14].

However, this kind of sleeper gained a limited space in the railway industry because of their high price [22].

d) Polyester scrap tyre composites

Waste tyres a creates lot of problems in our enviroment[45].Abu-jdayil, Mourad and Hussain [42] discovered that mixing rubber particle of the waste tyre with polyester resin in certain proportions leads to reduction in the strength of composite material. Too much rubber content that exceed ratio of 50 percent in the composite materials lead to reduction in strength due to low hydrophobicity towards polyester matrix [41,42].

III. Railway pads

The railway sleeper and sleeper pads are fitted below the rail way in order, to enhance damping properties of the track system [43,44].Yet, these sleeper tend to wear easily and detach from the main structure track system as a result of numerous factors for instance climate change and looseness of fastening systems [5].

Table 1- Durability of sleeper, foundations of failures cause of failure and measures that can be used to minimise failure in sleepers

Table 1. Durability of sleeper, reasons of failures and measures that can be used to minimise failure in sleepers

Type of railway sleepers	Life Span	Measures to minimise failure	Causes of Failure	Reference
Composite sleeper	0ver 60 years	Silica fume, reinforcement	Weak bond	[49]
Steel sleeper	50 years	Avoid moist place ,slag ballast, high salinity, zinc can be put on as coating and corrosive materials	Corrosion and Fatigue failure	[50][26], [51]
Concrete sleeper	50 years	To add fly ash, gout reinforcement multilayer abrasion resistant, steel fibre, to add silica fume, epoxy coating, metallic aggregate in the railway region to concrete sleeper	Cracking Derailment Impact loading	[50][33]
Timber sleeper	20 years	Place End plates and impregnation with timber synthetic chemicals and natural treatment	Split end share loading and trans, fungal attack and termite attack	[50][8]

IV. CONCLUSIONS AND SCOPE OF FUTURE WORK

A number of different technologies have developed for railway sleepers but their durability and vibration damping capabilities have been limited.

Timber sleepers possess good mechanical strength that is compared with composite. Nevertheless, termite attack, end splitting and fungal decay has been well-known as source reasons of timber failure. In addition, cutting down of trees has negative effects on the ecosystems and environment as a whole. Suitable ways of replacing timber sleeper is essential. A number of different technologies have been developed as substitutes for timber sleeper but their durability and vibration damping capabilities of timber sleeper have been not satisfactorily met performance requirement of modern trains due to their unexpected early failure. Impregnation of timber sleepers with artificial chemical and natural treatment shields it from termite attack and fungal decay. The use of an end plate helps to control end splitting.

Steel sleepers have superior mechanical strength. However, steel sleeper has early failure due to number of reasons. Salts from soil that come into contact with steel sleepers cause premature failure. The root cause of early failure and corrosion in steel sleeper are; ground water, metallic slag base-ballasts, moist environment or rain region and aggregates. Corrosive materials attached to track system are also the threat. Measures that are used to minimize failure from sleeper are coat that is applied to steel Sleeper as a protective layer, ballast made from slag should not be used with steel sleeper, steel sleeper should not be used in high salinity and coastal regions, steel sleeper should not be used in moist region. In addition acidic materials such as coat, mineral, clay, dirt and mud should not have contact with steel sleeper. In addition, if all these measures that are stated can't be prevented then zinc should be applied as protective layer.

Although Concrete sleepers has great compression strength and are commonly used in railway sleeper, Concrete sleeper has of low ductility and elasticity. Major failures of concrete sleeper are longitudinal cracking and rail-seat deterioration. However, there are protective measures that can be used to eliminate failures in concrete sleeper. The rail seat weakening can be eliminated by applying epoxy as first coating on the rail seat surface, using cast-in-plate steel plates that shield the rail seat part, addition of fly ash to the composite concrete sleeper in the surface of rail seat, adding silica fume, using steel fibre reinforcement grout in the rail seat region during fabrication of sleeper, using combination of steel aggregates in the rail seat region, spread over a multilayer abrasion-resilient pad assemblage. Longitudinal cracking can be eliminated by presenting superior expansive concrete inside bolt-hole region and placing traverse reinforcement bars to strengthen it transversely around bolt hole.

Composite sleepers possess great mechanical strength, good elasticity and durability. In addition, composite had improved damping properties in comparison to the traditional wooden sleepers and concrete sleepers. However, when using rubber particles in composite sleeper to improve damping properties of sleeper, the reduction of compression strength in the composite was noticed. Composite sleeper is having weak bond towards resin and filler due to low hydrophilicity. On other hand Composite sleeper made of thermoplastic materials can be re-hardened when cooled and softened by heating a reversible process can have influence on the change of mechanical properties. Nevertheless, Measures that can be used to eliminate reduction of compression strength is to use synthetic fibre as reinforcement with filler during fabrication.

Composite materials can be used to develop a railway sleeper material with improved vibrational dampening properties while maintaining good structural integrity.

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