DEVELOPMENT AND CHARACTERISATION OF PANTOGRAPH SLIDES FOR RAILWAY APPLICATIONS: A SHORT REVIEW

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ABSTRACT

High-speed railways have transformed global transportation, leading to increased economic activity and reduced congestion. Railway development is surging in Asia, encompassing upgrades to existing lines and the construction of new high-speed railways. This article explores the materials, processes, and properties of pantograph slides. A pantograph slide is an important component of top-running rails that enables the transmission of electrical energy from traction substations to moving trains. This review presents the evolution of pantograph slide materials, such as metal slide plates, pure carbon slides, powder metallurgy slides, metal-impregnated slides, and composite slides. The characterisations of pantograph slide properties, such as density, resistivity, hardness, impact, and flexural properties are also reported. This article delves into the utilisation of local materials, particularly carbon derived from palm kernel shells and coconut shells, as well as graphene from petroleum coke, for the development of current collectors. These findings may contribute to the understanding of pantograph slide materials and provide insights into the potential use of sustainable materials in high-speed railway systems.

Keywords: *Pantograph slide, carbon-copper composite, graphene reinforcement*

1.0 INTRODUCTION

High-speed railways bring about immense changes in the mode of transportation worldwide, aiming to boost economic activity and alleviate congestion [1]. The proliferation of electric train lines in Southeast Asia marks a substantial advancement in the region's transportation sector. Amid escalating urbanisation, population growth, and mounting concerns about environmental sustainability, electric trains have emerged as a viable solution to tackle the challenges of efficient and eco-friendly public transportation [2].

Rail lines that are currently operating and under construction in Southeast Asia are outlined in Table 1 and Table 2, respectively. Several projects are already operational, while several more are currently under construction. The operational trains are operated at speeds ranging from 120 to 160 km/h, while some of those under construction can be operated up to 250 km/h. In Malaysia, several electrical railway systems are in operation, including KTM ETS, KLIA Ekspres (ERL), LRT, MRT, and KTM Komuter. These systems employ various types of current collectors, as detailed in Table 3. Top running refers to trains operating with electrification through a pantograph-catenary system. KTM ETS, KTM Komuter, and ERL run on a 25 kV 50 Hz electrification system using an overhead pantograph-catenary setup [3]. On the other hand, side running indicates trains

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powered by a third rail system. While not classified as high-speed railways, these systems do significantly contribute to facilitate intracity and intercity transportation within Malaysia [4].

Table 1: Fast trains in Southeast Asia (in operation)

Line	Country	Operating Speed (km/h)
KLIA Ekspres	Malaysia	160
Airport Rail Link (Bangkok)	Thailand	160
Boten-Vientiane Railway	Laos	160
KTM ETS (Gemas – Padang Besar)	Malaysia	140
Sprinter	Thailand	120
Mindanao Railway	Philippines	120

Table 2: Fast trains in Southeast Asia (under construction)

Line	Country	Operating Speed (km/h)	Schedule for Opening
Bangkok-Nong Khai High-Speed Railway	Thailand	250	2026
Don Mueang – Suvarnabumi – U-Tapao HSR	Thailand	250	2029
Jakarta-Bandung HSR	Indonesia	200 – 250	2023
PNR South Long Haul	Philippines	160	2025
East Coast Rail Link	Malaysia	160	2026
Trans-Sulawesi Railway (Phase 2)	Indonesia	120	2024
North-South Commuter Railway	Philippines	120 – 160	2029

Table 3: Current collector types in Malaysia's rail systems

Line	Service Provider	Current Collector Type
KTM ETS	Keretapi Tanah Melayu Berhad	Top running
KLIA Transit – ERL	Express Rail Link Sdn. Bhd.	Top running
KTM Komuter	Keretapi Tanah Melayu Berhad	Top running
Light Rapid Transit (LRT)	Rapid Rail Sdn. Bhd. (Prasarana)	Side running
Mass Rapid Transit (MRT)	Mass Rapid Transit Corporation	Side running

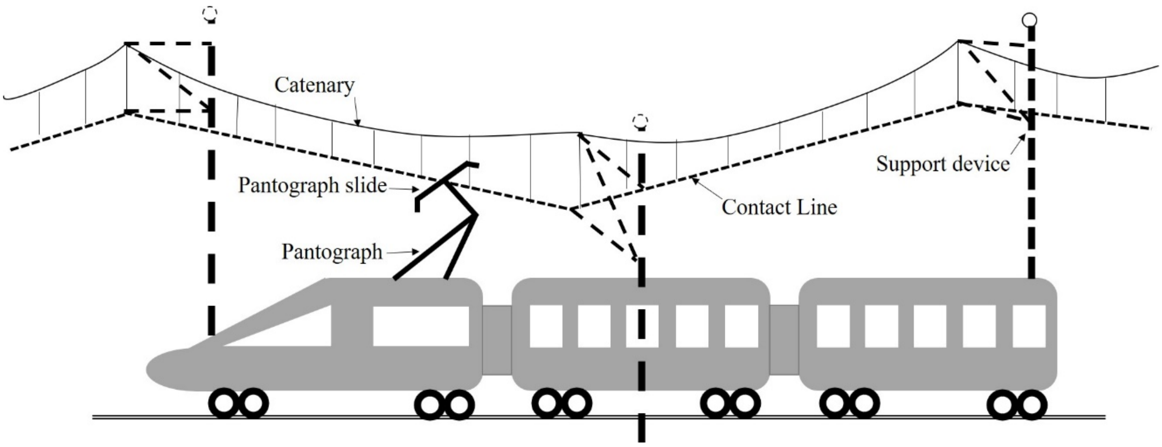

Figure 1: Pantograph-catenary system

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The pantograph-catenary system is illustrated in Figure 1. The catenary is a special power supply line positioned above the tracks to furnish electrical energy to the moving trains. The pantograph is a device mounted on the roof of the train cars, while the pantograph slide is the sliding current collecting component attached to the pantograph [5]. It forms the sliding-contact-current-collection system. The pantograph undertakes the transmission of electric energy. It is an integral subsystem within the high-speed railways, which transmits electrical energy from traction substations to the train in motion [6, 7]. The pantograph's role in maintaining transmission efficiency and reliability is pivotal for the trains, with its performance significantly influencing the development of high-speed electrified railways [8]. Its critical properties, including density, resistivity or conductivity, and impact toughness must meet specified criteria to ensure optimal performance [9]. As electric locomotives advance towards higher speeds and operate within increasingly intricate and diverse environment, more stringent performance requirements for pantograph contact strips have emerged. Consequently, the pursuit of novel contact strip materials that can amalgamate diverse excellent properties has become a prominent research focus across nations [10].

2.0 DEVELOPMENT OF PANTOGRAPH PROCESSES AND MATERIALS

Research on pantograph slides have been conducted extensively worldwide since the 1920s [11]. Figure 2 reveals the evolution of pantograph processes and materials in Asia. The development of pantograph slides has progressed through several stages involving various material selections, such as metal slide plates, pure carbon slide plates, powder metallurgy (P/M) slide plates, metal-impregnated slide plates, and composite slide plates [12]. However, studies aimed at enhancing the properties of pantograph slides have been limited in Southeast Asia, particularly in Malaysia. Currently, pantograph slides used for the KTM ETS have been imported from China and Korea.

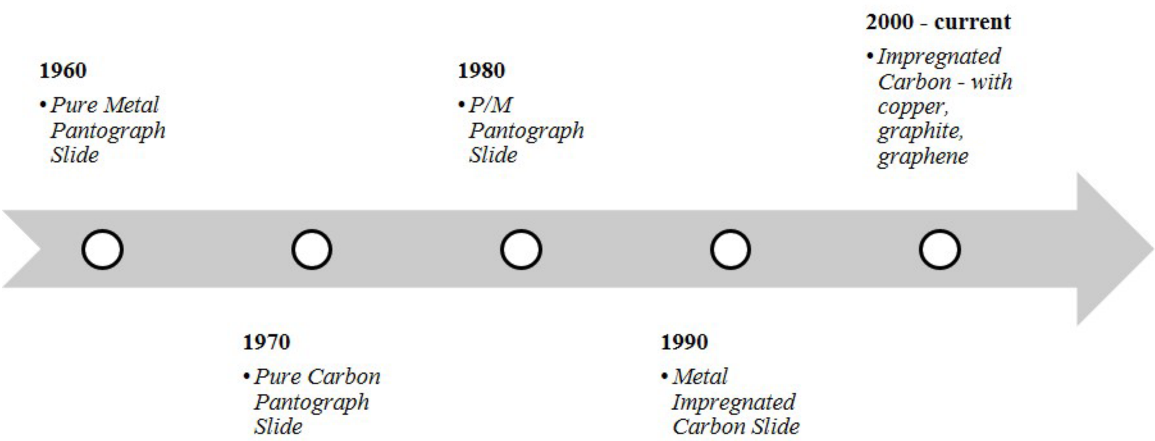

Figure 2: Development of pantograph processes and materials in Asia

Since the 1960s, most pantograph slides were made from pure metal. They exhibited high conductivity but suffer from poor lubricity and severe wear [11]. Pure carbon contact strips were commonly adopted in the 1970s due to their good self-lubricating properties. These strips undergo a process of hot pressing and roasting to form a blank, which is then impregnated with a pitch. Despite causing minimal abrasion to overhead contact lines, the blanks showed slightly high specific conductivity and low mechanical strength. As a result, this type of carbon contact strips was not suitable for trains operating at speeds exceeding 100 km/h [10, 11].

The P/M pantograph slide was introduced in the 1980s. The P/M process involved compaction, sintering, powder forging, and hot forging. It has excellent impact resistance, better

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conductivity, arc resistance, and wear resistance compared to pure carbon slide. P/M pantograph slides have also demonstrated good impact toughness and benefit from reduced friction coefficients due to the continuous formation of a lubricating film during operation [13]. They are well-suited for trains operating at speeds of 100 up to 160 km/h [14].

During the 1990s, metal-impregnated carbon slides were introduced. This type of slides involved infusing a base material, such as aluminium or steel, with particles of a harder and more wear-resistant metals, such as tungsten carbide or diamond. These slides gained popularity due to their high conductivity, self-lubrication capability, enhanced surface hardness, improved frictional properties, and extended service life. Pantograph slides manufactured using this method are suitable for trains running at speeds of up to 300 km/h. Despite their exceptional properties and performance, metal-impregnated pantograph slides require expensive and complicated manufacturing processes and carry the potential of brittle behaviour [15]. Traditional metal impregnation involves a single step in preparing the composite. The new composite impregnation involves two sequential steps: impregnation and carbonisation. This process includes infusing a carbon precursor material into a porous carbon structure and subsequently, subjecting the impregnated material to carbonisation.

Starting in 2000, carbon composites, which are often reinforced with carbon fibres, have gained widespread use in pantograph carbon strips in Asia due to their excellent electrical conductivity, high strength, and strong wear resistance [14]. The carbon/metal composite material is formed through cold or hot pressing, followed by sintering [10]. Copper-based composites are being investigated as potential materials for pantograph slides. These composites exhibit good conductivity, thermal conductivity, and corrosion resistance. With their comprehensive performance, they represent an ideal material for modern self-lubricating friction parts and sliding electrical contact components, which can play a crucial role in demanding work environments [16]. However, copper-matrix composite materials that lack graphite do not possess excellent anti-friction properties and have failed to meet the requirements for pantograph slide usage [13].

Recent research works have explored various lubricants, including graphite to enhance the self-lubrication properties that are crucial for pantograph carbon strips [13]. Copper-based graphite composites have been widely utilised, but the weak interface between copper and graphite often results in deteriorated physical properties [17]. Nonetheless, Jiangxiang et al. reported their successful preparation of a high-graphite copper-based composite material using the powder metallurgy method, which has improved tensile strength, impact toughness, and excellent mechanical properties. In this material, flake graphite is uniformly dispersed as clusters in the copper matrix, primarily serving lubrication and antifriction purposes without reacting with the copper matrix [13].

Graphene has garnered significant attention since its emergence in 2004 due to its remarkable electrical and mechanical properties [18]. It has been extensively explored as an additive to enhance the functional and mechanical properties of metal matrix nanocomposites for various applications that would benefit from its superior mechanical, electrical, and thermal characteristics [19]. Zhang et al. reported the preparation of a pantograph slide using sulfonated graphene (SG) as an additive through mould pressing, hot extrusion, and sintering. Their results demonstrated a notable improvement in the mechanical strength and wear performance of the pantograph slides. The inclusion of SG in the formulation reduced the occurrence of random cracks, increased fracture surface compactness, and curbed electro-erosion of slider materials, which significantly enhanced its mechanical strength and wear resistance [20]. However, significant potential for incorporating graphene into copper-based composites remains unexplored.

3.0 PANTOGRAPH SLIDE PROPERTIES

As a component of current collection by friction, the pantograph contact strip or pantograph slide is required to have good anti-friction, corrosion resistance, wear resistance and self-lubrication, as well as good electrical conductivity, thermal stability, and impact resistance as shown in Figure 3 [16, 17]. Wear resistance is essential to extend the lifespan of components and reduce operational

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cost. Additionally, a higher level of electrical conductivity holds significance in ensuring efficient energy transfer. This attribute not only enhances energy transmission during contact between the pantograph carbon strip and the current-carrying overhead catenary, but also minimises energy loss. Furthermore, the incorporation of self-lubricating properties in the materials serves the dual purpose of failing friction-induced wear and safeguarding the contact wire, thus delaying wear and tear. To avoid mechanical impairment and the potential for strip fracture or breakage, it is crucial to prioritise the impact resistance. Lastly, the thermal stability of materials is imperative that these materials exhibit resistance to high temperatures, thus preventing the risk of arc ablation. By effectively addressing these factors, a holistic approach to enhancing the operational performance and longevity of the components can be achieved.

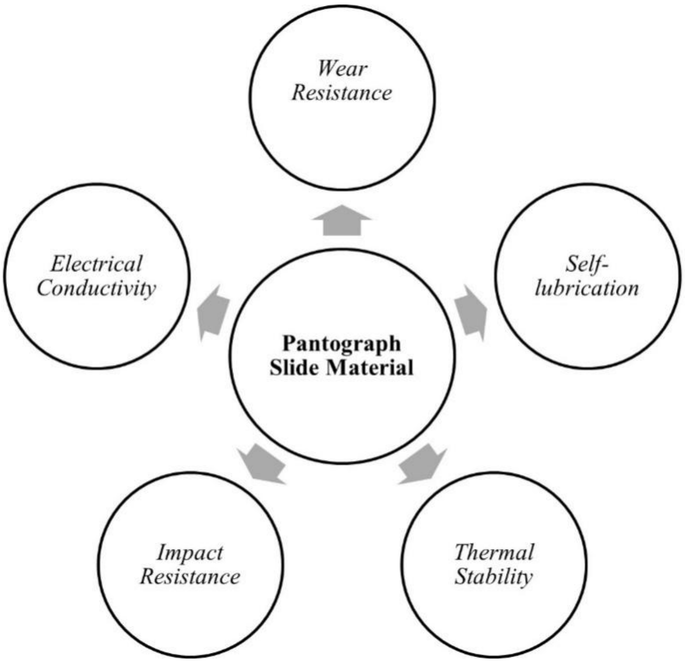

Figure 3: Requirement for pantograph slide material

Table 4: Technical data of commercial pantograph carbon strips from different manufacturers [9]

Manufacturer (Product code)	Material/ Process	Properties			
		Electrical Resistance (μΩ)	Density (g/cm^3)	Hardness (HRB)	Flexural Strength (N/mm^2)
Morganite (MY259)	Metallised pressed carbon graphite	< 1	2.80	90	90
PanTrac GmbH (RH83M6)	Impregnated carbon	7	3.40	105	102
Elekrokarbon a.s. (SK162)	Metal Impregnated (Cu)	5	2.30	110	60
Mersen (P5696)	Metal Impregnated (22% Cu)	7	2.30	90	85

Table 4 presents the characterisation of commercial pantograph slides, reported by Kuznar et al. [9]. To determine its optimum properties, the commercialised pantograph slide was characterised accordingly. The characteristics of the pantograph carbon strips depicted in the table

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are well-suited for the general weather and operational circumstances of trains in various locations, including Poland, Germany, and other nations in the Europe. As discussed before, high conductivity is desired for better operation. Lower electrical resistivity promotes reduction of energy loss and guarantee better energy transmission. Metallised pressed carbon graphite shows lowest value of resistivity compared to other carbon and metal impregnated strips. On the other hand, impregnated carbon strips exhibit best value of density and flexural strength. These properties are important to prevent mechanical damage occurrence. Metal impregnated carbon strip shows highest hardness value. This also represents good properties strip due to its direct impact on wear resistance and durability.

Table 5: Physical and mechanical properties of pantograph slides in different research works

Method	Materials	Density ($g{\cdot}cm^{-3}$)	Impact Toughness (MPa)	Hardness	Resistivity (μΩ.m)	Reference
Metal impregnated carbon slide	Carbon slide plate	2.25 – 2.60	0.22 – 0.35	75 – 118 (HS)	9 – 184	[11]
Traditional impregnation method	C/C composite with copper fibre and needle coke	1.65 – 2.04	0.11 – 0.16	74 – 76 (HD)	19 – 43	[22]
Impregnation and carbonisation	Copper mesh – C/C composite	1.67 – 1.98	0.46 – 2.60	54 – 69 (HRH)	0.80 – 40	[23]
Powder Metallurgy	Copper flake graphite composite	7.8 – 8.0	4.55 – 6.45	81 – 85 (HB)	0.195 – 0.227	[13]
Powder metallurgy	Graphite cluster copper-based powder	7.28 – 7.95	5.2 - 13	71 – 90 (HB)	0.162 – 0.210	[17]
Hot Powder Forging	Graphite-copper alloy matrix composite	8.13 – 8.23	6.05 – 10.2	-	-	[24]

Table 5 summarises previous research on pantograph slides and highlighting their properties and manufacturing methods. Impregnation-produced slides consistently showed densities below 2.5 g/cm^3. In contrast, powder metallurgy exhibited higher densities that surpassed 7 g/cm^3. Powder metallurgy slides also displayed more consistent resistivity, whereas impregnation-produced slides showed some variabilities in resistivity. Both methods have their advantages and disadvantages: impregnation can reduce weight but might impact the electrical performance of the slides, while powder metallurgy can enhance the mechanical strength but could increase weight. Further research is needed to optimise the properties and production processes of pantograph slides to ensure efficient and reliable operations in electrified railway systems.

4.0 LOCAL MATERIALS FOR THE DEVELOPMENT OF CURRENT COLLECTOR

There are growing concerns regarding the substitution of conventional raw materials with renewable and sustainable energy materials. Numerous studies have been done to transform waste into valuable materials with diverse applications [25].

4.1 Local Carbon Materials from Palm Kernel Shells and Coconut Shells

The activated carbon (AC) industry in Malaysia relies heavily on charcoal derived from coconut shells. This type of charcoal is sourced either from local suppliers or imported [26]. Conversely, activated carbon produced from oil palm biomass is both environmentally sustainable and economically viable. Palm kernel shells (PKS) comprises 51.6% carbon, which can serve as a

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suitable precursor for activated carbon due to their high density, elevated carbon content, and minimal ash content [27]. PKS presents a promising solution as AC source material owing to its abundance and potential as a renewable energy source. Malaysia's palm kernel production reached 4.2 million metric tons in 2020 [28], providing a substantial supply of this cost-effective agricultural waste material that researchers can convert into useful products. In general, two widely used methods for AC preparation are physical activation and chemical activation. A facile method for converting PKS waste into high-quality AC was developed by Andas et al. [29]. Meanwhile, Hidayu et al. showed that PKS can be used as a raw material with $ZnCl_2$ as the activating agents to produce activated carbon [30].

Selamat et al. [31] and Ibrahim et al. [32] investigated the incorporation of local carbon derived from PKS into the C-Cu composite for use as current collectors, with the aim of substituting conventional graphite. This substitution led to a 50% increase in the values of hardness and transverse rupture strength (TRS) of the C-Cu composite. Results from both studies exhibited similar TRS, hardness, and density properties in comparison to available commercial components. Despite the slightly lower resistivity value, it remained within an acceptable range. Their findings underscored the promising potential of using local materials to replace conventional carbon powder in C-Cu composite applications for current collectors, including pantographs.

4.2 Sustainable Graphene from Petroleum Coke

In light of global concerns, the imperative to repurpose existing petroleum streams, such as petroleum coke (petcoke) and its precursor oils for sustainable applications has gained prominence. With increasing emphasis on sustainable resource utilisation, the petrochemical industry has encountered several challenges in managing its diverse product streams. Even by-products of oil refining, like petcoke, prove challenging to utilise in a sustainable manner [33]. However, petcoke holds the potential for being converted into graphene, which presents an avenue to transform a carbon-rich byproduct into a valuable and versatile material with a multitude of applications, including in electronics, energy storage, composites, sensors, and more. Ongoing research and development in this field are focused on refining the conversion process and scaling up graphene production from petroleum coke [34]. Recent advancements also indicated progress in reprocessing petcoke into a sustainable, high-value alternative. Researchers have made strides by employing a chemical process known as electrochemical exfoliation to convert petcoke into graphene [35]. This promising method showcases the innovative strides being taken to repurpose petcoke into valuable materials, contributing to a more sustainable and productive industrial landscape.

4.3 Proposed Future Project

Figure 3 depicts a proposed graphical outline for a future project aimed at developing pantograph slides by utilising local materials. The forthcoming projects shall involve the development of graphene-reinforced carbon-copper composite from local carbon materials. The local carbon derived from PKS will be integrated with conventional graphite. Additionally, this project will investigate the impact of incorporating graphene as a filler to enhance the properties of the manufactured pantograph slide for railway application. The effect of the material's composition (copper, carbon, graphite, graphene) and its processing parameters (compaction temperature, post-baking temperature) through the warm compaction process shall be studied. The primary goal is to ascertain the feasibility of leveraging local materials to enhance the properties and performance of the pantograph slide. The chosen route, namely the powder metallurgy approach that uses warm compaction, stands out due to its cost-effectiveness and ability to yield comparable TRS, hardness, and density properties to existing commercial components. This project will also explore the incorporation of graphite and graphene to enhance the self-lubrication and resistivity of the resultant composite. This comprehensive research endeavour aims to contribute to the advancement of pantograph slide technology through the utilisation of locally available resources.

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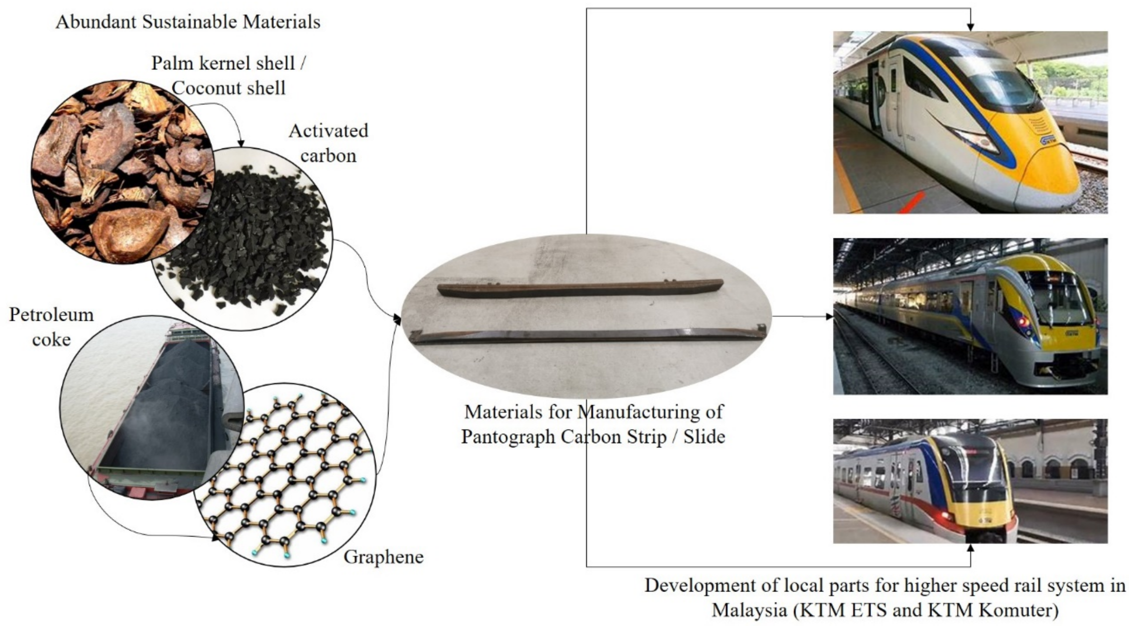

Figure 3: Proposed graphical outline for the development of pantograph slides from local materials

5.0 CONCLUSION

In conclusion, the development and enhancement of pantograph slide materials for high-speed railways have been the focus of extensive research. The current collector system plays a crucial role in ensuring efficient power transmission and the overall performance of the electrified railways. Over time, pantograph slides have evolved from metal slide plates to pure carbon, powder metallurgy, metal-impregnated, and composite materials. Each process and material have their advantages and limitations in terms of properties, such as wear resistance, electrical conductivity, impact resistance, thermal stability, and self-lubrication. Recent studies have focused on incorporating graphite and graphene into the pantograph slide materials to improve their performance. The characterisation of pantograph slide properties may include measurements of density, resistivity/conductivity, hardness, impact toughness, flexural strength, and tensile strength. An emerging trend involves the utilisation of local materials, such as palm kernel shells and coconut shells in the development of current collectors. This approach has garnered attention due to its potential as a sustainable and economically viable alternative. Moving forward, further research is imperative to investigate the compatibility of local carbon materials as pantograph slides. This research seeks to meet the demands of electrified rail systems, ensuring efficient and dependable power transmission in the evolving landscape of railway technology.

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