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Proposal of En19 & En24 steels to face major challenges in indigenized track maintenance machines for Indian railway

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The objective of the present review is to describe the basics of railway track maintenance& to explain the need of the indigenization of some important parts of different machines for Indian railways, which needs regular replacement & bears the heavy cost of import. Indian railway uses two important maintenance machines (a tamping machine unit & ballast cleaning machine Unit), which earlier were imported from an Austrian company Plasser & Theurer. While localizing parts in India, two important alloy steel materials are generally proposed are En19 and En24. This paper also gives the basic idea and properties of the above materials which are desirable and match with German standards, and therefore can be used to fabricate some important parts in Indian railway maintenance machines. Along with the above, the current work has also found the limitations & challenges faced by the Indian railway while using the above materials in some specific components of maintenance machines. Thus, this work finds the research gap in which further work & research could be done to increase the self-reliance capability of the Indian railway.

Keywords: Railway, Machine maintenance, Alloy steel, Indigenization

1 Introduction

Indian railway is in the fourth position among the world's top five rail network systems. As per the Indian government data[1], after 2019, India is working hard to indigenize the maintenance machines which generally were imported from a foreign company. The average import cost was so high therefore railway started working on the indigenization of track maintenance machines[2]. The most common & widely used maintenance machines are: (i) Track tamping machines (For maintaining the rail track geometry), (ii) Ballast cleaning machines (to regulate & cleaning the ballast)[3–7].

As we know that the Indian railways is suffering from heavy load due to its large rail network system[8,9]. The average number of trains passing on a railway track as well as the total load on a single train whether it is a passenger or is goods train is very high[10]. Therefore, heavy dynamic forces are acted on a railway track. Due to heavy dynamic forces, in general, two types of faults happen on railway tracks:(i) Longitudinal fault& (ii)Alignment fault[11,12].

In the longitudinal fault, the railway track goes downwards to its normal position in Y-axis direction as given in Fig. 1. In alignment fault rail displaces left or right from a straight line in the direction of the Z-axis as given in the diagram[13].

Above two faults are very serious and lead to accidents which may cause risk of life of human beings. Therefore, it is important to regularly check and to correct the fault on regular and periodically. Many railway ballast reaction parameters may be acquired throughout the simulation procedure[14–19]. The study investigated the permeability of ballast beneath railway sleepers during construction, since it can influence the carrying limit and stability of railway tracks. Tamping thus extracts the permeability of railway ballast quantitatively. Prior to the tamping procedure, the area should be defined. The schematic view of Unimat 08-4x4/4S track tamping machine is shown in Fig. 2. The permeability of railway ballast in different places varies throughout the tamping procedure[20].As part of this study, we used the simulation during the tamping process to identify the permeability of railway ballast at the defined location, which is indicative of the evolution of the porosity of ballast beneath the middle sleeper during the tamping process. It deals with various types of machines for maintaining the railway track geometry by packing

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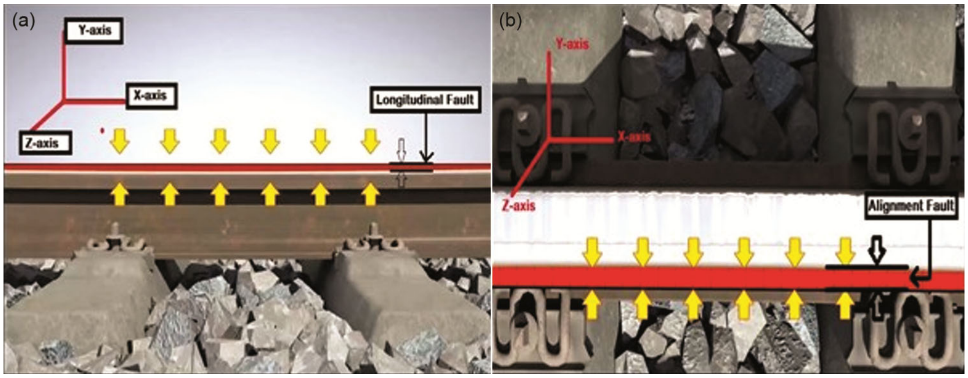

Fig. 1 — Railway track geometry faults with (a) Longitudinal fault and (b) Alignment fault.

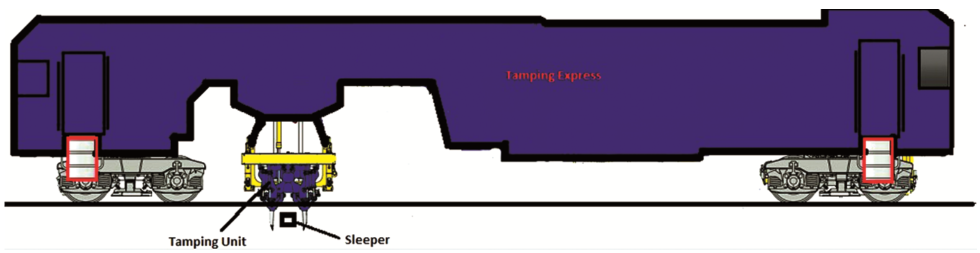

Fig. 2 — Schematic view of Unimat 08-4x4/4S track tamping machine.

the ballast under the railway track. For effective machine operation, a minimum cushion of 150 mm of clean ballast is suggested. Ballast should be present in sufficient quantities in shoulders to allow for the needed lift (approximately 20 mm in every tamping activity) and packing retention after tamping[21].

In general, a tamping process involves three important processes: (i) Necessary work before tamping, (ii) activities during the tamping process and (iii) work after tamping.

It is necessary to perform certain operations prior to the tamping process. The tamping unit of a multi-purpose track tamping machine is shown in Fig. 3. One of the most important operation is field assessment which will be conducted to establish the present track profile and the overall lift. To achieve proper packing, ballast must be pile up in the tamping zone. The worker should be able to see the top of the sleeper, and the ballast must not block the raising rollers. Clean and sharp ballast should be used instead of rounded ballast. Sleepers that are broken or damaged will be replaced[22]. The most important aspect of tamping is to determine the optimal length of railway line for maintenance by a single tamping machine in the context of track maintenance. The procurement and logistics of this machine are also extremely important. Despite this, there is no systematic method managers can use to evaluate the machines' true capacity, which appears to be influenced more by the track availability for maintenance than by their performance[23].The distance between the outer side of the tamping tines and the lower end of the sleeper in the closed position of the tamping tool must be adjusted for rails and sleepers. Tamping tools should be placed centrally between the beds into the ballast to prevent damage to the sleepers. Tamping tools should be placed centrally between the beds into the ballast to prevent damage to the sleepers. A squeezing period of 0.4 to 0.6 seconds is generally enough for maintenance packing. For tracks with caked-on ballast, a longer squeeze time may be necessary[24].

In general, the tamping (pressing) pressure must be within the given range for Indian railways as follows: (i) The central standard Trial-9 that is widely used on Indian railways: 90 - 100 kg/sq.cm[25], (ii) Wooden ties: 100 - 110 kg/sq.cm[25], (iii) Pre-stressed concrete ties: 110 - 125 kg/ sq.cm[25].

A complete set of tamping tools should be included in the machine. Tamping tines should not be worn out loose. The allowable limit for tool blades to wear is 20% of its sectional area.

Slew and lift compensation, if necessary, must be taken into account. Lifting or elevating should typically be 50-mm. The applicable provisions of the long welded rail handbook[26] must be followed for the long welded rail track. A centrally hinged link connects the squeezing cylinder to the tamping tools. Vibration of the hydraulic motor is transmitted through these tamping arms to the tamping tools. Two basic purposes are served by it. The vibration is transferred to tamping tools that create fluidity in ballast, allowing smooth penetration into ballasted tracks for tamped operations. A second feature is that it gets swiveled inside for squeezing function after a hydraulic cylinder is extended and mounted to a vibration shaft for the squeezing function. As the Tamping unit is penetrated below the bottom of the sleeper, squeezing action is performed in order to fill voids and squeeze ballast through the tool.Once the tamping process is complete, some operations are important to take into consideration. Loose fittings must be checked and tightened**.** The ballast must be carefully dressed. The ballast must be properly stabilized between the ties. Using the recorders in the tamping machine, the final track data should be recorded [27].

2 Materials & Methods

Before 1945 maintenance activities were carried out manually this involved a heavy workforce. It took large time to carry out maintenance manually. Indian railways started mechanization of railway track maintenance by importing various tamping machines from an Austrian company Plasser & Theurer[28]. This company was having the patent for a long time on maintenance machines so the average import cost was so much high even now. Because of high import costs, Indian railways started making important tamping units & parts of maintenance machines in India[29]. Indigenization process is done with the help of reverse engineering. Any reverse engineering approach aims to create a three-dimensional mapping of the product in CAD file. Part digitization, feature extraction, and CAD modelling are the three processes of reverse engineering. In Fig. 4, a schematic view of the static structural analysis of the tamping arm employed in the tamping unit is presented. Overall, Fig. 4 (a-d) depicts the distributions of pressure, force, total deformation, and normal stress, respectively.

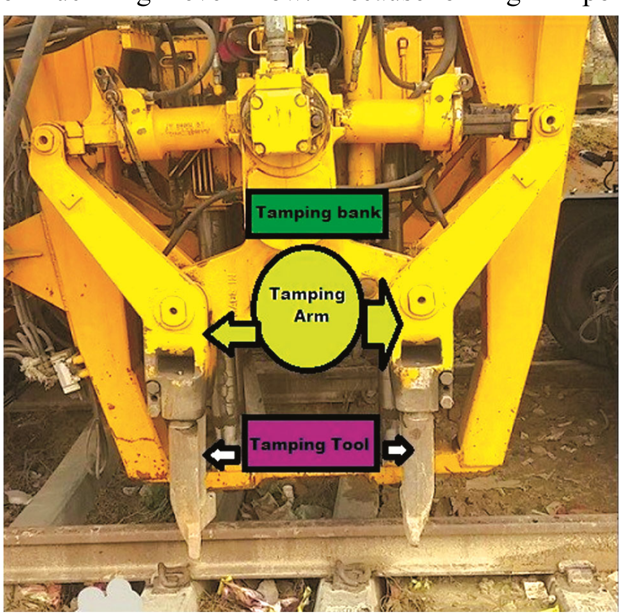

Fig. 3 — Actual view of tamping unit of a multi-purpose track tamping machine.

A variety of contacting and non-contacting digitizers are used to digitize parts. Typically, feature extraction is accomplished by segmenting the digitized data and extracting surface characteristics like edges. Fitting a variety of textures to segmented data points is how part modelling is done. The methodologies for part digitization, segmentation, and surface modelling are discussed in this study[30].

As per the reverse engineering process railway workshop firstly took the individual parts of a typical tamping unit which is imported & follow the steps as given below in Fig. 5.

In the process of localizing the tamping unit of all types of tamping machines by replacing the German standard materials by the Indian standard materials by following a set of processes.

2.1 Challenges with german standard part in India

Plasser & Theurer is an Austrian company which follows the German standard while manufacturing various maintenance machines &their parts. It also exports its machines to various countries including India. The most common maintenance machine is tamping machine. Indian railway has purchased various tamping machines for plain tracks tamping and for point & crossing. In tamping machine, the part which periodically needs to change is the tamping unit because tamping unit directly comes in the contact with ballast while performing tamping operation[31]. In tamping unit mostly parts (tamping arm, squeezing cylinder & tamping bank) are made of $42CrMo_4$ (European grade) steel by Plasser & Theurer except tamping tool[32]. Typically, this steel is utilized in the design of dynamically stressed components in engineering practice. We are aware that the "42" in 42CrMo4 refers to its 0.42% average carbon content[33]. In general, $42CrMo_4$ steel is

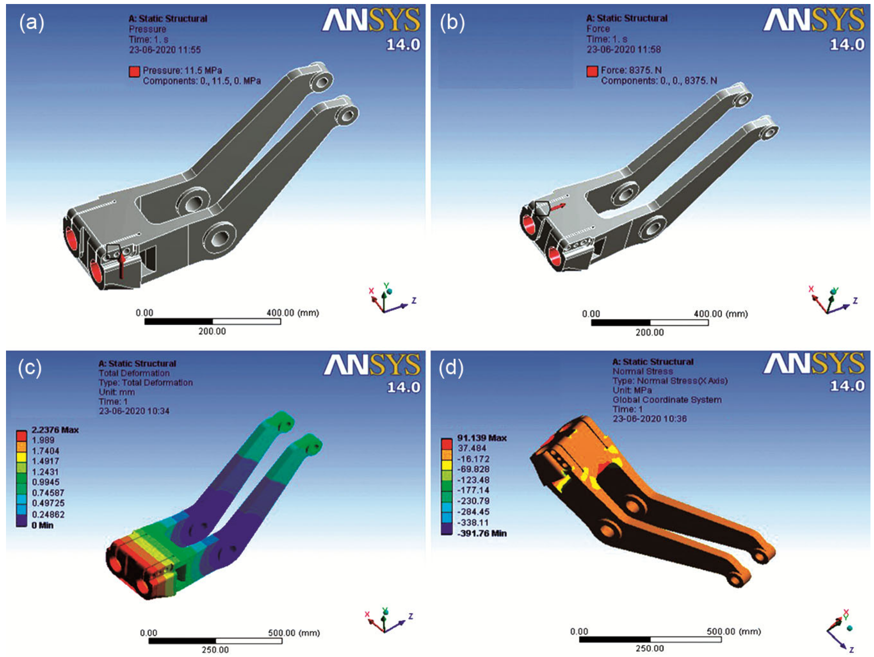

Fig.4 — Schematic view of static structural analysis of tamping arm used in tamping unit with (a) Pressure, (b) Force, (c) Total deformation and (d) Normal stress.

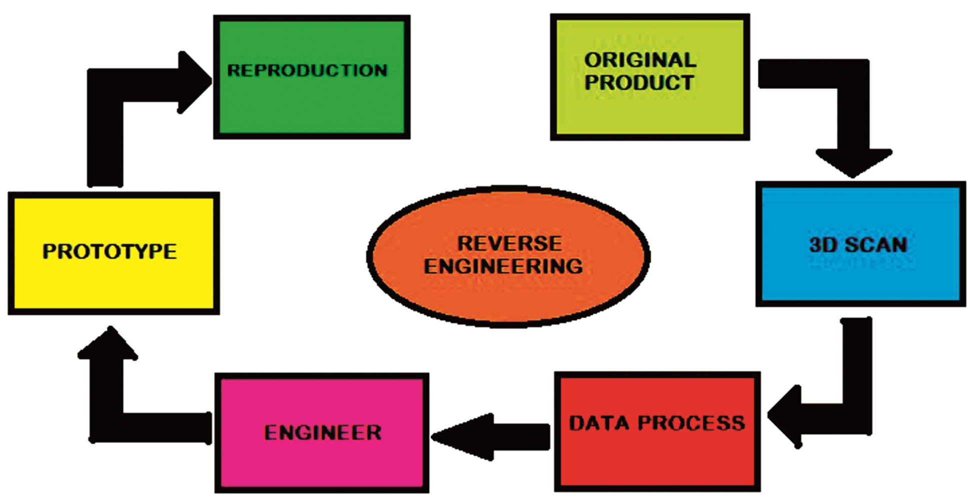

Fig.5 — Block diagram of process of reverse engineering.

supplied hot-rolled or annealed, with hardness below 241HB.

In the European countries the type of ballast is different than that of Indian ballast. Due to diversity in India, Igneous rock is founded in southern region, in Himalayan region metamorphic as well as igneous rocks are found and in middle & west India sedimentary rocks are found therefore this directly affect the tamping unit. So same material which is used for tamping arm, squeezing cylinder & tamping bank cannot be used in Indian scenario in same manner as given in Fig. 6. Another important factor

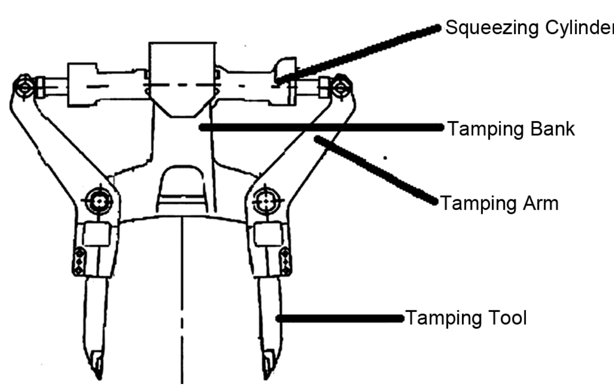

Fig.6 — An indigenized continuous action tamping unit.

for replacing German grade is the lesser cost when material with approximately similar grade used in wearable components. High import cost also forced Indian railway to indigenize the parts. When it comes to replacement of this grade by a cheaper and similar property material then En19 is most suitable one as show in Table 1.

2.2 En19 & its desirable properties in railways

While indigenizing the tamping arm, the most commonly used material is En19. American SAE 4140 circular bar is also known as En19 steel brilliant round bar[34].The chemical composition of the material taken by the Indian railways is given in the Table 2.

For Tensile Strength tensometer determined the ultimate stress in tension, breaking load. The tensometer in question was made by Kudale. It makes use of a 20 kN load cell. The tensometer's lowest count is 0.1mm. Elongation varies from 0-500mm. The tensometer can handle a minimum load of 10N. The tensometer has an accuracy of 1%. A370-E8 was the ASTM standard for the tensometer that was utilised. The sample whose tensile strength has to be determined is fixed between the tensometer's two jaws. The moveable jaw then moves while the tensometer is activated until the specimen splits in half [36]. Braking load & ultimate stress of En19 are given in details in Table 3.

Bright round bar is a 1% chromium–molybdenum medium hardenability special - purpose high tensile steel that is often hardened and tempered with in tensile limit of 850–1000 MPa. It is used when better mechanical qualities than carbon steel are required. Axles, good strength bolts, drive shaft, crankshaft connecting rods, studs, propeller shaft joints, and crankshaft rifle barrels, are some of the most common applications. The process of heat treatment involves heating and cooling steel to achieve certain results. Young's modulus, hardness, toughness, and yield of a component must all be achieved. Temperature and hardening, on the other hand, are two of the most common heat treatments used to enhance the microstructure and mechanical properties of steel. The purpose of steel hardening is to improve both strength and wear resistance[37–40]. It is important to note that adequate carbon and alloy are the most important requirements for hardening steel. A material with enough carbon can be toughened immediately. A tempering process improves toughness, hardness, and relieves internal tensions. The hardness of the specimen after tempering is determined by the tempering temperature and time. Hardness was measured using the HRC scale following HT, which revealed a significant increase in hardness. Therefore, tempering plays a critical role in the modification of mechanical properties and microstructure characteristics of materials[41].The mechanical properties of EN19 are provided in Table 4.

Table 1 — Difference between European standard & British standard.

No.	Constituents	42crMo$_4$ (Weight%)	En19 (Weight%)
1	C	0.38-0.45	0.35-0.45
2	Mn	0.6-0.9	0.5-0.8
3	Si	≤ 0.4	0.10-0.35
4	S	-	0.02-0.04
5	P	≤ 0.025	≤ 0.025
6	Cr	0.9-1.2	0.9-1.5
7	Ni	-	-
8	Mo	0.15-0.30	0.2-0.40

Table 2 — Chemical configuration of En19 steel used by Indian railway [35]

No.	EN No.	EN 19(Weight %)
1	C	0.43
2	Mn	0.65
3	Si	0.23
4	S	0.016
5	P	0.019
6	Cr	0.96
7	Ni	-
8	Mo	0.23

Table 3 — Ultimate Stress & Breaking Load of EN19 Steel Alloy [36]

Sample	Breaking Load (N)	Ultimate Stress (N/mm^2)
general	6628.00	527.69
Anealing	6158.00	490.31
Normalizing	7138.00	738
Quenching (Oil)	16259.00	1295
Quenching (Water)	10218.00	1357
Quenching (Brine)	18147.00	1423

Table 4 — Properties of En19[42]

Properties (Mechanical) Properties	Metric	Imperial
Tensile Stress	655.00 MPa	95000.00 psi
Yield Stress	415.00 MPa	60200.00 psi
incompressibility	140.00GPa	20300.00ksi
Modulus of rigidity	80.00GPa	11600.00ksi
Young's modulus	200.00 GPa	27557.00 ksi
coefficient de Poisson	0.28	0.28
Elongation at break	25.7%	25.7%
Brinell hardness	197.00	197.00
Knoop hardness	219.00	219.00
Rockwell scaleB	92.00	92.00
Hardness, Rockwell C	13.00	13.00
microhardness	207.00	207.00
Machinability	65.00	65.00

Temperatures for tempering EN19 alloy steel range from 205 to 649°C, depending on the desired hardness. Hardness can be increased by tempering steel at a lower temperature. Tempering at 316°C (600°F) results in a tensile stress of 225 ksi, whereas tempering at 538°C (1000°F) results in a tensile stress of 130 ksi[36]. The first choice for customizing the qualities of materials is heat treatment during the process, steels undergo changes that extend their service life in relation to their strength. In general, En19 steel can be forged at temperatures between 125°C and 90°C Celsius & has a density of 7.85kg/cm3. Nonetheless, if this steel is welded in its heat-treated state, its mechanical properties will be compromised, and post-weld heat treatment is recommended. The available literature for En19 is tabulated in Table 5.

Since many properties of the En19 alloy steel match with the German standard material, therefore many parts of typical tamping unit can be made of En19 Steel with some desirable properties. Therefore, Indian railways with some modification stared using En19 Steel. Following are the Parts of a critical tamping unit of all tamping machines in which Indian railway uses En19 steel material: **(i)** Tamping blank**, (ii)** Squeezing cylinder**, (iii)** Tamping arm

Table 5 — Literature survey of En19 useful in Indian railways

S. No.	Aim	Output parameter	Conclusion
1	The metallurgical properties of polished tungsten carbide inserts were compared using En19 steel[43].	Fatigue experiment was performed of En19 Steel before & after the heat treatment on the fatigue testing machine.	After heat treatment the material En19 showed an improvement in fatigue life & hardness increased from 16 to 45 hardness rockwell C.
2	Microstructured carbide inserts for En19 alloy steel machining [44].	Micro structures in the form of holes and slots were created by laser-radiating the rake faces of cutting tools.	The tool life of structured cutting tools was extended by 15% over standard material and by 36% over unstructured cutting tools.
3	Liquid pure tin was used to evaluate liquid metal embrittlement of En19 steel specimens during tensile testing [45].	Each of the samples was subjected to a metallographic investigation.	Temperatures ranging from around 400 C for low-strength steels to around 480 C for high-strength steels.
4	The effects of partial and intense cryogenic treatment on En 19 steel tribological Behavior[46].	A SEM was used to analyze the nanostructures of CHT, SCT, and DCT samples.	Wear resistance has increased by 118.38 percent for SCT specimens and 214.94 percent for DCT samples.
5	Optimization of machining parameters to achieve the desired technological parameters [47].	Using response surface methodology, parameters such as surface roughness, tool radial vibration, and material removal rate were measured.	Surface roughness is largely affected by feed rate (72.19 %), followed by effect of cutting speed (10.69 %) and by feed rate (1.86 %).
6	The polymer quenching assessment of medium carbon low alloy forged steels [48].	The microstructure of specimens quenched in 10 percent and 30 percent polymer solution was examined using a Carl Zeiss microscopy.	Quenching polymers would increase ductility, toughness, and impact strength.
7	Fatigue behavior of En19 on heat treatment[41].	Fatigue experiment was performed on the fatigue testing machine.	En19, the number of cycles after heat treatment for fatigue failure increased.
8	Parametric optimization under cryogenic machining of En19 steel[49].	Integrated Taguchi-present worth method.	Applied to the maintenance system in total quality management.
9	Wear in high-speed turning of low carbon steel [50].	After a series of machining tests, a few important relationships have been discovered.	Using uncoated carbide tools, high speed machining can lead to a near-merging of wear zones.
10	A study of the effects of heat treatment on the microstructure of En19 steel [36].	Observe and compare the changes in the microstructure, strength after the heat treatment.	A specimen's strength is improved by quenching, and its toughness is improved by tempering.
11	Plasma nitriding of low alloy steel and its physico-mechanical properties [51].	The pulse plasma technique can be applied to the hardening, coating or etching of surfaces.	Samples are shortly achieved very good mechanical & metallurgical properties and the observed Physico-mechanical properties.
12	Analyze grey relational to optimize multi-response objectives when machining En19 steel [52].	The material removal rate and surface roughness are validated by grey relational analysis.	In dry machining, spindle speed is ranked first, feed rate is ranked second, and depth of cut is ranked third.
13	Graphite mixed EDM of En-19 alloy steel [53].	An in-depth examination of the machined surface was conducted to determine whether the concentration of graphite powder during the machining process affected the final surface.	Both material removal rate and peak current, gap voltage, and graphite concentration increased with a higher voltage.

The indigenized multifunctional tamping machine's squeezing cylinder is a key component. Recently in Indian railways, engineers been working on producing indigenous track tamping devices, and indigenized multifunctional is the most recent one under development. Machine for tamping failures in the tamping unit were investigated, and it was discovered that the squeezing cylinder is responsible for the majority of reported failures. Cylinder squeezing by introducing En19 steel as a new material[54].Central periodical overhauling workshop Prayagraj has worked on the construction and maintenance of a variety of indigenous tamping equipment[55]. They conducted a post-POH investigation and found that evaluation of tamping units from April 1, 2018 to December 31, 2018, revealed that squeezing cylinders accounted for 51% of all reported failures[54].Tamping arms connect the squeezing cylinder to the tamping tools through a centrally hinged connector. Vibration from the hydraulic motor is transmitted to the tamping tools via these tamping arms. It has two primary functions. to begin, vibration is transferred to tamping tools, which promotes fluidity in ballast and allows for smooth penetration of ballasted rails during tamping operations. Second, it swivels inside for squeezing action when hydraulic cylinder mounted on vibration shaft is extended. Squeezing operation takes place to fill the cavities and squeeze the ballast using tamping tools once the entire tamping unit has been pierced below the bottom of the sleeper. Because this tamping arm is mounted on a tamping gear box and rotates in a phosphorous bronze bush as a lever mechanism, its effectiveness is primarily concerned with smoothness[56].Lifting and lining, or raising the track to the level established by earlier measurements while simultaneously positioning it laterally, is how a tamping machine works. The tamping tines enter the ballast once the rail is in the desired location, and the tamping operation begins. Following that, the squeezing movement begins, which is characterized as a closing motion of the tines. Amount of nominal squeezing the tamping is done using the non-synchronous tamping concept. characterized as the simultaneous motion of all tamping tools with the same force, regardless of the course[57].

2.3 En24 & its desired properties in Indian railways

En24 is generally used in hardened and tempered condition to achieve optimum mechanical properties. Before heat treatment, EN24 consists mainly of ferrite and bainite. Different treatments change the matrix/phase structure. These changes affect the mechanical properties of alloy steel EN24. Despite En24's microstructure being quite similar to the prior specimen, it exhibits improved tensile strength, yield stress, % elongation, and hardness properties after stress relieving treatment. En24 was categorized as a wrought steel for autos and aircrafts when it initially became popular in the early 1900s, and it was used to make a variety of products and materials for these industries. It is most often known as En24T, and it is frequently employed in the industrial industry due to its strong tensile qualities in T state. Some of application[58] are gears for power transmission and other gears that require maximum toughness, crankshafts, axles, propeller shafts, and gearbox shafts with high tensile characteristics. It also finds application in connecting rods, cranks, and other elements must be rigid while being extremely durable.

En24 steel, which is a Ni-Cr-Mo wear steel, is widely used in machine parts, gears, and shafts. It is typically hardened and tempered in order to achieve a combination of hardness and ductility that's optimum. In this study, hardening and tempering temperatures were varied in relation to microstructure and hardness of En24 steel. Microstructures were studied using scanning electron microscopy (SEM) and X-ray diffraction (XRD). The Scanning electron microscope micrographs are shown in Fig. 7.

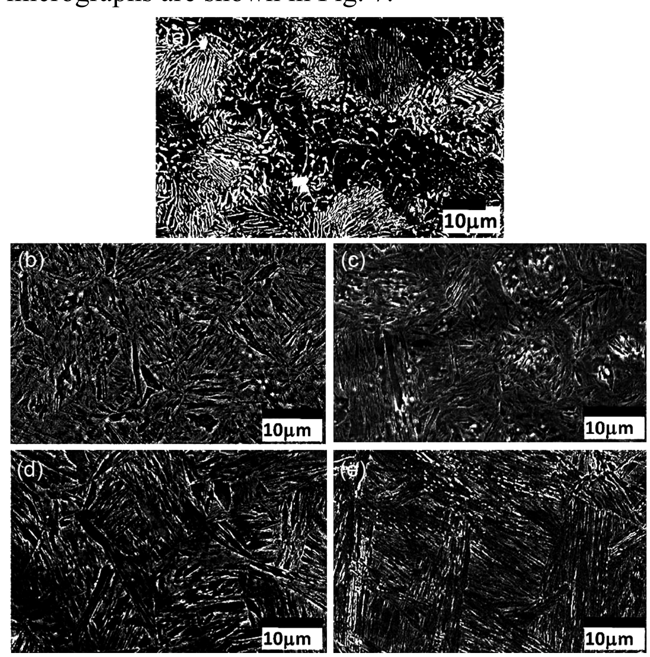

Fig.7 — SEM image of En24 steel (a) annealing at 1123 K and after austenization at (b) 1123 K (c) 1173 K (d) 1223K and (e) 1273 K followed by oil quenching. *Reprinted from reference 35 with permission of ISIJ International, 2012.*

With an increase in hardening temperature from 1123 to 1273 K, hardness decreased, whereas it increased with an increase in hardening temperature after tempering at 823K. Tempering begins when the steel reaches room temperature to achieve T condition hardening, thoroughly anneal before heat treatment is recommended[59]. A standard annealing procedure consists of heating En24T gently and evenly to 840-860°C, cooling it in the furnace to 580°C, and then allowing it to cool to room temperature[60]. The En19 steel's chemical composition is provided in Table 6. It is possible for the heating, cooling, and soaking processes to differ based on the component's size and form.

Using both experimental and artificial neural network methods, the results were obtained with regard to fatigue life prediction of En24 steel variable surface treatments increased En24's fatigue life by 21%. A variety of surface treatments increased the fatigue life of En24 steel by 21%. Increasing the surface roughness index (Ra) from 2 to 0.8 mm improves fatigue performance by 20%. Specimens fail strictly brittle, without lateral distortion. Experimental and projected maximum stress and failure cycles were compared, and the ANN prediction was found to be accurate with a minimum error of less than 1% [62]. In Supplementary Fig. 8 fatigue life of En24 is shown at different Loading conditions 100, 125& 150 Kgf, respectively.

Table 6 — Composition of En24 Steel[61]

No.	Content	Percentage(weight %)
1	C	0.36-0.44
2	Si	0.10-0.35
3	Mn	0.45-0.70
4	S	0.040 Max
5	P	0.035 Max
6	Cr	1.00-1.40
7	Mo	0.20-0.35
8	Ni	1.30-1.70

A failure study was performed on a faulty pinion gear used in the automotive industry for transmission of power [63]. As well as being a case-carburized steel gear with little nickel and chrome, the pinion gear is heavily corroded as a result of an environmental problem. Surfaces of the teeth are severely rusted and damaged. In reality, the crack developed due to stress and can only be identified in specific places. The crack, however, grows in response to stress, and is only apparent in distinct positions. In a load capacity of 1 kg, a wear test has been conducted on the pin on disc as given in Fig 8. Overall, in Fig. 8 (a), the values of maximum stress and number of cycles for En24 steel are presented based on experimental data. Additionally, Fig. 8(b) illustrates the wear rate at 1 kg for En24 steel before and after heat treatment.

The addition of nickel and chromium content contributes to fighting disintegration, in addition to the heat situation. En24 brace has better machinelike features and wear-fighting characteristics when compared to disappointment gear and En24 before heat situation[64]. An environmental issue caused the pinion to corrode due to case carburized steel with minimal nickel and chromium content. As indicated by the failure analysis, the pinion teeth are highly rusted at the surface. It is caused by stress corrosion cracking and can only be detected in specific areas.

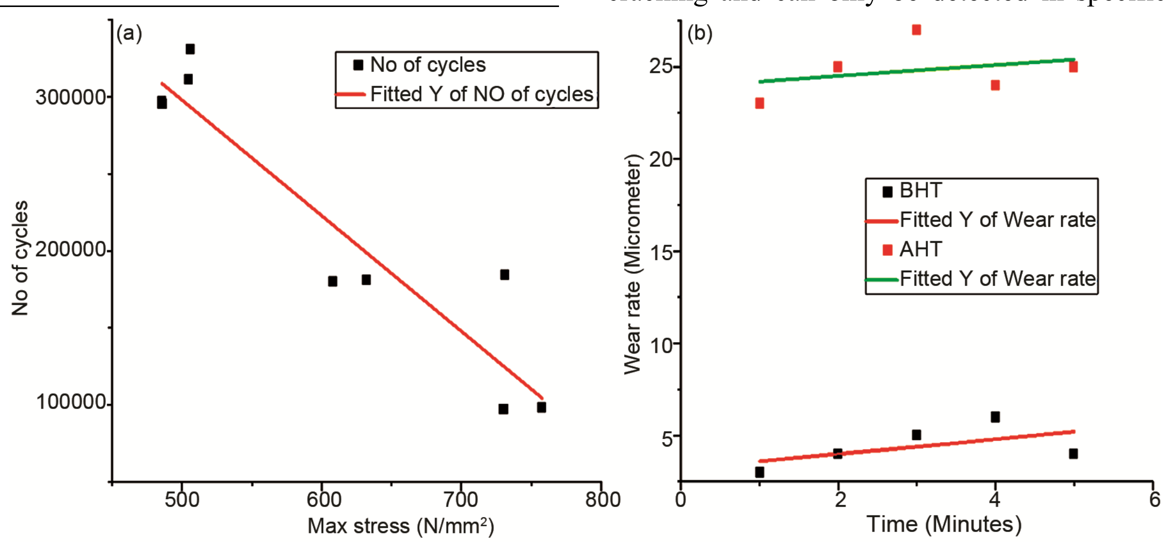

Fig. 8 — (a)Values of max stress & no of cycles for En24 steel (Experimental) and (b) Wear rate at 1Kg of En 24 before and after heat treatment.

In order to overcome the failure, high nickel and chromium content steel (En24) is chosen. During the gas nitriding process, steel's mechanical properties are improved. Comparatively to case carburized steel and En24 steel prior heat treatment, mechanical parameters such as hardness, wear, and tensile are improved[65]. Basic mechanical properties of En24 are given in Table 7.

Every production unit strives to provide high-quality items at a low cost and in a timely manner. Hard machining has been shown to be a suitable alternative for steel component machining in this situation. Hard machining is the procedure of machining hardened steel sample with harnesses ranging from 45 to 65 HRC. Hard turning has a number of advantages over cylindrical grinding, including a higher material removal rate, more operational flexibility, shorter set-up and cycle times, lower operating costs, and lower power and energy usage. In comparison to cylindrical grinding, it is also a more environmentally friendly method[67].

2.4 Application of En24 in tamping tool

Track tamping machine with neighboring tamping tool groups spaced so nearly together that the neighboring tools of adjacent groups are immerse in the ballast between adjacent ties, and a common drive for the adjacent groups of tamping tools. The traditional track tamper consists of two opposing tamping tools organized for immersion in the ballast adjacent to the track Sleeper, with each tie positioned between the opposite tines, and for retaliation in the direction of track elongation to tamp the ballast under each sleeper upon reciprocation of the preferably vibratory tools. The tamping tools are vertically adjustable on a carriage frame that runs down the track for continuous tamping of one tie after another in one type of track tamper[68].The tamping tool diagrams are shown in Fig. 9. Tamping units work according to the asynchronous constant pressure principle. As the tamping tools move, they push the ballast until the desired force is achieved, ensuring that each tool delivers the same amount of force to the ballast. In an asynchronous constant pressure compacting operation, each of the tools continuously moves for various lengths of time, crushing the ballast until the necessary pressure is reached. All tamping tools provide the same level of pressure to the ballast being tamped, ensuring that the forces between tool pairs and the surface pressure of each tool are balanced. Resistance is created up next to each set of tools during ballast tamping. The tool's movement is fully independent of the resistance it encounters from the ballast. The tool's movement is independent of the ballast's resistance. Associated tool pairs automatically stop squeezing once the resistance reaches the pre-selected level (hydraulic pressure in the squeezing cylinder), while other tool pairs continue to squeeze until their resistance likewise reaches the pre-selected level [69].

Table 7 — Mechanical properties of En24[66]

Property	Approximate Value
Tensile strength	850 MPa
Yield strength	680 MPa
Elongation % (in 50 mm)	13
Hardness	30-31HRB with 100kg load and Diamond indenter (measured in lab)

Indian railway while indigenizing the tamping tool, used reverse engineering process and tried to find the metallurgical properties of imported tamping tool. Then chips of tungsten carbide fixed to En24 tool to provide wear resistance as given in Fig. 9.

2.5 Technical eligibility of tamping tool

Tungsten carbide tamping tool shall be made of chromium molybdenum/nickel chromium molybdenum alloy steel or other special grade steel that meets the functional requirements and has the technical capabilities specified in this standard. However, the mechanical qualities of such steel must fulfill the following requirements. The tool should be able to endure the following while tamping: (i) Squeezing pressure of 135 Kg/sq cm (minimum), (ii) Vibration frequency (minimum): 35 HZ

The maker shall provide the grades (Indian standard or similar international standard) and relevant specifications of the steel utilized. Steel in the shank section of the tamping bank's tamping arm should be properly treated to avoid wear and tear during the tungsten carbide tamping tool service life.

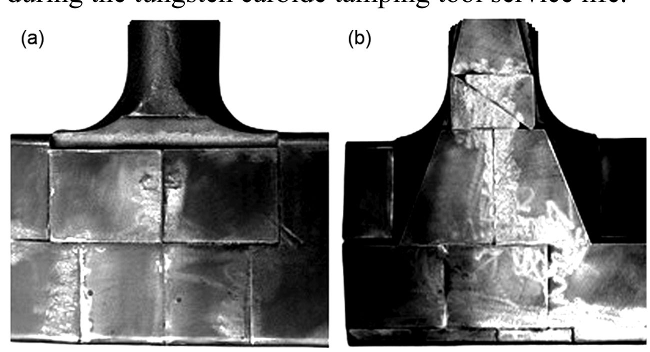

Fig. 9 — An actual diagram of tamping tool with (a) Front side of tool and (b)Rear side of tool.

2.6. Chemical composition requirement

The steel should be of sufficient grade and composition to allow for effective brazing and joining with tungsten carbide inserts. When requested by the purchaser or the inspecting authority, the producer must provide the grade (Indian standard or comparable International standard) of steel and chemical properties of each cast of steel and sample of forged and heat-treated TCTT[70]. Tungsten carbide insert mechanical qualities must exceed the following minimal requirement as given in Table 8.

If the customer or inspecting authority requests it, the maker shall provide the aforementioned information about the tungsten carbide inserts utilized. In addition, the manufacturer must supply the purchaser/inspecting authority with test certifications, covering testing procedure and reference technical documentation. Tungsten carbide inserts of appropriate size should be utilized for increased impact, wear resistance, and brazing. Corrosion protection for the components is essential. The TCTT's packing must resist the tool's weight, and tungsten carbide chips should be protected from harm during handling. Rust-prevention oil must be applied to the holding area[71]. As the above requirement the currently available material for tamping tool is En24 alloy Steel. En24 have some properties which are required for tamping tool.

Table 8 — Minimal required mechanical properties of TCTT[71]

No.	Properties	Minimum requirement (min)
1	Hardness	HRA 84/HRC 65
2	Density	13.2 g/cm3
3	Rupture strength (transverse)	2600 N/mm2
4	Compressive strength (ultimate)	2600 N/mm2

3 Results & Discussion

In order to study the effects of tamping and stabilizing on ballast bed resistance, the resistance and resistance work of ballast beds at various displacements in the initial state, after tamping, and after stabilizing are calculated and are plotted in Fig. 10 (a-b). A comparison of longitudinal and lateral resistance of ballast beds before and after tamping and stabilizing is also performed.

$$r_s(r_s \cdot l) = b - \frac{b-a}{\left(1+\left(\frac{d}{d_0}\right)^p\right)} \quad \ldots(1)$$

$$w_s(w_s . l) = w_0 + c_1 d + c_2 d^2 \quad \ldots(2)$$

The change in ballast packaging during tampering process at various stages is shown in Fig 11(a-d).During the tamping operation on newly constructed railways, the lateral resistance was reduced by 56.5% and the lateral resistance work was reduced by 64.9 %. In the aftermath of the stabilizing operation, the lateral resistance and lateral resistance work are increased by 168.6 % and 209.8 %, respectively[72]. A tamping and stabilizing operation can significantly increase the support stiffness of ballast beds, which meets the requirements of trains. Track lifting has a considerable effect on ballast bed quality, and the lift amount should stay between 20 mm and 30 mm if you wish for good tamping results.

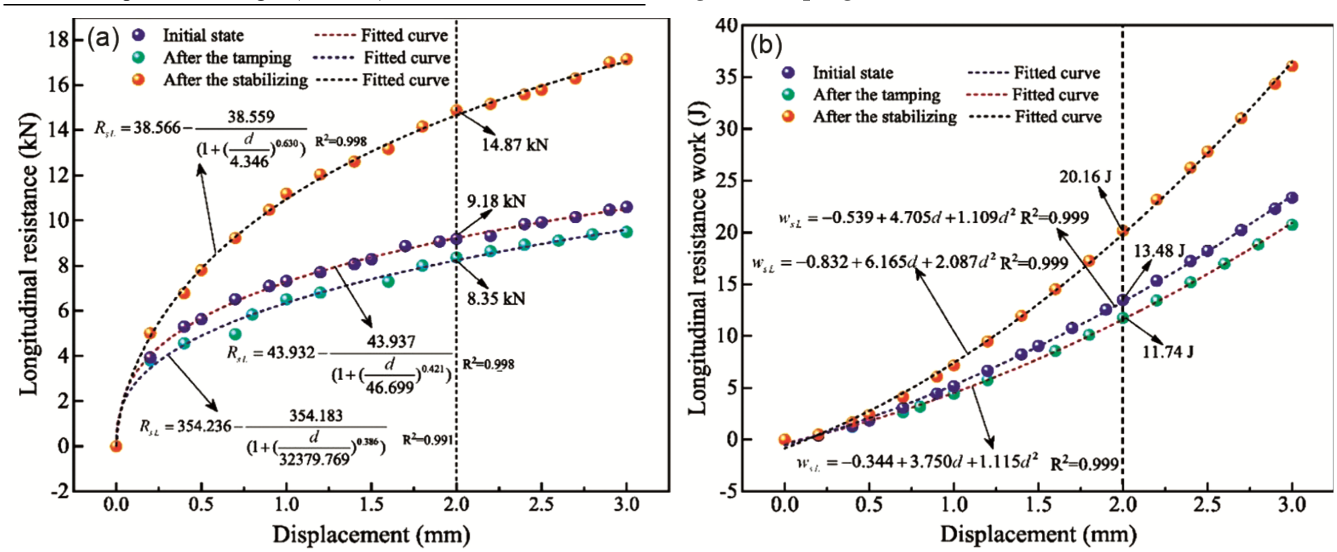

Fig. 10 — Displacement for various stages are plotted with (a) Longitudinal resistance and (b) Longitudinal resistance work.

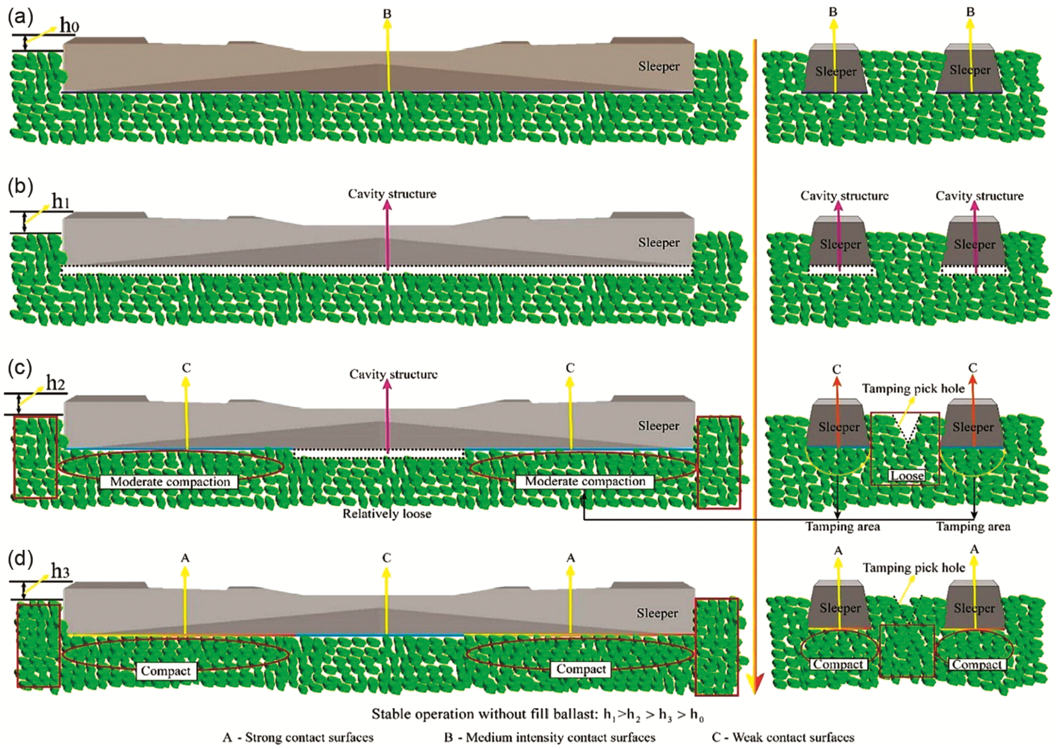

Fig. 11 — Ballast packing change in tamping process (a) Starting state (b) After lifting (c) After tamping and (d)After stabilizing *(Diagram reproduced from reference 44).*

Table 9 — Life cycle analysis of a typical multi-purpose tamping unit[2]

No.	Name of the Machine	Approx. life of Purchased Machine	Approx. Life of Localized Machine
1	Multi-purpose Tamping unit	1500 km	900 km

4 Conclusion

Indian railways' vision 2010-2020 document envisioned the transformation of Indian railways from a technology importer into a technology exporter, and the development of tight links between the research, design, and standards organization (RDSO), government institutions, and education institutions, such as IITs, NITs, and research labs of the CSIR [73].However, a review of the documents found that there was no strategy for developing indigenous track machine capabilities as set out in the vision whitepaper 2010-2020.According to the railway board (December 2014), indigenization rates reached 100% in the case of simpler, less sophisticated machines33%, 30-50% in the case of machines of intermediate complexity, and 20% in the case of very complex machines. The majority of smaller track machines, such as track relaying equipment, rail borne maintenance vehicles, light tampers and so on, are indigenized completely, while the proportion of indigenized parts in other machines where developmental orders were placed on Indian companies varied from 36 to 47 percent. As Indian railway is now working on high-speed trains but average load on a single train is still very high therefore regular maintenance of railway track is very important for proper functioning of Indian railway. This maintenance if done manually, will take more time and work force required for this job will also be high. So mechanization of maintenance work is need of time. Indian railway had purchased many automatic & semi-automatic maintenance machines from 1990 to till now, but since average cost of an imported machine and its parts is very high so it is necessary to indigenize important parts of a maintenance machine in order to reduce the maintenance cost of a machine. In all machines the two important tamping machine are tamping machines & ballast cleaning machines. In tamping machines tamping tools need to replace after certain interval therefore rather that import it, Indian railways make it indigenously. When En24 steel used with coated tungsten carbide is used in place of German standard material tool it worked better but life of tool is a big challenge. The average life of an indigenized tamping unit is 900 km which is less than expected as given in Table 9.

This paper shows that considerable research exists in rail maintenance, but most of it is focused on preventive maintenance or on limited forms of predictive maintenance which use expensive, dedicated vehicles or devices with little or no use of recent technologies and techniques in data processing, communication, and sensing. The emergence of technologies such as IoT and Industry 4.0, the use of 4G and 5G communication solutions, as well as cloud-based collection and storage, and not to mention software-based approaches are all paving the way for what is now being called the "Internet of things." Massive data collection and processing, high-speed, stable, and safe connections, intelligent data analysis and data extraction, and flexibility are all critical for smart railway maintenance systems [75].

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