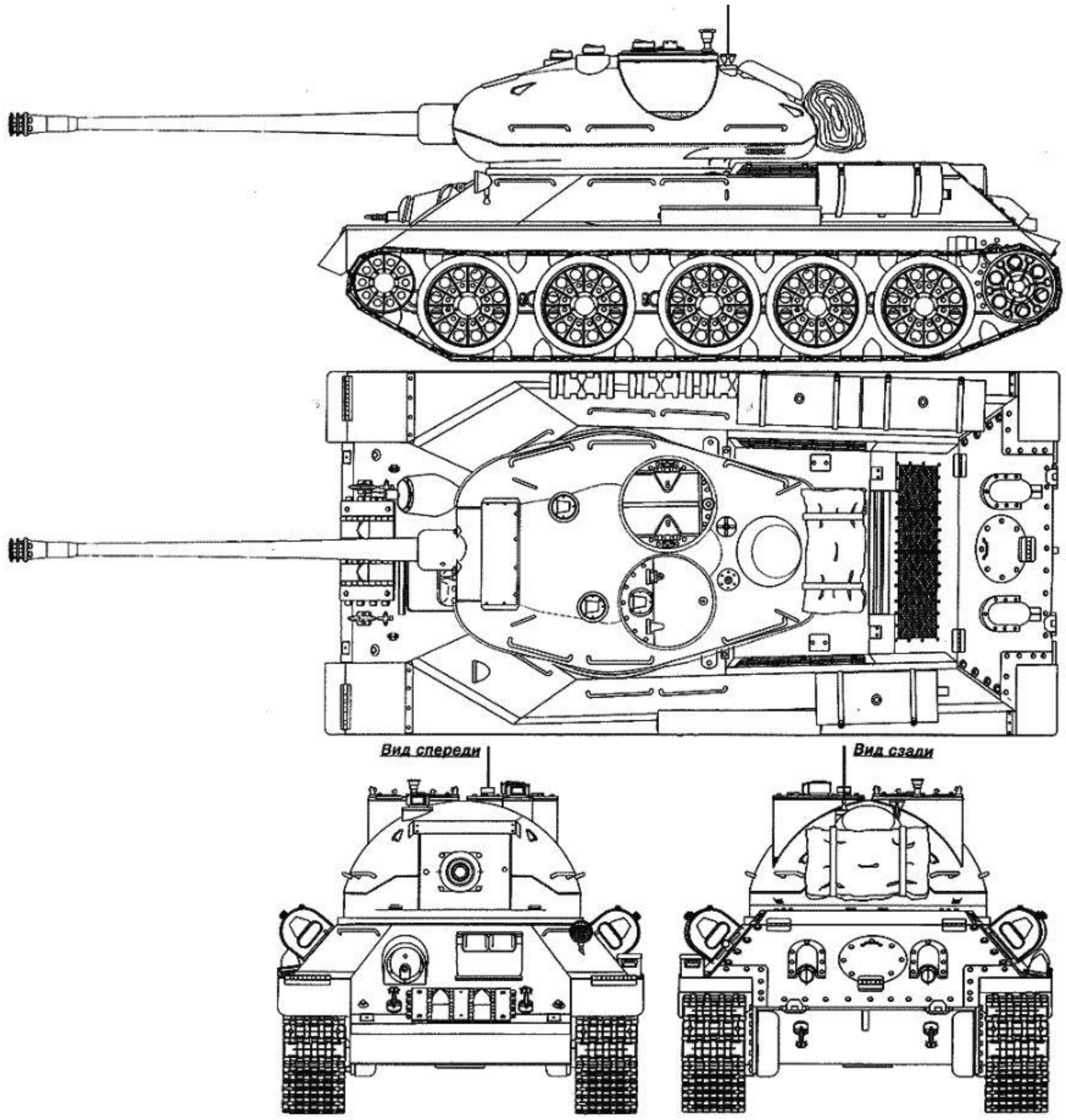
# Medium T – 34/85



# ABSTRACT

The present work decomposes all of the prevailing issues found in the tracks of The Tank Museum's T-34/85 in terms of wear and corrosion. These have been taken in count for the creation of their corresponding design engineering solutions.

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## 1. Introduction

In the course of fourteen years the Medium T-34/85 Tank was reproduced nearly *fifty-thousand* times, making it the most produced in World War II. [1] This Russian tank wasn't only transcendent, thanks to its 45-degree sloped armour design, it was also a major threat to other great tanks such as the German Panther and Tiger 1. Despite all of its attributes, it still encountered issues regarding wear and corrosion, which, in the long term, risked its functionality. These issues can be seen today, by simply looking at the tracks of The Tank Museum's captured T-34/85.

## 2. Analysis

A divergent analysis approach was used to begin decomposing the issues taking over the lower part of the tank. This paper will focus on the tracks' current status and its cause. The stationary T-34/85 comprises two double rear drive sprockets, two front double idlers and five double rubberized road-wheels. Only the tracks, and the surfaces directly in contact with it, will be analyzed. A USB-microscope was used to record the physical characteristics of the prevailing issues on the surface of the components. The sub-surface characteristics will be discussed later on.

The following images were collected after various visits to the museum:

**Fig. 1 Left track w/ debris + close up to its underside. Fig. 2 Right track and its underside.**

### 2.1 Tracks

The tracks have been designed wide so the ground pressure can be reduced. The waffle- pattern found in the T-34/85's tracks includes a raised pattern on the outside of every track link to maximize the traction. Each track consists of 74 steel track links. Every other track link has a guide horn which serves to mesh with the sprocket wheel and hold the track in position. The track links are hinged to one another by 148 pins. The pins are prevented from falling out by keepers. Each track has holes for fastening additional spuds, and they're fixed by two bolts to the track.[2] Although it is known that castings of non-magnetic austenitic steel were used for the manufacture of tracks, there is missing information, in terms of its percentage composition. As well as for the case- hardened track pins. (2$^{nd}$ T.T.O, 1950: 90, 98) There currently is considerable wear on the underside of the plates. The elevated underside waffle-pattern shows a lot if indentations and wear. Corrosion is present on the guide horns contact areas with sprockets, and road-wheels, as seen in Fig. 5. On the pin contact area with the track plate, rust, and mostly, wear can be found.

**Fig. 3 Right tracks + driven sprocket-wheel.**

**Fig. 4 Left-lose track + driven sprocket-wheel.**

## 2.2 Additional Contacting Surfaces

As the sprocket wheels rotate they drive the tracks by means of the rollers which bear against the guide horns. The wheel is fixed by a ring, which is screwed by four studs to the end of the final drive shaft. The securing ring is covered by an armored cap. The hub of the wheel has a flange. In this model the rims of the wheels are hardened. The discs of the wheel are bolted to the flange. The discs have six large exit-holes and six seatings for the shafts of the rollers. To *prolong* the life of the rims, steel tyres are fitted. The shafts are housed between the discs and carry bronze bushes upon which the rollers rotate. Carbon steel was used for both the sprocket wheels and its rollers. The inside of the sprockets were casted, and the rollers hardened. [2] Wear is present on the contact areas of the exit holes, where snow and mud has gone through. There are cracks on contact area between the sprocket wheels, specially its rims, and tracks. Since the road-wheels are rubberized, their plates and rims aren't greatly affected. This sacrifice is clearly seen in the uniform wear around the contact area with the casted-road wheels, and around the contact area with the track plates.

**Fig. 5 Left track-underside + horn.**

**Fig. 6 Right track's 3$^{rd}$ road-wheel's rubber.**

Some properties of Carbon Steel to be known:

| | |
|---|---|
| Density | ≈ 7.8 g/m^3 |
| Young's modulus | 200 - 215 GPa |
| Shear modulus | 77 - 84 GPa |
| Elastic limit | ≈ 400 MPa |
| Tensile strength | ≈ 550 MPa |
| Compressive strength | ≈ 335 MPa |
| Fracture toughness | 27 - 92 MPa^0.5 |

**Table 1 Carbon Steel approximate properties.**

The casting composition used in the T-34/85's final drive is the same, but with higher hardness, as that of the turret. [3] From this information an approximate for the chemical composition used in the tank can be estimated:

| C | Mn | P | S | Cr | Cu | Mo | Ni | Si |
|---|---|---|---|---|---|---|---|---|
| .23 - .25 | .83 - .89 | .015 - .018 | .010 - .019 | 1.31 - 1.38 | .11 - .21 | .18 - .21 | 1.98 - 2.02 | 1.32 - 1.44 |

**Table 2 Estimated chemical composition.**

The tracks were casted from a variety of carbon steel plates containing different amounts of the components found in Table blank. The track plates were then austenised for a few hours, and finally quenched. After that, they were casted into shape- keeping its austenitic composition. The hardness used by the Russians is said to be higher than the one used by the Americans. It aimed to obtain maximum resistance to penetration by sacrificing structural stability on impact. [3] Yet, as seen in Figures 1 and 2, there's several scratches present on the tracks' surface.

The use of high silicon steels was unique within the Soviet Union. When they were using steels with as much as 1.5% silicon, other countries like the U.S were using steels with no more than 0.4% silicon. It is known that silicon has only got one moderate on hardenability, which mostly embrittles the still when exposed to certain temperature changes. [4] Even though molybdenum is mainly used for temper embrittlement, it clearly was still taken as part as the strategic elements for the T-34/85. But since the Russians tempered their steels so they wouldn't get close to the temper brittleness, it left them with the lack of need for molybdenum whatsoever. Nonetheless, as Table 2 shows, it was still applied.

For all cases regarding the current tracks and its interacting surfaces, it seems that the alloy content was not wisely selected; some components have more alloy than needed to produce hardenability, and some may not even have enough content. In order to conserve the tanks strategic elements, the component's key function and priorities will be used as guides.

## 3. Critique of Existing Design

The tracks could be more efficient if changes are made to its materials. In terms of two-body abrasive wear, it is always the harder material that takes away from the softer material. [5] Currently, the sprocket-wheel's rollers take away material from the track's horns. For a more efficient maintenance the smaller components should be the ones being replaced- termly. Most of the horns' tips are worn out, and the rest are in the process of being worn out to the point in which their shape becomes circular. While the T 34/ 85 was mobile, the sprockets' rollers not only rubbed against the track horns, they simultaneously were inducing surface scratches and a driving force for stress-corrosion on the horns' upper half. The tracks, specifically their underside, need to be harder so Stress Corrosion Cracking (SCC) - micro cracks, don't take place- influencing both the corrosion and wear propagation. Since the tracks' underside are there to maximize traction, it's crucial for their waffle- pattern to remain intact. The exposed sides of the track plates are the most affected by what seems to be a combination of Localized corrosion (crevice on pin locations,) Fretting Corrosion, General Attack Corrosion and Corrosion Fatigue spread unevenly; all within the underside and sides of the tracks. The plate-links need to be more brittle for all of the impact and load falls onto the tracks- specially its guide horns, because that is where the most wear is concentrated. Now, the exposed part of the pins have little to no wear at all, which is probably because of the seemingly correct tolerance between pin holes and pin diameters. Some pins do stick out more than others, which can be a sign the tracks need adjustment, or the case hardened steel pins aren't providing the correct amount of grip. Sprockets and rollers, similarly to the double tire road-wheels, should be made out of a tough- low density material, but no harder than the material used for the tracks' horns, because their purpose is to consistently bear against the track's horns. The rollers should too be composed of a less-hard than the horns', but just as brittle. Indentations are not wanted since they can promote micro-cracks that lead to oxidation. Road-wheels show a great amount of wear on both the exposed and unexposed sides of their double tire wheels. The five double road-wheels on both track sides, have got stress induced cracks all over the rubberized tires, which was most likely caused by uneven impact on rough surfaces during the Korean War. [6] It can be seen in graphs blank- blank that there are different rates of material degradation per each individual component, yet track-plates and horns are produced in one piece.

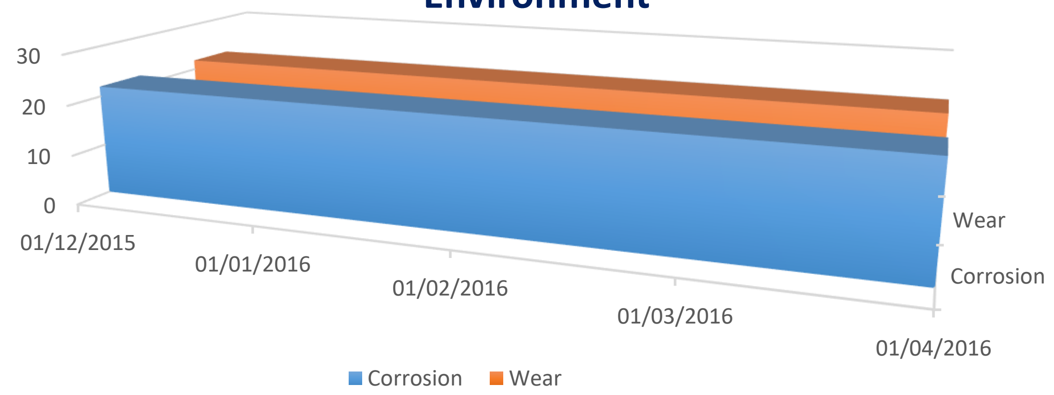
The atmospheric chemical compounds present during the war certainly had an effect on the T-34/ 85. There were drastic weather changes; In July it was hot and humid, and a few Months later temperatures dropped below zero. [7] From this information it can be said that the drastic change influenced the wear rate by affecting the expansion and contraction of the materials' compositions- caused by a thermal shock. Since the troops were near the coast line, there was viscosity and higher levels of salinity in the air. When it was time for spring, the tank experienced downpours of rain and sloshing through mud, which is when the exit holes in the sprockets came in handy. The exit holes went through mud and perhaps snow- causing the appearance of small indentations and cracks around the exit holes in both the idler and driver sprockets. Since the T 34/85 is stationary inside the Tank Museum, the annual weather will not be taken into account as a key factor.

### 3.1 New Design

Considering the T-34/ 85 to be a large-scale production, the improvements on its current design will then be built around production's and assembly's efficiency in addition to durability. As analyzed before, the failures within the current track have a direct effect on the components it makes contact with, and vice versa. Its worn out tracks caused its current load distribution to be in disadvantage for the whole tank, by inducing vibration and reducing traction. To let the track's traction be independent from the current track-plates' frames or pattern, the new tracks will have its plates located on the underside. Instead of the worn-out inconsistent pattern, it will have sets of smaller plate-couples equally spaced out to allow traction. The space between these plates will also allow the flow of impurities- reducing the possibilities of concentrated corrosion, such as the one seen within the current track plates. The track itself will consist of the hinged components; plates, horns, keepers and pins. For a simpler maintenance there shouldn't be distinct functions in one component. So, if one component is damaged, only one function will be affected. A linked-together design will be more effective in terms of maintenance and assembly, because the rest of the components will be easily interlocked within the links themselves. The track horns will be secured and interlocked between each couple of plates. To allow for more effective use of materials, the new horns will not be a completely full shape either. These will only mimic the original horns shape, by reducing about fifty-percent of the original material amount. In a way, the new horns will be the frame of the original ones. Each component will be hinged to one another by pins, which will be prevented from falling out by keepers. These new keepers will be reduced in length, and be as thick as the track frame. The links, pins and keepers will be above the track plates. As the tracks are on solid plane-ground the links with the horns, pins and keepers will not be in contact with the ground. There will be a layer on top of the track to protect the contact area between track links and road-wheels, as well as sprockets. The only part of the road-wheels that needs to be improved is the rubber used around each double wheel. For both the idler and driver sprocket wheels, the design- in terms of components will remain quite similar, except for the exit wholes, they'll be bigger to allow greater flow of impurities. For greater grip and tension within the tracks, a double driver sprocket-*gear*, rather than a double sprocket-*wheel*, can be made. A sprocket-gear is very adaptable to the new track design since the gap between each couple of keepers allows for the mating with the possible sprocket-gear's teeth. Given that the aim is to replace the current components within the T-34/85's system, the dimension will remain the same.

The two main elements to consider for the new material selection of the steel tracks are Aluminum and Manganese because, with the respective high amounts, an excellent combination of high strain rate toughness coupled with up to 17% reduction in density is gained in the steel produced. [8] For the tracks' links, where the pins will go through, Mangalloy will be used especially because of its 12 - 14% Manganese content, which allows it to become harder the more it is impacted or compressed while retaining its original underneath toughness. [9] As the compressive abrasion takes place and surface wears, the tracks will take a mirror-like finish as they renew themselves. To provide the horns with protection for extreme wear and impact, Tungsten Carbide will be used. All of the components functions will remain the same, so the horns need to be hard, tough, and brittle enough to sustain all of the impact while meshing with the sprocket's rollers. Despite Tungsten Carbide's density value seen in Table 5, the frame-like horn design will end up weighing about the same as the original horns. With the hardness close to a diamond's, the re-designed horns are less likely to afford cracks and scratches- allowing corrosion to take place. [10] By making the steel rollers out of Tungsten Carbide as well, the wear prevention will be even more effective. For an additional prevention of corrosion a Tungsten Disulfide coating can be used. Because of its great durability, the coatings might need to be applied once a year only. The track plates will constantly be withstanding about 32 tons of weight [1], so a material such as Aluminum Oxide will fit perfectly with the track plate's function. As it is hard and wear resistant, it also provides high strength and stiffness, making the plates more than capable to do the job. The pins are essential, since they will make sure all the components are in place, and with the help of the keepers, the components will *stay* in place. Considering their function a great fracture toughness, and hardness as well as wear resistance are desirable, which is why Silicon Nitride will be used. It is great for a low maintenance operation, causing it to be more expensive than most materials, but also more reliable. [11] By analyzing the Magnesium Alloys applications in Aerospace, the light-weight feature became a major advantage, especially for the sprockets' re-design. [12] Magnesium AZ91E Alloy's properties seen in the Table 4 and corrosion resistance made it the best suited for the sprocket-gears. Its properties could be affected by high temperature, but since the T-34/85 spends most of its life stationed inside the museum within the controlled environment this will not be a great disadvantage. Regarding the double tyre-road wheels, there needs to be a high abrasion resistance. The current T-34/85's rubber could be used for Vulcanizing, but a more reliable material such as Polybutadiene Rubber might be better. Compared to other rubbers, the synthetic BR possess superior abrasion resistance. [13] The new components will certainly be of higher quality as well as endurance, and their price is directly affected by their production process seen in Table 6. When designing for durability it is known that the more abrasion and corrosion resistance (less maintenance needed), the more efficiently the medium T-34/85's system will work, causing it to be a durable design.

**Fig. 7** Corrosion & Wear Rates Under Controlled Environment



### 3.2 Theoretical Mathematical Modelling

The durability of all tank designs is highly dependent on the agility of wear and corrosion within the system. Many have investigated and experimented with both subjects in hopes of finding a correlation. All of the analyzed investigations imply that the corrosion concentration is directly proportional to the amount of wear. When it comes to military vehicles, the subjects' rates are directly affected by their amount of movement and type of environment they're exposed to. [14] But when analyzing a steel coupons having corrosion allover its surface, the correlation is no longer constant. In Kingsley's and Gideon's paper it's shown that the wear rate has more probabilities of increasing with exposure time, compared to corrosion. (Kingsley O. & Gideon C., 2014) It *is* most of the time a tensile behaviour that will open micro-cracks, which would *then* proceed to allow the electrochemical diffusion. Factors such as the residual stresses after working a material can also lead to micro-cracks. As discussed in Nazir's Corrosion Journal (M.H. Nazir, 2015), the propagation of these micro-cracks can be prevented by compressive residual stress, which *inevitably* produces a lower corrosion rate.

If there were the available tools and time to record relevant data, the following would've been precisely calculated:

As told by the Linear Elastic Fracture Mechanics (LEFM) analysis: short cracks, as the ones in the stationary tank, see larger crack propagation. So by integrating Paris constant [15] it'd be possible to find the fatigue-crack collapse; all being influenced by the thermal stresses during the Korean War. So, the linear coefficient of thermal expansion can provide clues to the chemical composition of the materials used in the current tank. The "Design Life" of the tank is defined by its Damage Ratio [16], it's specified in the PDS that it's an average 0.5. The Essential Work of Fracture (EWF) method is key to calculate the amount of work that was required to cause the present cracks to take place. [17] The FoS (Factor of Safety,) Actual Mechanical Advantage, and Efficiency are key for the material selection for a new design.

In terms of wear there seems to be a tribochemical wear, which is capable of increasing with exposure to increase of temperature, but since the T-34/85 is stationary within a controlled environment it isn't an issue as shown in Figure 7. Scanning Electron Microscope method could've been used, so reliable data could be integrated into the corresponding formulas. A more accurate value for the time-dependent concentration of ionic compound in controlled environment found using duty cycle concept could've been obtained.  For more details, refer to Appendix.

## 4. Product Design Specification

| | |
|---|---|
| **Assembly** | Each track component to be efficiently hinged to each other, with pressure- pins. |
| **Cost** | Manufacturing cost + transportation |
| **Customer** | International |
| **Damage ratio** | Partial inspection access and no harmful consequences in the event of failure. |
| **Dimension** | Equal to original dimensions, except for exit holes in sprockets, which will consist of a bigger diameter. |
| **Environment** | Controlled environment inside the Tank Museum. (18-25 degrees C.) |
| **Finish** | Corrosion + Wear resistance, to continue use under controlled environment. |
| **Maintenance** | Minimal (e.g., lubrication allowed) |
| **Market** | Worldwide. |
| **Materials** | Light weight- transportable- not easily damaged by impact. |
| **Performance** | To be fixed in place effectively. Track plates to contact the ground. Adjustable tension with pins, providing better traction. |
| **Process** | Mass production. |
| **Quantity** | 2 sets of: Wide tracks, double sprocket gears, idler sprockets, 5 double-tyre road-wheels; Per system. |
| **Reliability** | Maximum 5% failure rate over service life. |
| **Safety** | |
| **Shelf life** | Effective long-lasting if maintenance is applied when/where needed. |
| **Weight** | ≤ 0.5 Ton. |

**Table 3 Product Design Specification.**

### 4.1 Function and Operation

As the driving shaft of the final drive allows the new driver sprocket-gears to rotate, they engage with the track keepers. While the double-tyre road-wheels rotate they compress the new Mangalloy tracks creating the polish finish on their contact area. During this process, the high-strength Alumina plates will be supporting all the load with its thin protective coating, preventing from oxidation and losing strength whatsoever. When on bumpy and/or mushy ground, the newly expanded sprockets' exit holes will provide a maximized flow of impurities such as mud or snow. The gaps within the hinged tracks links will also serve as exit holes, so there will be much lower probabilities of third-bodies concentration, which allows to predict less abrasion and micro-cracks.

## 5. Material Selection

| | Density (g/cm^3) | Young's Modulus (GPa) | Shear Modulus (Gpa) | Elastic Limit (MPa) | Bulk Modulus (GPa) | Fracture Toughness (MPa) | Hardness (MPa) |
|---|---|---|---|---|---|---|---|
| **$Al_2O_3$** | 3.95 – 4.1 | 215 - 413 | 88 - 165 | 69 - 665 | 137 - 324 | 3.3 - 5 | 5500 - 22050 |
| **$Si_3N_4$** | 3.29 | 166 - 297 | 65.3 - 127 | 60 - 525 | 120 - 241 | 6.1 | 8000 - 30500 |
| **WC** | 15.6 | 600 - 686 | 243 - 283 | 335 - 530 | 350 - 400 | 2 – 3.8 | 17000 - 36000 |
| **ZE41** | 1.77– 1.83 | 44.12 | 17 | 80 - 280 | 33.1 | 13 - 15 | 540 - 685 |
| **AZ91E** | 1.81 | 44.8 | 17 | 150 | 35 | 12 - 18 | 784.6 |
| **Mangalloy** | 7.88 | 200 | 80 | 350 -380 | 160 | 100 - 220 | 750 - 1800 |
| **Gray Cast Iron** | 7.15 | 80 - 138 | 31 - 57 | 140 - 420 | 130 - 140 | 10 - 24 | 882 - 1353 |
| **High Carbon Steel** | 7.85 | 200 - 215 | 70 - 84 | 400 | 155 - 175 | 27 - 92 | 1569 - 6375 |

**Table 4. Material Selection.**

| **Component** | **Material** | **Process** |
|---|---|---|
| **Track links** | Mangalloy | Cast austenitic, quench annealed and work-hardened |
| **Track horns** | WC | Continuous casting + Electroless Nickle w/ WS2 |
| **Track plates 'shoes'** | $Al_2O_3$ | Casted + (optional) Anodizing w/ WS2 |
| **Keepers** | $Si_3N_4$ | Hot pressed |
| **Pins** | $Si_3N_4$ | - |
| **Sprocket plates (optional)** | AZ91E | Die castings |
| **Sprocket rollers (optional)** | WC | - |
| **Road-wheels (optional)** | BR | Continuous Processing Polymerisation |

**Table 5. Re-designed component's selection of materials and processes.**

### 5.1 Assembly

Each track consists of 74 couples of Mangalloy track links. In between each couple, the Tungsten Carbide 'framed' horns will be hinged, which serve to mesh with the sprocket gears and hold the track in position. There are 148 Silicon Nitride pins to hinge all the components, and 74 keepers of the same material, to prevent the securing pins from falling out. The two double sprocket-gears will remain at rear. These Magnesium Alloys gears proceed to be screwed by four studs to the end of the final drive shaft. Each driver sprocket has six large gaps between the six seatings for the shafts of the Tungsten rollers serving as exit holes. The shafts are then housed between the gear-plates upon which the rollers rotate. Finally, the new double-tyre road-wheels' Polybutadiene Rubber will be pressed and welded on the plates of the current 'bogie wheels.'

## 6. Components Details

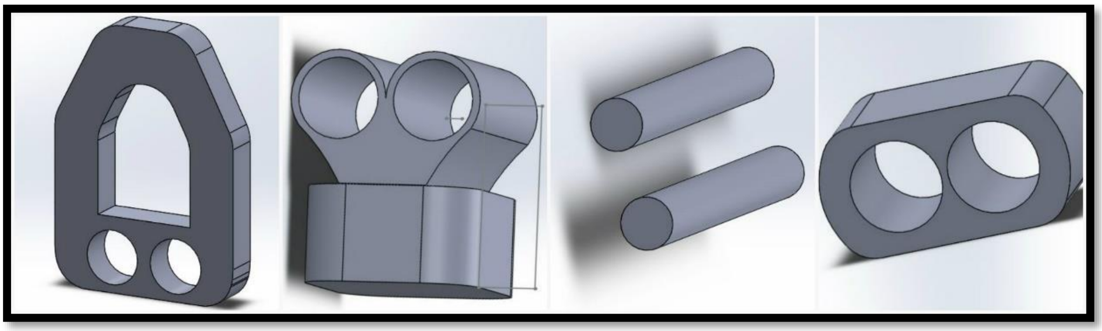


**Fig. 10 Re-designed components. From left to right: Horn, Track Plate/ Shoe & Link, Pins, Keepers.**

Engineering drawings with more detail can be found in the Appendix.

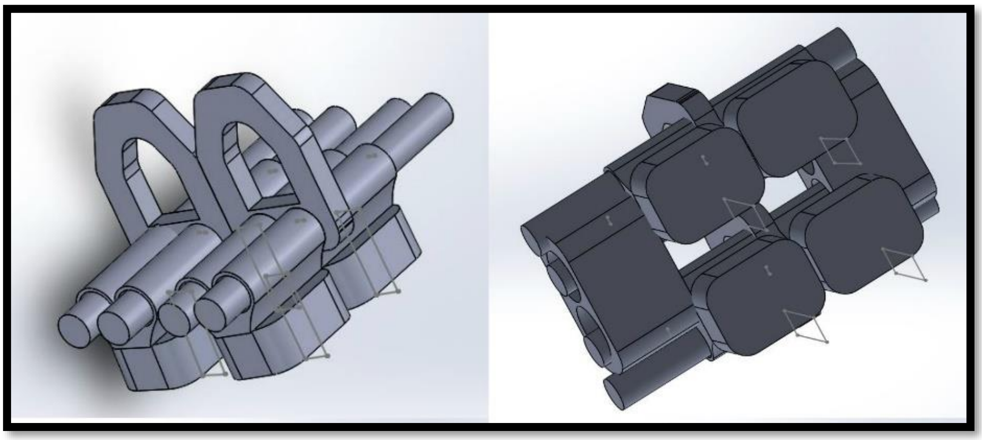


**Fig. 11 A couple of double-track sets assembled in Solidworks.**

Each of the T-34/85's new tracks will comprise 72-times the assembly done in Solidworks.

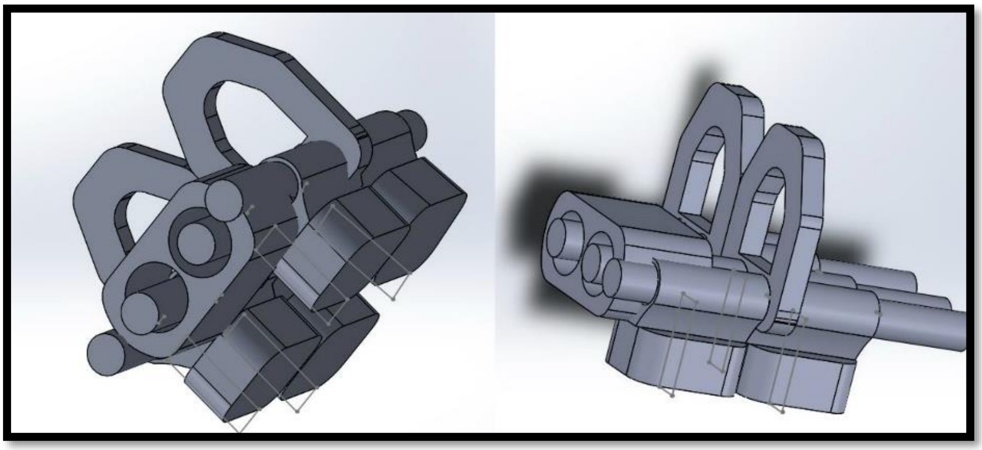


**Fig. 12 Solidworks' approximate-theoretical assembly.**

## 7. Conclusion:

The prevailing wear and corrosion issues found in The Tank Museum's stationary T-34/85 will greatly affect one of its main functionalities once no longer stationary; Its mobility. A holistic design approach was used to create engineering solutions to the individual components' issues affecting their corresponding functions. Simple mathematical modelling was incorporated to predict the effectiveness of the new components in the current tank's system. Which has proved that the more abrasion and corrosion resistance, the more efficiently the T-34/85's system will work, giving rise to a durable design.

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# APPENDIX

| | Density (g/cm^3) | Young's Modulus (GPa) | Shear Modulus (Gpa) | Elastic Limit (MPa) | Bulk Modulus (GPa) | Fracture Toughness (MPa) |
|---|---|---|---|---|---|---|
| **Mn** | 7.4 | 198 | 75 | 350 | 120 | 120 - 150 |
| **Mg** | 1.8 | 45 | 16.5 | 80 - 280 | 45 | 17.6 - 20 |
| **Al** | 2.68 | 70 | 26 | 30 - 280 | 76 | 18 - 35 |
| **Si** | 2.32 | 0.001 - 0.05 | 0.02 | 2.4 – 5.5 | 1.5 - 2 | 0.03 – 0.7 |
| **C** | 2.1 | 4.1 – 27.6 | 1.7 – 11.5 | 4.8 - 76 | 2.3 – 15.3 | 0.4 – 2.4 |
| **W** | 19.25 | 411 | 161 | 317 | 310 | 2 – 3.8 |

**Table 6. Key Elements.**

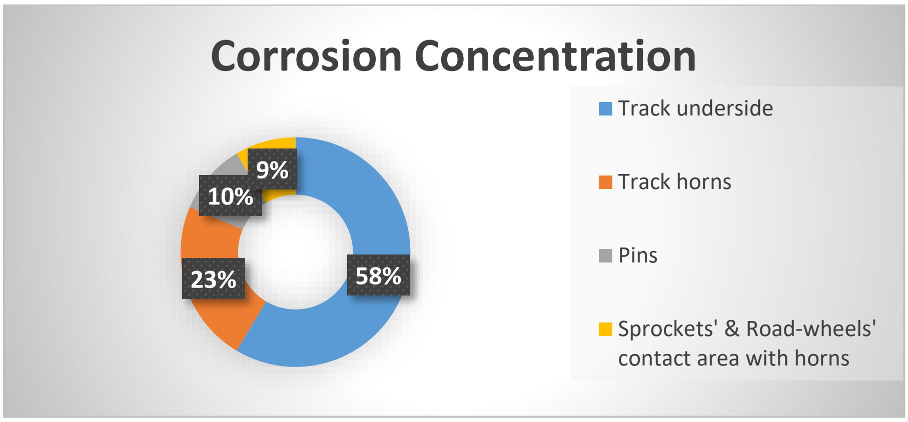


**Fig. 8 Current corrosion concentration seen on tank's parts pie chart.**

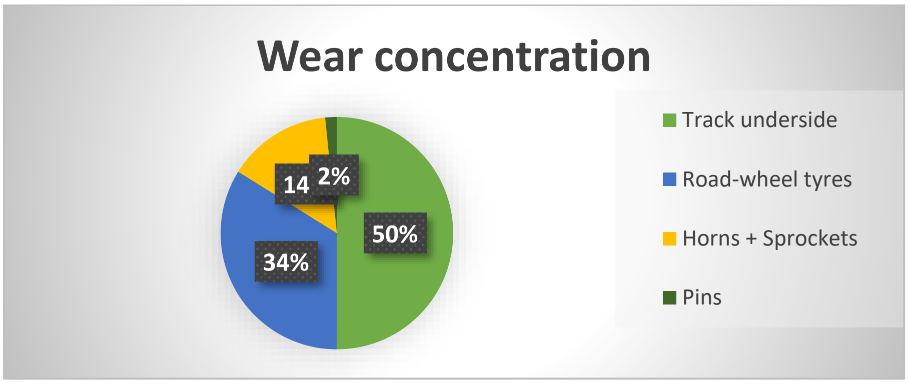


**Fig. 9 Current wear concentration within components pie chart.**

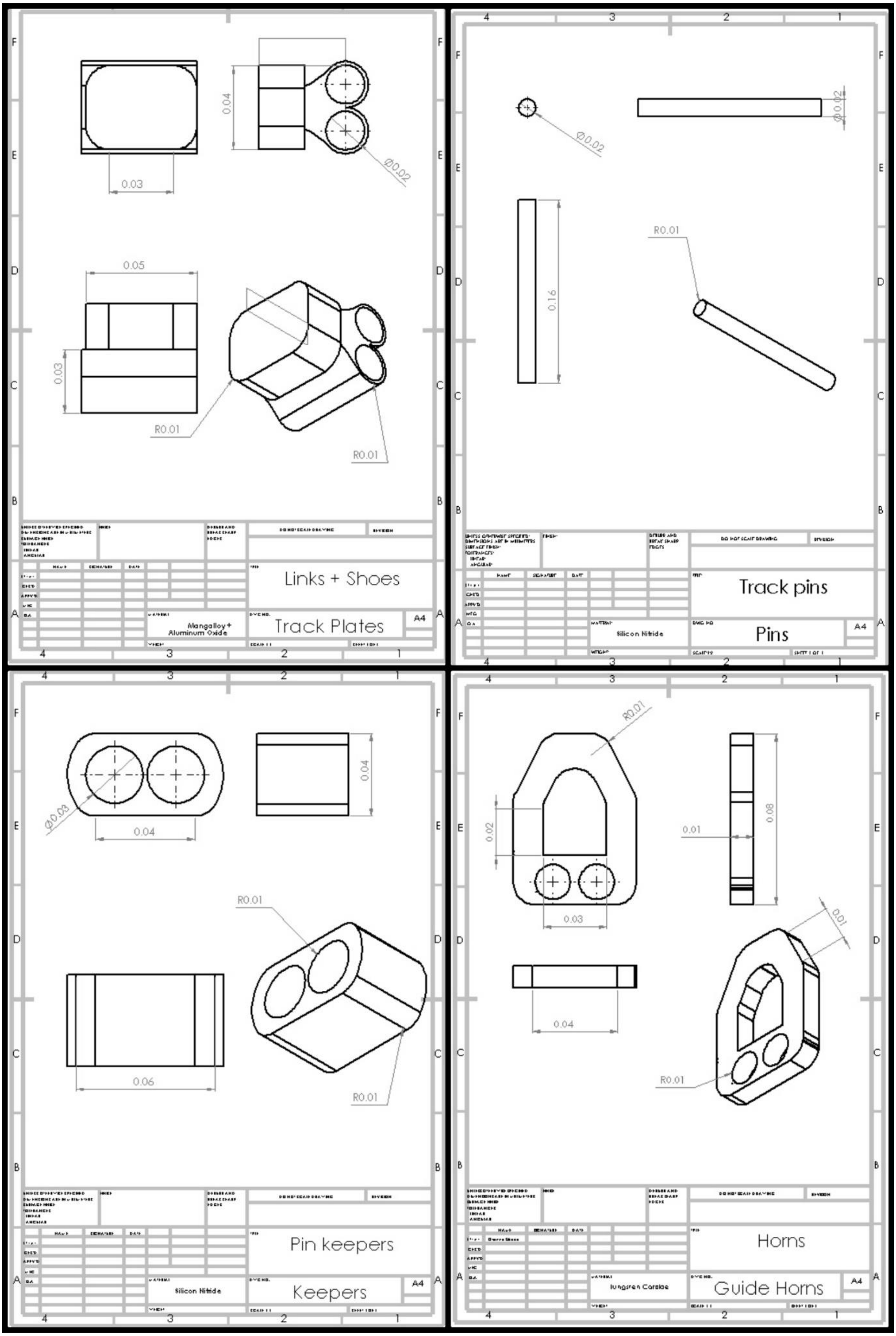


**Fig. 13 Components' Engineering Drawings.**

| | |
|---|---|
| **Time-dependent concentration of ionic compound in controlled environment found using duty cycle.** | (t) = 15 x ((coefficient of friction x g)/ (m^3)) |
| **Wear** | W = K x (W/H) |
| **Actual Mechanical Advantage (AMA)** | AMA = R/E |
| **FoS** | SF = Actual breaking strength/ N |

**Table 7. Formulas.**

Current tracks' time-dependent concentration of ionic compound in controlled environment found using duty cycle concept:

Coefficient of friction = Fd/N

Coefficient of friction = 313920/32000

Coefficient of friction = 9.81

(t) = 15 x ((9.81 x g)/ (500^3))

(t) = 1.15 x 10 ^-5

| **Tank Weight (Kg)** | **Track Weight (Kg)** | **Maximum Speed – Road (kph)** |
|---|---|---|
| 32000 | 500 | 55 |

**Table 8. Key T-34/85 Data. [1]**