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Go Kart Chassis

Rethinking go kart chassis materials

Gideon Hornman

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Go kart chassis

Rethinking go kart chassis material

A DISSERTATION REPORT COMMISSIONED BY
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AND
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Preface

This report was written during my dissertation at Creator teknisk utveckling AB, from now on named Creator AB, for the purpose of the bachelor automotive engineering degree program hosted by Fontys Hogeschool Automotive. I was given the task to manage the go kart project which consisted of managing production of a proof of concept go kart chassis and researching the root cause of the problems leading up to the proof of concept. When completed, this project gives insight whether the new material chosen for the go kart chassis would make a profitable business opportunity for the three companies involved.
In the summer of 2016 I first came in contact with mister Daniel Haglöf, CEO of PWR Racing Team AB. We discussed opportunities for a dissertation at the company. In December 2016 mister Haglöf and I spoke again. He wanted to get me involved in a go kart project in which his company was participating. I got in contact with mister Jon Lind, the initiator of the project, and things went from there.
Firstly, I would like to thank Jon Lind for his support and trust in me, and for insisting, on my first day, on calling him in the middle of the night. Daniel Haglöf for suggesting me as a project manager, thank you. Thank you to Mats and Lars-Göran Eriksson at ME Racing Services AB, Stefan Irlander and Daniel Andersson at PWR Racing Team AB and Tommy Fälth at Creator AB for your support during the project. Marc Mussaeus thank you for guiding me through and raising the bar to challenge me. Priscilla Speelman, my girlfriend, thank you for your countless hours of driving the karts and your support throughout the dissertation. Thank you Jesper Sjöberg for test driving. Lastly, thank you Jerry Svedlund for having me as a dissertation student at your company.

Vikmanshyttan, Sweden, June 2017

Gideon Hornman

Summary

Introduction
Go karting is a motorsport heavily depending on the material used. Go kart chassis have bad performance consistency and have a significant performance drop off after half a racing season (4 race weekends of 80 minutes each). A chassis costs up to 12000 SEK (1231 Euro). The problem is stated as: *'The useful lifespan of a high performing go kart chassis is not long enough taking it's price into account.'*
The engineering research question for this project is: *What is the root cause for the performance drop of a go kart chassis?* Docol R8 is a material that the project team has a lot of experience with and will be tested to see if it can bring a lifespan improvement to a go kart chassis. The pragmetic research question is therefore stated as: *Can the lifespan of a go kart chassis be doubled by using Docol R8?*
Body
A go kart chassis is an active part of the system. A go kart has no differential mounted in its rear axle. In order to overcome severe understeer a technique called wheel lifting is used. The chassis plays an important role in this technique, acting as a torsion spring between te front and rear axle and supplying the right geometry to make the technique work.
Hypothesis are formulated in order to find the cause of the chassis performance drop. Hypothesis include metal fatigue, various plastic deformation possibilities, material grinding away of low ride height and so on.
A torsional stiffness test rig is developed to test whether the stiffness of a chassis changes over its lifespan. This turns out to not be the case. The torsional stiffness is a constant, falsifying various hypothesis. All remaining hypothesis focus on plastic deformation. The cause for performance drop off is plastic deformation as a result of the steel being stressed over its yield strength. Plastic deformation has a negative impact on the performance because it alters the handling characteristics. Which type of deformation has the biggest influence is not known.
Counter measures to the found root cause are of two types: material and design. Using material with an increased yield strength will make the chassis more resistant to plastic deformation. Design changes may also provide a solution but this is outside the scope of the project.
Docol R8 has a 33 percent higher yield strength and an equal Young's modulus as the now used 25CrMo4 steel. A proof of concept chassis is constructed out of Docol R8 and tested. The test consist of a similar amount of track time as a full racing season. Various parameters are measured during testing. The proof of concept chassis handles very well from start to finish of the test and shows minimal plastic deformation compared to a regular chassis.
Conclusion
The root cause research pointed out that *plastic deformation is the cause to the performance drop off experienced by drivers.* This answers the engineering research question. The proof of concept build out of Docol R8 tubes shows at least 5 times smaller plastic deformation on certain parameters after a similar amount of track time. The answer to the pragmatic research question can therefore be formulated as: *Yes, because of the improved yield strength the Docol R8 chassis will last longer than one racing season.*
Recommendations include researching other materials and design changes. Further testing on the existing proof of concept could be performed find its ultimate lifespan. Also the hypothesis on plastic deformation could be verified by testing a used chassis before and after straightening.

Contents

1 Introduction

Go karting is a motorsport in which the performance is depending on two factors: The driver and the go kart. The chassis of the kart has an important role in the karts performance as it plays an active part in the karts dynamic behaviour. In competition drivers seek a chassis that handles to their liking and provides consistent performance for a reasonable length of time. This last part is a factor that no chassis manufacturer to date has been able to manage. Since selling chassis is a big revenue stream for the manufacturers there is no initiative to improve this.
The problem that occurs is that the go kart chassis drops in performance significantly after only half a racing season. The handling consistency before this drop off is not great either. The price of a bare chassis can be up to 1200 SEK (1231 Euro). The problem statement can be described as: *The useful lifespan of a high performing go kart chassis is not long enough taking it's price into account.*
The engineering research question is : *What is the root cause for the performance drop of a go kart chassis?*
A previously researched material called Docol R8 produced by SS AB could be a solution to this problem, prolonging the lifespan of a chassis. The project team has gained a lot of experience with this material over the last decade in other applications. The pragmetic research question is: *Can the lifespan of a go kart chassis be doubled by using Docol R8?* The answer to the research question can be used to decide on the feasibility of a business plan around Docol R8 go kart chassis.
The root cause research aims at finding the cause for the performance drop off. This research consist of looking into the dynamics of a go kart and assessing a used chassis, setting up hypothesis and testing these hypothesis. Then a conclusion on the hypothesis can be given.
To research whether Docol R8 provides a solution to the found problem, a closer look at Docol R8 specifications will be taken, a proof of concept is described along with extensive testing. Then a conclusion is given. Recommendations on how to continue will finalize the report.

2 Problem statement

In go karting, specific restrictions are in place to keep the sport reasonably affordable and simple. These restrictions make for technical challenges in the design of go karts. The present report focusses on the chassis (see figure 1). The restriction that has the biggest influence on the chassis design is the ban on differentials in the driven rear axle.
A go kart does not have a differential mounted on the driven axle like most vehicles have. This is forbidden in competition by the sporting commission CIK/FIA [1, Article 2]. Since there is no differential, the fixed rear axle will cause severe understeer problems when cornering as long as both rear wheels are on the road surface (see figure 3). To solve this problem go karts make use of a technique called wheel-lifting. The inside rear wheel is lifted of the road surface when cornering (see figure 2).

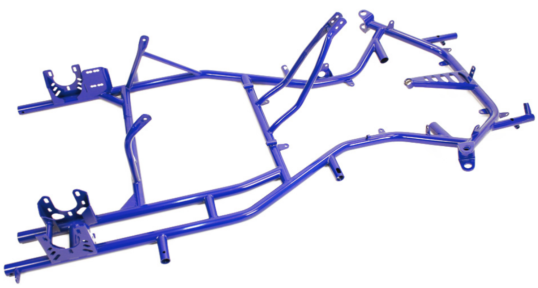


Figure 1: A go kart racing chassis.

Figure 2: Micheal Schumacher lifting the inside rear wheel during cornering at Circuit La Conca.

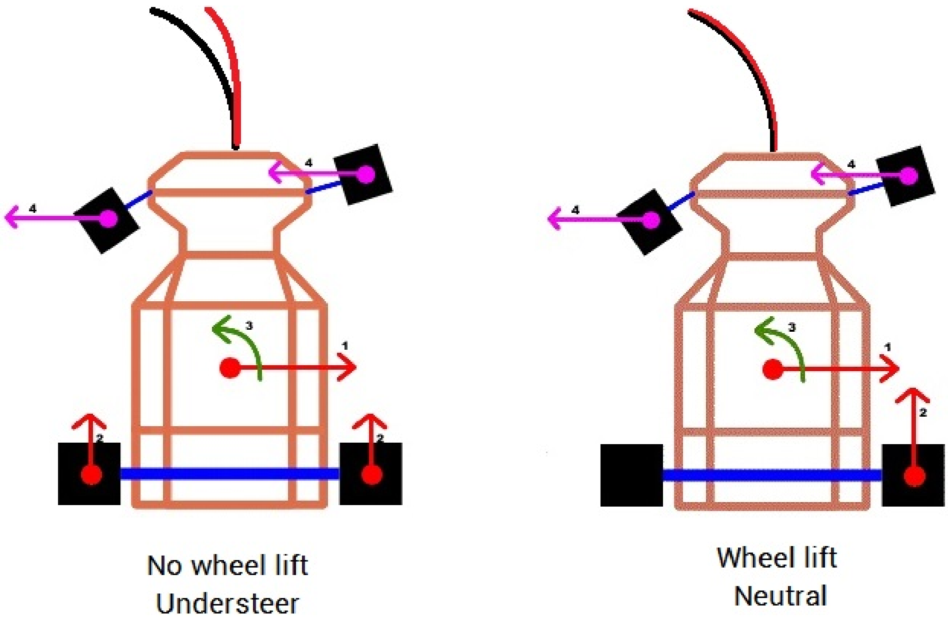


Figure 3: Influence of wheel lift on cornering behaviour. Intended line in black, actual line in red.

Before continuing to the next part it is necessary to understand the terms caster and scrub radius.
Scrub radius: The distance between the points where the kingpin projects on the ground and the tyre centerline meets the ground (as displayed on the left side in figure 4). When steering, this will be the radius of the tyre's trajectory.
Caster angle: Angle of the kingpin, seen from the side of the go kart, relative to the vertical line crossing the middle of the kingpin (as displayed on the right side in figure 4).
King pin inclination: Angle of the king pin, seen from the front, to a vertical (as displayed on the left in figure 4).

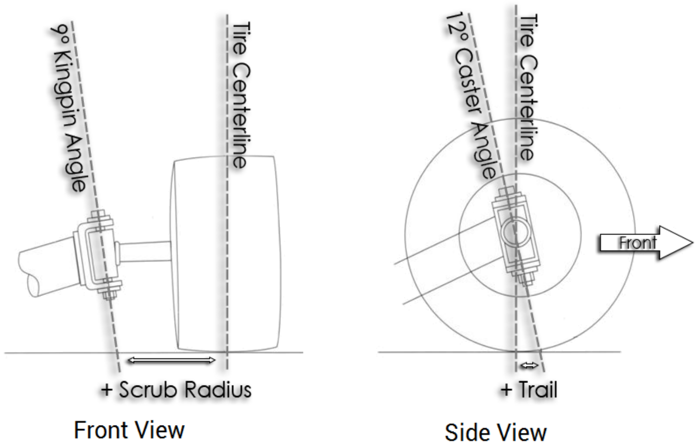


Figure 4: Scrub radius and caster visualized.

To lift the inside rear wheel go karts have a significant positive caster angle (10 to 15 degrees, [2]), a large positive scrub radius (150 to 170 mm, measured of a 2016 Tony Kart) and a significant king pin inclination on the front axle. When cornering, this leads to the inside wheel digging into the road surface and the outside wheel lifting. Because of the rigidity of the chassis, one wheel will need to lift off the ground. Centrifugal force working on the drivers body will tilt the chassis to the outside of the corner, in turn lifting the inside back wheel. Now only the outside rear wheel and the two front wheels are in contact with the road, therefore solving the understeer problem.
The steering input controls the amount of wheel lift. This is however not a direct control. The chassis, connecting the front and rear axle, acts as a torsion spring in between. The torsional stiffness of the chassis is an important performance factor. Too stiff and the control will be unstable or 'bouncy', too soft and the wheel will not lift at all. The cornering performance is thus depending on the geometry and the stiffness of the chassis.
Other means of controlling the wheel lift, by using a sprung suspension system, are forbidden by the sporting commission CIK/FIA [1, Article 2.10]
The performance of the chassis decreases over time. Top level drivers will renew their chassis every 4 to 6 race weekends because of this. A bare chassis has a resell price of 12000 SEK (1231 Euro) The overall complaint is that a chassis is said to 'soften' over time. The problem can thus be stated as: *The useful lifespan of a high performing go kart chassis is not long enough taking it's price into account.*
The goal for this project is defined in a two part questions:
The pragmatic research question: *Can using Docol R8 tubing double the lifespan of a go kart chassis?*
The engineering research question: *What is the root cause for the performance drop of a go kart chassis?*

3 Hypothesis

A used go kart chassis is acquired for inspection. A close visual inspection is carried out to get a good overview of the sort of wear a chassis has to endure. This inspection is used to set up hypothesis on the performance drop of the chassis.

3.1 Physical alterations to a used chassis

The chassis is a 2016 model Tony Kart. Tony Kart is considered the industry benchmark for go kart chassis. The chassis is used for one racing season, approximately 9 racing weekends. A racing weekend consists of a day of testing and a day of qualifying and racing. This totals roughly 80 minutes of track time. The previous owner sold this chassis for parts. It is considered worn out.
At first glance the chassis looks reasonably good, the paint is still shiny. At closer inspection several wear factors become apparent.

3.1.1 Material grinding away

On some sections of the chassis tubes severe grinding damage can be seen on the underside (see picture 6). This grinding is caused by the chassis hitting the track surface. The go kart has very little ground clearance. The most damage can be found on the front tube and the two main tubes (see figure 5). In these places the tube has lost a maximum of 1 mm in outer diameter. The wall thickness of 2 mm has been halved. The effect of this wear could be a decrease in stiffness. The yield-strength of the tubes could also be reached faster. Other then that there will be no downside.

3.1.2 Cracks

In three places cracks can be found in the tubes. Two of these cracks are in the steering column support. These two cracks will not influence the performance. The third crack is in front of the right rear axle bearing support. This crack runs right next to the weld and is a known spot for cracks to develop (see picture 7). Since the right rear is where the engine is mounted the stress that leads to this crack could be produced by the loading and unloading of the chain drive. The crack could influence the stiffness of the chassis.

3.1.3 Plastic deformation

The chassis shows severe plastic deformation. The chassis is placed in a chassis welding jig to reveal this deformation. The complete chassis has sagged. Form a side view the chassis is slightly 'banana' shaped (hollow). The offset from a horizontal reference line is approximately 10 mm. The attachment points for the front spindles have bent up. The left side more than the right side. This wear could influence the performance in several ways. Because of the sagging the ground clearance is further reduced making the kart hit the ground more often. The bending up of the spindle mounting points will increase the amount of camber (the difference in angle of the wheel centreline, from a vertical, seen from the front). The twisting of the chassis (left has bent up more than right) will cause a change in weight distribution over the wheels. The overall geometry of the go kart is important for the inside rear wheel lifting as described in chapter 2.

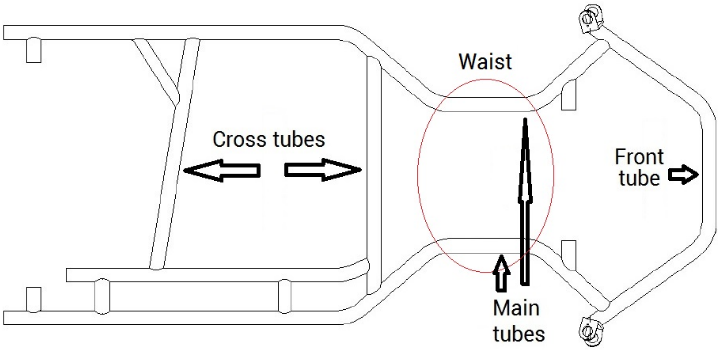


Figure 5: Chassis tube names and waist area defined.

Figure 6: Grinding wear on the underside of the main chassis tubes.

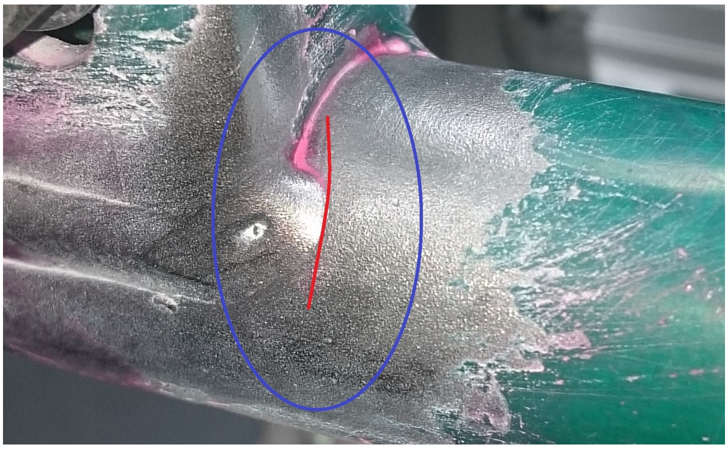


Figure 7: A crack in red in front of the right rear axle bearing support.

3.2 Forming hypothesis

The cause for the complaint of softening of the go kart chassis is unclear. No conclusive evidence can be found in preliminary research. Therefore every conceivable cause is formulated in the present chapter. This results in several hypothesis. All these hypothesis are based on knowledge at the time and are formed during brainstorming about the subject in cooperation with the following experts: Tommy Fälth and Stefan Irlander. All hypothesis will be stated here with the assumptions of why that hypothesis could be correct.

(1)*"Softening of the chassis is caused by grinding away of material on the underside of the chassis due to touching the road surface."*

Because high level drivers run their karts with very little ground clearance the chassis hits the road surface and the curb stones often. Over time, this leads to the grinding away of material on the underside of the chassis. This loss of material may alter the torsional stiffness of the chassis and thus change the driving characteristics.

(2)*"Softening of the chassis is caused by metal fatigue in the tubes forming the chassis."*

Due to constantly alternating loads on the chassis from both weight transfer and road surface irregularities, the chassis may suffer from metal fatigue. Chassis are known to bend out of shape over time which implies that stresses are close and sometimes over the yield strength. This is a sure sign that metal fatigue could cause microscopic cracks in the tubes causing a change in E-modulus. The change of E-modulus will then influence the torsional stiffness.

(3)*"Softening of the chassis is caused by fatigue in the heat affected zone of the welds connecting the tubes of the chassis."*

The fatigue could also appear in the heat affected zone (HAZ) of the weld because of the change in material characteristics. This hypothesis is backed up by the knowledge that chassis have severely cracked in the HAZ before, this being the final stage of fatigue. The HAZ is naturally more brittle and stress tends to concentrate in these areas. Both brittleness and stress concentration accelerate metal fatigue. This problem may influence the torsional stiffness.

(4)*"Softening of the chassis is caused by loss of tension in the chassis which is introduced during production."*

Go kart chassis are over defined in their construction. This can lead to the introduction of preload in the chassis. If during production preloaded tubes are in fact welded together this preload could fade away over time as the chassis settles. The constant load changes on the chassis could take away the preload quickly and change the torsional stiffness of the chassis.

(5)*"The chassis sags, takes on a banana shape, causing the caster to increase and lowering the ride height. This causes the performance to drop."*

Chassis used for half a season or more will often be bent in one way or the other. Measurements have shown that deformations of 25 mm are no exception [4]. Stresses will have exceeded the yield-strength of the steel. Sagging of the chassis may cause it to have a lower ground clearance and increase the caster.

(6)*"The spindle connection points on the front axle bend upwards, crosswise. The increased KPI now lowers the performance."*

Bending up of the front suspension mounts, crosswise bending, may cause a change in king pin inclination. Altering the wheel lifting effect, causing the performance to drop.

(7)*"The chassis twists about its longitudinal axis (X) causing it to drop in performance."*

Twisting of the chassis will cause an incorrect weight distribution. This may cause a change in the handling characteristics.

(8)*"The driver believes a new chassis will give him an advantage because the go karting scene and industry tells him this is the case. The placebo effect causes the driver to gain speed with the new chassis"*

Some stories go round supporting this phenomenon. The driver would be given his old chassis, freshly painted, and improve on his performance. These are however only stories and this non-technical hypothesis is outside the scope of this project.
To get a clear overview of the correlation of the hypothesis a fish bone diagram (figure 8) is created. This diagram also includes the driver psychology.

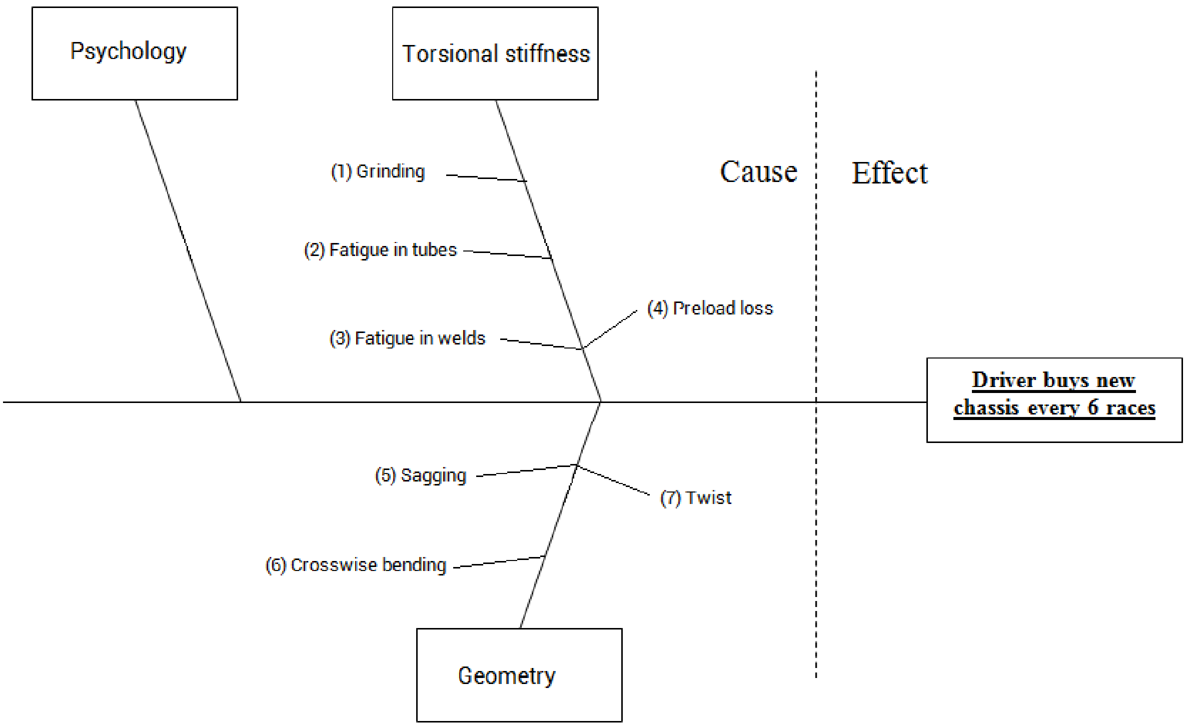


Figure 8: Fish bone diagram of potential problem causes.

4 Testing the hypothesis

4.1 Torsional stiffness test rig

In order to test various hypothesis a torsional stiffness test rig is constructed. This test rig is designed to measure the torsional stiffness of a go kart chassis. Torsional stiffness is multiple times proven to be an important characteristic of the go kart chassis because of the wheel lifting described in chapter 2 [3]. The basic setup of the test rig was inspired by a study carried out by a university in Italy [3]. The front axle is twisted in a parallel vertical plane to the rear axle by use of a lever and ballast weight.
A mobile version of the test rig is useful for gathering large amounts of data on the performance of a chassis during its lifespan. The mobile version can be used at the track in-between testing sessions. However a mobile version will greatly increase the costs of the system. A trade-off provides the solution. The trade-off is shown in table 1.

		Mobile		Inmobile	
Criterea	Relative importance	Points	Score	Points	Score
Material costs	5	3	15	7	35
production time	3	3	9	7	21
accuracy	9	6	54	8	72
amount of data	7	9	63	6	42
Score			141		170

Table 1: Trade-off for mobile or stationary test rig.

A stationary test rig is constructed out of aluminium extrusion profiles. The material provides quick construction and adaptability to various chassis. The test rig consist of a fixture for the rear axle, a pivot point in the front and mounting points for two dial indicators. Across the front axle a beam is fixed to the top of the spindle mounts which extends to one side providing a lever to hang weights off. A photograph of the completed test rig is shown in figure 9.

Figure 9: Chassis rigged for testing.

The dial indicators measure the amount of deflection the spindle mounts have. This measurement combined with the width of the chassis is calculated to the torsion angle the front axle has relative to the back axle. The weight suspended on the extended section of the front axle beam provides the torque. A simple equation of equilibrium transfers the weight and distances to the torque applied. These two calculations combined in turn give the torsional stiffness of the chassis. An abstract overview and free body diagram of the setup is displayed in figures 10 and 11.

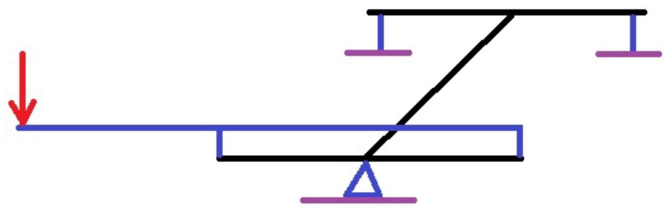


Figure 10: Overview of setup. Black = chassis, red = force, blue = test rig, purple = table.

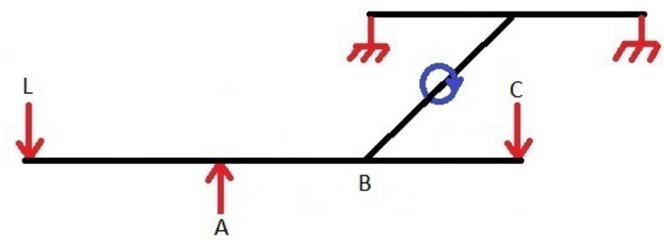


Figure 11: Free body diagram of chassis with forces and fixes in red, resulting internal counter-acting torque in blue.

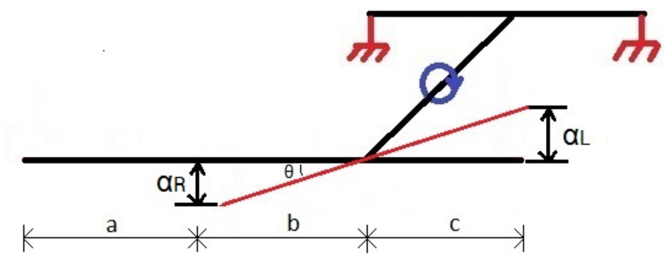


Figure 12: Free body diagram of chassis with defenitions used in angle calculation.

To convert the dial indicator measurement to deflection angle the following mathematical steps are taken:

$$\theta = (tan^{-1}\frac{(\alpha_l + \alpha_r)}{b+c})\frac{180}{\pi}$$

θ : Resulting angle in degrees
α : Measured deflection in millimetres

See figure 12.

To calculate the applied torque the following mathematical steps must be completed:

$$\Sigma T_A = 0 = -La - C(b + c)$$
$$A = \frac{L(-a + b + c)}{b + c}$$
$$\Sigma F = 0 = -L + A - C$$
$$C = -L + \frac{L(-a + b + c)}{b + c}$$
$$T_B = \frac{\mid A \mid + \mid C \mid}{\frac{1}{2}(b + c)}$$

The resulting torsional stiffness is then calculated:

$$K = \frac{T_B}{\theta}$$

K : Torsional stiffness in Nm/degree

For convenience the equations have been programmed in an excel-sheet. A screen print of the excel sheet is shown in table 2.

Data input fields							
Chassis width front measured centre to centre on C knuckles	670	mm			Applied torque to chassis	265,8559	Nm
Applied load	20,3	kg			Deflection angle	1,861885	degrees
Length of load lever to C knuckle	1000	mm					
					Torsional stiffness	142,7886	Nm/degree
Deflection left	10,58	mm					
Deflection right	11,2	mm					

Table 2: Torsional stiffness calculation sheet.

The test rig itself will also deform under the load of the setup, influencing the measurement. To test whether the influence is of any significance a check measurement is carried out to measure the amount of error. The maximum force is exerted on the lever. Both the difference in distance of the chassis relative to the test rig and the test rig relative to the steel table is measured. The 30 mm thick steel table is considered to be infinitely stiff. The measurement points out that the test rig deflection relative to the chassis deflection is only 1 percent. This amount of error will be left out of the final data assessment since it is considered to be insignificant.

4.2 Torsional stiffness over a lifespan

Two chassis are tested for torsional stiffness on the test rig. Both the chassis are produced by Tony Kart in Italy and are of the same type. One chassis is brand new and the other is approximately nine race weekends old. Nine weekends is by top level drivers considered twice the useful lifespan of a chassis. The used chassis shows multiple visual signs of wear. See chapter 3.1. Since the main complaint is 'softening', it is to be expected that the used chassis shows a lower torsional stiffness than the brand new chassis.
The testing of the chassis is done with an increasing amount of load. This way the torsional stiffness can be mapped and checked for progressive/digressive or linear behaviour. The acquired data from both chassis can be found in figure 13

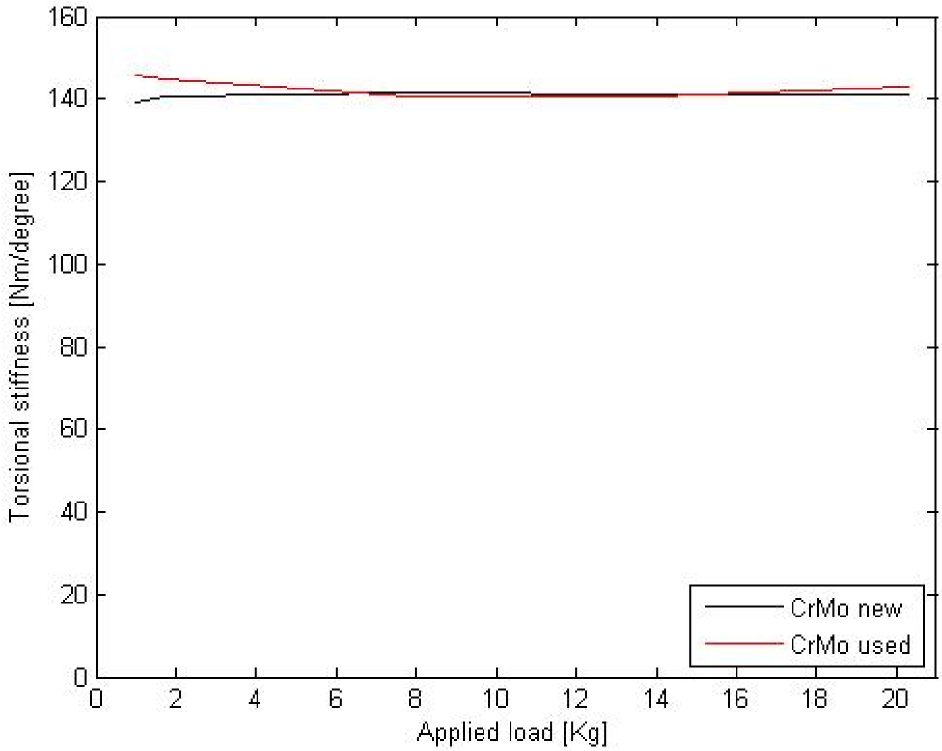


Figure 13: Torsional stiffness of new and used chassis.

The torsional stiffness of the used and new chassis are approximately the same. The largest difference is at the lowest load. Here the chance of a measurement error is most likely. Still the difference is only 6.5 Nm/degree. At higher loads, at more realistic load changes during driving, the difference completely disappears. Therefore, the stiffness of both chassis is considered equal.
The gained knowledge is completely counter-intuitive. While the whole go-karting world is talking about 'softening' this data shows no evidence of that. Also this falsifies the torsional stiffness branch in figure 8 in chapter 3.2.

4.3 Preload in the chassis

As stated in chapter 3.2, preload loss could be a cause of the problems the driver experiences. The preload build into the chassis could fade away quickly once the chassis is in use. This hypothesis is falsified by the results of the torsional stiffness test in chapter 4.2. If pre load was lost, the stiffness should have decreased, which is not the case. This hypothesis however has more to it. Chassis builder Tommy Fälth:"The chassis are build without any preload, however after welding, straightening of the chassis might be necessary." [4]. Although the tubes forming the chassis are loosely placed in the welding jig, the input heat from welding may put the chassis out of shape. This will need correcting after cooling. Slight preload of tubes may occur in the process since the chassis design is over-defined by nature. The stiffness data however rejects this.

4.4 Deforming and performance

Deforming has a negative impact on the performance of a go kart. A go kart chassis that is twisted about its longitudinal (X) axis, will have a significantly different weight distribution than a straight chassis. Weight distribution will influence the amount of grip the tires can supply. Less vertical force working on the tyres means less grip. A sagged chassis that has taken on a 'banana' like shape will struggle with wheel-lift as the geometrics are altered.
To get an insight to which points in the chassis are subjected to the highest stress, leading to the plastic deformation, a simple FEM analyses is executed. The basis of the model is the geometry of a Tony Kart chassis. Torque is introduced in the same way as the torsional stiffness test rig (see chapter 4.1). Exact numbers do not matter in this calculation as it is only performed to get an idea of where the stress is located. The result of the simulation can be seen in figure 14.

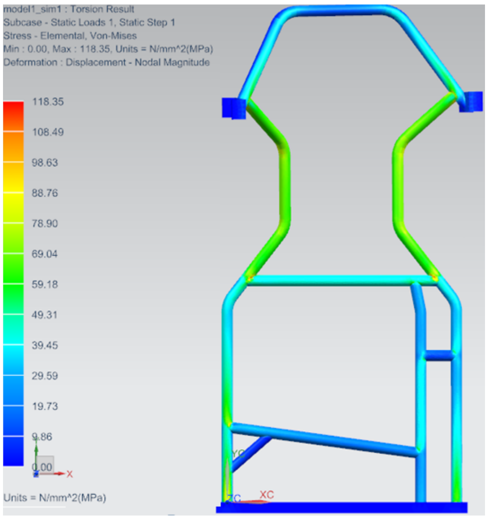


Figure 14: Result of FEM analyses on chassis

In the FEM result a clear pattern can be seen. The waist (see figure 5) of the chassis takes the most stress. This makes sense as the rear of the chassis is much stiffer due to more structure. Looking at the chassis described in chapter 3.1 and comparing it to the simulation results there are clear similarities. The most deforming can be seen at the start of the waist. In summary: the waist of the chassis has a major influence on the chassis flexibility.
Flex within the elastic capabilities of the chassis may cause metal fatigue. Metal fatigue may in turn cause plastic deformation as it develops microscopic cracks in the chassis. These cracks would however also influence the torsional stiffness, which is not the case. Thus the plastic deformation must be due to the material exceeding it's yield strength. This can be caused by

aggressive driving and clipping high curbstones on the racetrack (see picture 15). Depending on the racetrack, many times this driving behaviour is necessary to get the fastest lap times.

Figure 15: A kart on two wheels after hitting a curbstone.

Jesper Sjöberg, 2016 Swedish Rotax karting champion, says:"After a while, when you put the snipers on (measurement device for camber on the front axle), you can see the value increasing" [6]. The increasing camber is for drivers the tell tale sign of plastic chassis deformation since it is easy to measure. The camber increase is due to the connecting points of the spindles bending upward and inward, crosswise bending.

4.5 Conclusion on hypothesis

To get an overview of the falsification of hypothesis a visualisation is included in table 3. All hypothesis regarding an altercation in torsional stiffness have been falsified.

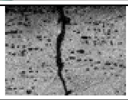
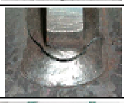
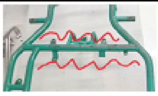
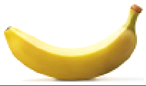
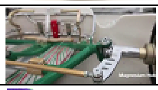
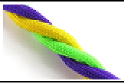
no.	Hypothesis	visualisation	Falsified	Verified	Reason
1	Grinding away of material		X		*No effect on torsional stiffness*
2	Fatigue in tubes		X		*No effect on torsional stiffness*
3	Fatigue in welds		X		*No effect on torsional stiffness*
4	Preload loss in construction		X		*No effect on torsional stiffness*
5	Sagging of chassis				
6	Crosswise bending				
7	Twisting of chassis				

Table 3: Visualisation of hypothesis testing results.

Concluding: *The cause of performance decrease in a go kart chassis is due to plastic deformation. This deformation is caused by the chassis being stressed over the materials yield strength.*
Any plastic deformation will have a negative impact on the performance of the go kart. Deformation can occur along multiple vectors. Which vector is of the biggest influence on performance is not clear.

5 Counter measures

Counter measures for the found cause can be researched in two areas: design and material, or a combination of the two. A material with an increased yield strength will increase the chassis resilience to plastic deformation. An altered design may provide the chassis with an equal torsional stiffness and lowered stress levels.

5.1 Material

Go kart chassis are now constructed out of 25 CrMo 4 steel [5]. This steel was for decades the go to high strength steel. Many different values can be found for it's yield strength. This type of steel is produced by many different factories in varying qualities. The most occurring value is used, 517 MPa.
Nowadays high-tech steels are mass produced which have greatly improved yield strengths, some examples are SS AB Docol tube 980 (750 MPa) [11] and Docol R8 (690 MPa)(see appendix A). Various stainless steel types have very high yield strengths when heat treated. For instance 17-7 stainless in CH900 condition has a yield strength of 1793 MPa [10]. Whether hardened stainless steel is usable in this application is to be researched. Carbon fibre tubing is not able to deform plastically. When it's ultimate strength is reached, it will fail and crack. The ultimate strength of M55 UD carbon fibre is 1600 MPa [12].
Unfortunattely the sporting commission CIK/FIA has a rule in place which restricts the materials used to magnetic steel types [1]. Some stainless steels may have enough permeability to pass the test described by CIK/FIA in the technical regulations. Carbon fibre is not an option because of this rule. To test whether there is a stainless type that has enough permeability to pass the test is outside the scope of this project.

5.2 Design

By changing the design the stress levels in the material could be lowered. The torsional stiffness should not be altered in the process. To reach this goal various design changes can be experimented with. For instance, the waist width of the chassis can be changed. A wider waist with smaller diameter tubing may give a similar torsional stiffness while having lower stress levels. More radical design changes are worth wile looking into as well. This however is outside the scope of this project.

6 Docol R8 as a solution

In order to answer the pragmatic research question, stated in chapter 1, the project is set out to test whether Docol R8 steel could bring a durability improvement to an existing chassis design. Potentially a hypothesis will be verified in the process. To test the durability a proof of concept chassis is produced. The existing design will be of a Tony Kart chassis.

6.1 Comparison of materials

The Tony Kart chassis is originally constructed out of 25 Chrome-Molybdenum 4 steel [5]. A steel type used in most go kart chassis.
Docol R8 is a high strength steel tubing product line developed by SS AB in Sweden, and produced by SS AB in Finland. The product is specifically developed for automotive motorsport application in chassis and roll cage construction. The tubing is produced by cold forming sheet material into tubing and welding the seam. For more information see appendix A.
By comparing the two materials on paper an insight into the feasibility of an improvement in durability will be gained. Of interest for the application in go karts are the yield strength, Young's modulus, price and weldability

6.1.1 Yield strength

The yield strengths are:

25CrMo4: 517 Mpa [7]
Docol R8: 690 Mpa (see appendix A)

The Docol R8 steel has a 33 percent higher yield strength. This will help the chassis to keep it's original shape.

6.1.2 Young's modulus

Although no exact number has been found for the Young's modulus of Docol R8, it will not be very different from 25CrMo4. The Young's modulus of steel is a characteristic that is hard to alter. To get an impression the following graph is useful (see figure 16).

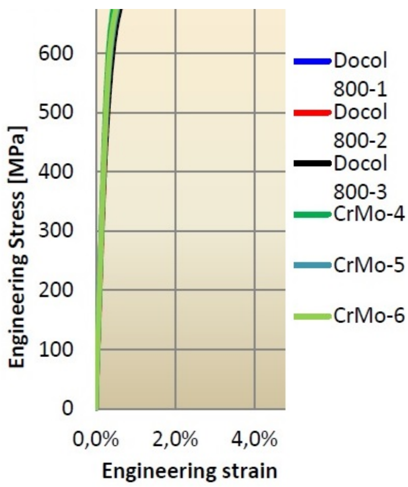


Figure 16: Tensile test with Docol R8 and 25CrMo4.

In the tensile test results the angle indicating the Young's modulus is equal for both materials. This is positive as the aim is to improve durability without changing the handling characteristics. A difference in Young's modulus would inevitably change the torsional stiffness of the chassis.

6.1.3 Price

The shown prices are for 30x2mm tubes which are the main tubes used for go kart chassis.

25CrMo4: 210 SEK/meter (21.49 Euro/meter) [8]
Docol R8: 156 SEK/meter (15.96 Euro/meter) [9]

Docol R8 is the cheaper material. This is mainly because the project is in very close proximity of the producer SS AB. A go kart chassis is made up of approximately 6 meters of tubing. The steel price makes up a small percentage of the reselling price of 12000 SEK (1231 Euro).

6.1.4 Weldability

The weldability of the material is interesting concerning the cracks that have been found in the heat affected zone, see chapter 3.1. Although this is not an issue regarding the goal of doubling the lifespan of the chassis, the difference between the two materials is worth noting.

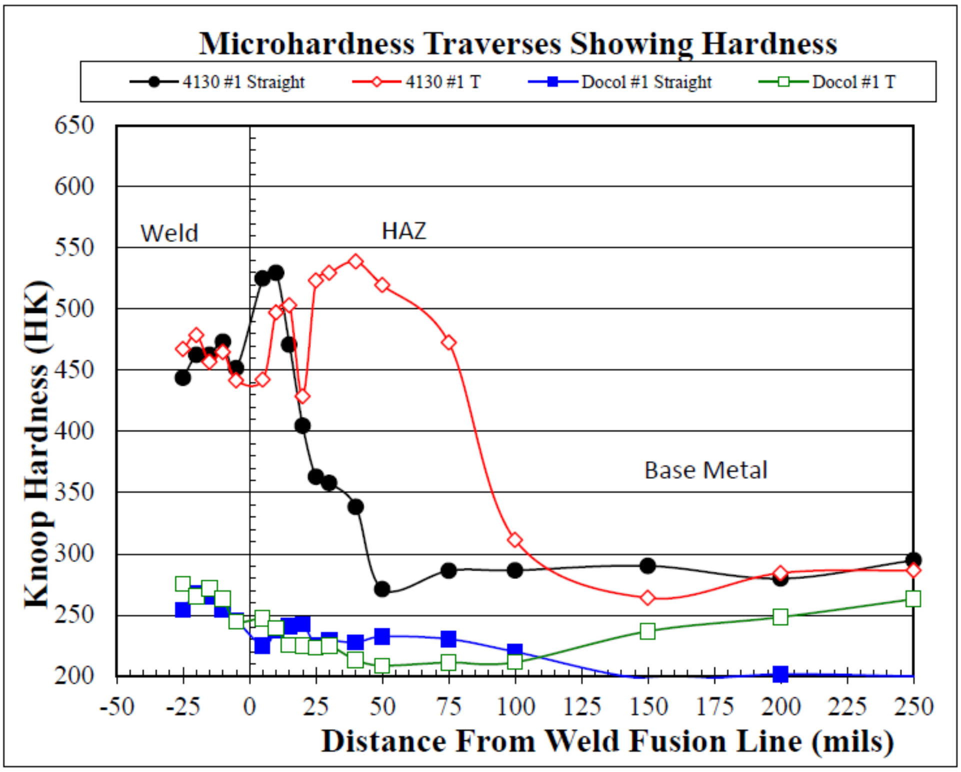


Figure 17: Weld hardness test with Docol R8 and 25CrMo4.

In figure 17, the hardness across a weld is displayed. The 25CrMo4 (4130 USA standard) is much harder in the heat affected zone. Docol R8 keeps its original hardness. The disadvantage of hard welds is that they are brittle. This will make the weld crack sooner. The proof of concept chassis constructed out of Docol R8 will be less prone to cracking in the heat affected zone.

6.2 Proof of concept

6.2.1 Production

To produce the proof of concept chassis a welding jig is rented and adjusted to fit a 2017 model Tony Kart. These steps are carried out by Creator AB. The welding jig holds all tubes that make up the chassis to ensure a straight end result. Tube bending and welding is executed by ME Racing Services AB. This company has many years of experience in building drag race chassis.

The Docol R8 chassis is TIG welded instead of MIG welded like the original Tony Kart chassis. TIG welding was chosen because of the improved amount of control over the input heat and the nicer looking end result. Because Docol steel does not harden in the HAZ (see chapter 6.1.4) there will be no difference in stiffness of the weld compared to if it was welded with MIG.

The chassis is further assembled with parts taken of a 2016 Tony Kart. A new rear axle is mounted to ensure that this active part of the chassis dynamics is in good condition.

6.2.2 Testing

The goal of the test is to check whether the chassis will last a full racing season worth of track time instead of the normal half season. To do this the chassis will have to run approximately 8 times (the amount of weekends during a season) 80 minutes (the amount of track time during one race weekend). This totals 640 minutes.

The testing on the proof of concept chassis can be split up in three sections: initial test, duration testing and final test. This testing will be carried out on go kart specific race tracks. Namely the Västerås and Borlänge racetrack. During these events several parameters on the deflection of the chassis and the torsional stiffness will be measured. This data presents proof of the performance of the Docol R8 steel in the chassis and may verify or falsify the left over hypothesis. The deflection parameters are:

- Camber: The camber on the front wheels normally increases as the spindle mounting points bend upwards. The Camber and king pin inclination are directly dependent of one another. The camber is measured with a go kart specific measuring tool called ”snipers”. A laser, pointing parallel to the spindle it is mounted to, will show a dot on the laser mount of the other spindle. See picture 18. This parameter is measured in the amount of squares on the display, therefore no unit is chosen.

- Twist: The amount of twist in the chassis is measured with a horizontal laser line. The rear axle is shimmed to be horizontal. Than the front axle is measured. If the front axle is not horizontal as well, the chassis has twisted. Parameter measured in millimetres.

- Sag: This parameter indicates the sag of the complete chassis. In simpler terms, the amount of banana shape. A straight edge is fixed to the underside of the chassis, which has three cross tubes. The deflection is measured from the straight edge to the front tube. Unfortunately this can only be measured with a bare chassis, reducing the amount of data points. Parameter measured in millimetres.

- Cross weight: the corner weights of any four wheeled vehicle is the amount of weight carried by each of its tyres. The cross weight is the ratio of the left front and right rear tyre divided by the right front and left rear tyre expressed in a percentage. 50 percent is the ideal number as anything else means the kart acts like a seesaw. This is measured with four digital scales. For repeatable results each time the same ground surface was used. See picture 19 to get an impression. This measurement is dependent on the chassis twist. Chassis twist will alter the cross weight.

- Torsional stiffness: As in chapter 4.1 the torsional stiffness of the proof of concept chassis is measured at the start and at the end of the testing. Parameter measured in Nm/degree.

Figure 18: Sniper mounted on spindle. See the two red dots on the panel, the most left dot comes from the other end and indicates the camber as well as the toe setting.

Figure 19: Kart set up for measuring cross weight.

Initial test:
The initial test consists of acquiring the first data points and to measure whether the chassis is able to deliver competitive performance. The venue for this test is the Västerås racetrack. Two highly skilled drivers are present. First the kart is run to find the best setup for the circumstances. New tyres are put on regularly to make sure tyre wear is not an influence. After several outings the speed is there. The kart manages a 34,3 second laptime. This is 0.3 seconds faster than the times that were put out during a race there two days earlier. A very good result.
To exclude external conditions from the equation and measure the performance the following test is executed. A driver will drive both the proof of concept chassis and the original Tony Kart chassis with the same engine, setup and tyre set. This is necessary to get a reliable result. Both go karts show the same performance and handling characteristics under these conditions. This is off course the minimal result because if the chassis does not perform, there is no reason to go forward.
Duration testing:
At the Borlänge racetrack duration testing is undertaken. This test consist of putting 9 hours of track time on the proof of concept chassis and monitoring the parameters every hour. To make sure this is a resemblance of real competition racing new tyres are put on regularly and the lap times must be close to those in race weekends.
Final testing:
To finalize the testing the go karts are taken back to Västerås racetrack. Once again the competitive level of the proof of concept chassis is measured by comparing it to the original Tony Kart. The Tony Kart has not been driven in the meantime and will therefore still perform as new.
The chassis handled very well and showed no different lap times or driving characteristics than the new Tony Kart chassis. To get an impression of the on track testing see pictures 20 and 21.

Figure 20: Priscilla Speelman driving the proof of concept kart in Borlänge.

Figure 21: Priscilla Speelman lifting the inside rear wheel of the proof of concept kart.

6.2.3 Test results

The torsional stiffness of the proof of concept chassis is measured before and after testing. The results can be found in figure 22. As stated in chapter 4.2 the small load data points tend to be unreliable. At higher load the difference disappears. Therefore it is considered that there is no difference in stiffness in both new and after one season of driving and between the proof of concept (Docol) and the original chassis (CrMo).
The data gathered during testing has been plotted in figure 23.

- Camber: In the top graph the camber is shown. The first data point is 0 camber for left and right, then it jumps up quickly. This is due to the bolts, bearings and other parts settling. Afterwards there are small deviations to be seen but overall the values do not alter. Very different from what can be experienced on the original chassis. Here drivers can experience up to an increase of 1[-] per race weekend (80 minutes)[6].

- Cross weight: In the second graph the cross weight is displayed. Again some variations can be seen but no serious deviation from the ideal 50 percent. Unfortunately there is no data of an original chassis on the topic since scales are not often used in go karting.
- Twist: Chassis twist can be found in the last graph. This measurement is at a constant 0 until it goes up to 1 mm at around 600 minutes. The cause for this is probably that one of the drivers jumped curbstones at an excessive rate, forcing the steel over its yield strength. Off course this is what happens in real racing as well. On a Chrome-Molybdenum chassis twist of around 5 mm can be expected after this length of time[4].
- Sag: In the last graph two blue dots can be seen. Unfortunately sag can only be measured on a bare chassis. Therefore there are only two data points. The total sag after the testing was 3 mm. On an ordinary chassis values of up to 25 mm can be expected [4].

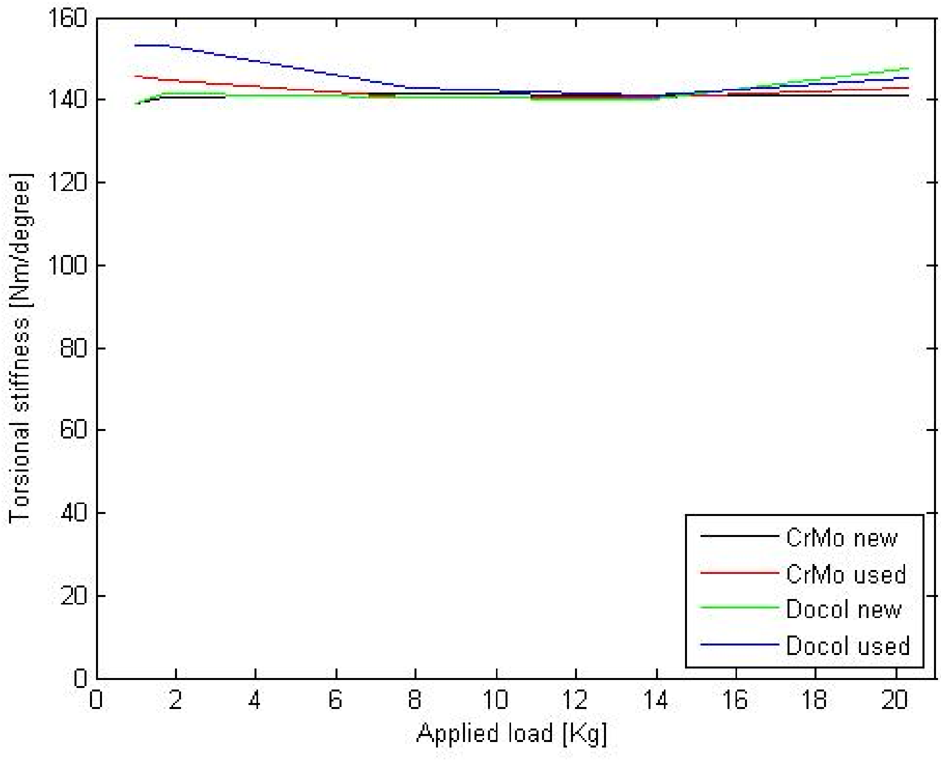


Figure 22: Torsional stiffness test result. Proof of concept = Docol, Original Tony Kart = CrMo.

The data obviously shows a big improvement on the durability of the chassis. Unfortunately this also means that there is no way to conclude on the refined hypothesis with this data. Due to a limited budget there are no possibilities to conclude on the hypothesis at this moment. The proof of concept did perform exceptionally well. Further testing could confirm the hypothesis and show the next failure mode.

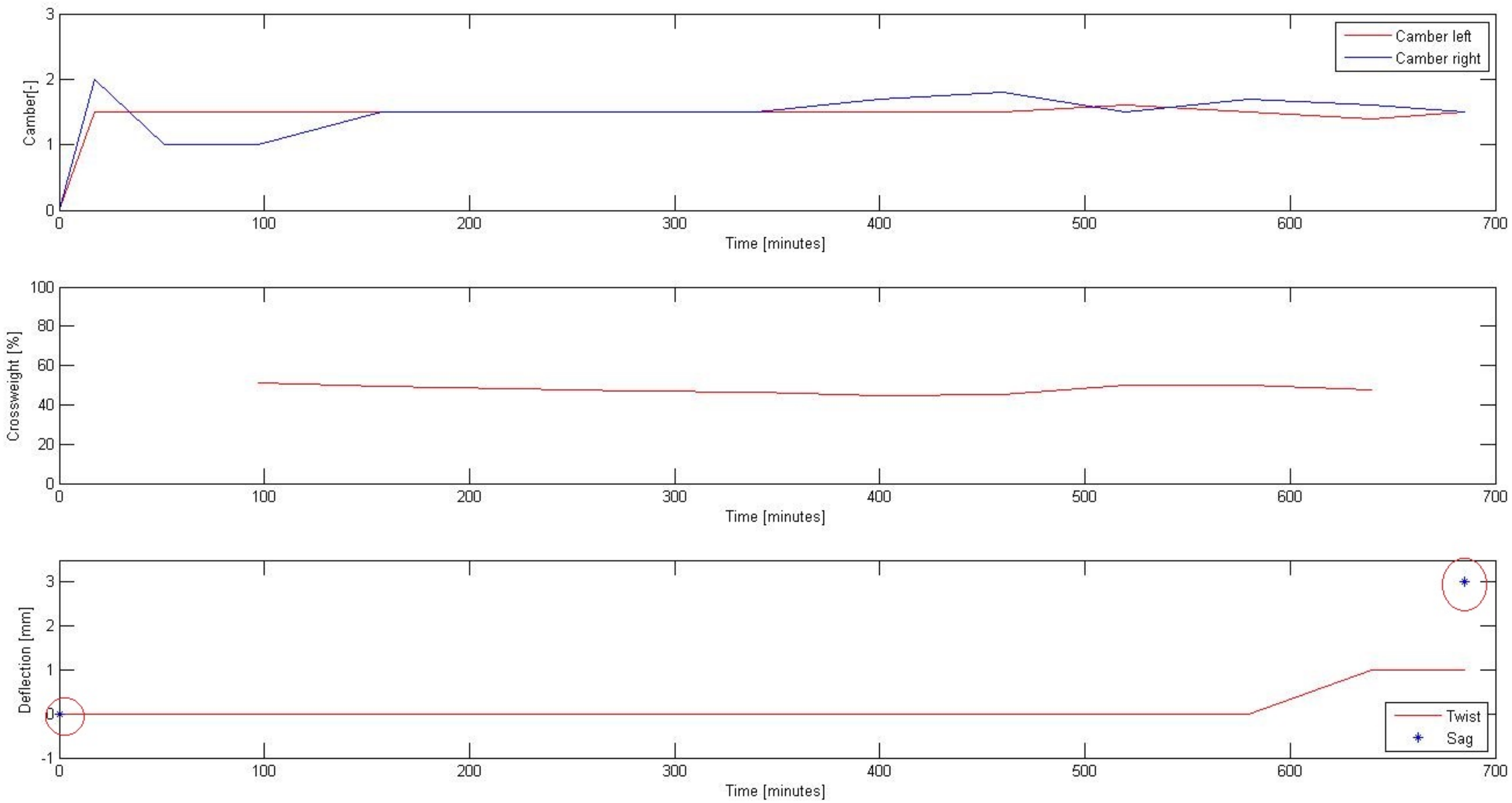


Figure 23: Data gathered during testing. Note the two blue dots in the last graph.

7 Conclusion

The conclusion on the research is split up in two main parts of the research process: the engineering research question and the pragmatic research question.
The root cause research conducted, following the engineering research question, shows that *plastic deformation is the cause of chassis performance drop off.* All plastic deformation has a negative effect on the performance. Which deformation is of the biggest influence on the performance has not been verified. Counter measures come in two forms: material and design. Docol R8 has several benefits for use in go kart chassis. It's yield strength is 33 percent higher than the now used 25CrMo4. This increases the chassis resistance against plastic deformation significantly.
The proof of concept chassis shows improvements of a minimal 5 fold in deforming parameters. The performance is very constant. The chassis is not further tested than 8 race weekends or approximately one racing season. A failure mode is yet to present itself.
The pragmatic research question stated: Can the lifespan of a go kart chassis be doubled by using Docol R8? The answer to this question is: *Yes, because of the improved yield strength the Docol R8 chassis will last longer than one racing season.* Other benefits are an improved performance consistency, lower price, improved weldability. These factors make for large progress in the field of go kart design.

8 Recommendations

Recommendations on this project consist of those towards the hypothesis testing and further research on the counter measures.
The hypothesis have been ruled out by falsification. The remaining hypothesis have been accepted but not verified. The hypothesis can be ruled out or verified by testing the same chassis in both a bend condition and after straightening. This test will give further insight on the hypothesis.
The counter measures stated in chapter 5 include researching more materials and looking into design changes. Stainless steel types with sufficient permeability that may double or triple the yield strength should be researched and possibly tested.
Design changes should look into lowering the stress levels while maintaining the torsional stiffness. The advice is to start this research with FEM analyses using loads that will cause the chassis to sag. Although it is not known whether this of the biggest influence on performance, it is biggest deflection seen on go karts.
The proof of concept chassis should be further tested towards its point of failure. This will give a measurement for the lifespan of the Docol R8 chassis and will show its failure mode. Potentially design changes can be made to lengthen its lifespan even further.

9 Used sources

Cover photograph
CRG Racing Team (World Cup Braga Portugal, 15-9-2010). Max Verstappen during the world cup at Braga in 2010 driving a CRG KF3 kart.
Consulted on 2-3-2017 from:
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Appendices

A Docol R8 Brochure

DOCOL®
HIGH STRENGTH STEEL

Docol Tube R8

Extra High Strength Tubes for Racing and Safety Applications

General Product Description

Docol Tube R8 is a product range of TIG welded cold sized circular tubes in high strength steel, intended for applications requiring a combination of extremely high performance and lean design.

Docol Tube R8 is produced using tube designated SSAB high strength steel, with high yield strength in combination with excellent bending and welding properties.

Docol Tube R8 is approved as an allowable material in the SFI specifications for roll cages in different types of drag racing vehicles.

Applications

Docol Tube R8 is developed especially for roll cages, racing car tube chassis, and similar safety components.

Units

Docol Tube R8 tubes can be ordered in imperial or metric units.

Dimension

Docol Tube R8 tubes are produced with narrow tolerances, intended to fit into each other (some exceptions apply). Both inner and outer weld beads are removed for perfect fit.

A number of selected dimensions of Docol Tube R8 can be ordered from stock. Customized dimensions can be produced upon request.

	Thickness mm	Diameter mm	Thickness, inches	Diameter, inches
Total span	0.5 - 4	16 - 54	0.019 - 0.157	5/8 - 2 1/8
Stock items	1.25 - 2.50	19 - 50	0.049 - 0.095	3/4 - 2

Exact lengths of 6 000 mm -0/+10 mm. Other lengths upon request

Mechanical Properties

During the tube manufacturing the steel tubes undergo controlled mechanical hardening which contributes to the final mechanical properties of the products.

Inspection and mechanical tests on the tubes are performed according to EN 10305-3.

Profile grade	Yield Strength $R_{p0,2}$		Tensile Strength R_m		Elongation A_{50} %
	MPa min	ksi min	MPa min	ksi min	min
Docol Tube R8	690	100	800	116	13

Chemical Composition

Thickness	C % max	Si % max	Mn % max	P % max	S % max	Al % min	Other alloying elements
0.5 - 4.0	0.16	0.4	2.10	0.03	0.01	0.015	Nb, Ti, Ni

Tolerances

Tube tolerances are according to EN 10305-3.

Delivery condition

The tubes are not intended to undergo any heat treatment after welding and sizing as that may alter the mechanical properties of the material.

The tubes are oiled with anti-corrosive oil.

Fabrication and Other Recommendations

For information concerning fabrication, see SSAB´s brochures on www.ssab.com/downloads or consult Tech Support, help@ssab.com.

Appropriate health and safety precautions must be taken when welding, cutting, grinding or otherwise working on the product.

Contact and Information

For further information about the possibilities and practical benefits of Docol Tube R8, please contact us at tubes@ssab.com, visit our website www.ssab.com/shape or contact any of our sales managers.

Tech Support will be pleased to assist you with additional technical information concerning this SSAB product.