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The Mechanisms Design and Stress Analysis of Convertible Booster Seat

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Abstract: Transportation is one of the significant things today as it has a positive economic and social impact. However, most of the car seats available on the market are created not to prevent whiplash, especially to smaller passengers. Therefore, the objectives of this study are to design convertible middle rear seat using the morphological chart and to analyze the strength of a convertible booster seat mechanism. Solidworks 2018 was used to design the mechanism of the convertible booster seat. Characteristics that being studied to perform a better convertible booster is the mechanism, the joining method and the material used for the mechanism. Solidworks simulation 2018 was chosen to analyze stress concentration, displacement, and strain of the convertible booster seat. For the simulation, all the mechanisms are tested with different loads, of 20, 40, 60 and 80 kg. Graph of stress analysis, displacement and deformation of the mechanism were recorded and analyzed. The success of this study will able the researcher and manufacturer to implement the convertible booster seat for the safety of passengers especially kids and dwarf that use the middle rear seat.

Keywords: Solidworks 2018, Safety, Stress Analysis, Displacement, Strain, Booster

1. Introduction

Whiplash can affect anybody in the car and that often includes babies. Neck injuries sustained in a fender bender happen as often as possible and can be expensive in term of treatment required after the crash. Taking steps to ensure the neck and spine of all occupants are protected as much as possible and focusing on prevention procedures makes absolute sense for the whole family [1]. Short adults normally will face problem in wearing the seatbelt at the rear seat. The seatbelt usually will be at the neck of short adult thus if any collision happens, they will get neck injuries easily. But if they do not wear the seatbelt, they will be exposed to pitching the cars and getting serious injuries as if they do not have airbags. According to a World Health Organization census in 2002, 49,736 newborn children between 0 to 4 years old and 130,835 kids between 5 to 14 years old were injured or slaughtered while travelling as

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tenants in motor vehicles. Among all kind of injuries, injury to children caused by traffic accident has ranked in second place insignificant [2]. While in 2009, 1314 children died and 179000 were injured in motor vehicle collisions (MVCs) [3].

Purposing the exact definition of a car seat to answer some of the consumer's question meaning or aims has imposed various thinkers from many fields such as social policy and psychology over the years because the meaning itself is too broad and general define. Like portable car seats that are not produced by car maker, it is called Car Restraint System (CRS). CRS is a portable seat for an infant or a small child that attaches to an automobile seat and holds the child safely [4]. It is a near-ranging notion affected in a complex way by the person's state and their knowledge about the car seat. Differently, car seat as seat for a child who has outgrown both an infant seat and a toddler seat [5]. Therefore, a car seat is extremely important to serve an infant and short adult's safety and comfort in a moving car. Meanwhile, the Ministry of Transport announced that child seats would be made compulsory by 2020 [6]. On the other hand, the United Nations raised the bars for children's car safety by introducing UN R129-02 with a new high back booster seat [7].

Hence, a set of preparation to overcome these problems is needed by establishing a booster rear seat to help short adults wearing seatbelt safely and correctly. This booster seat also helps parents to secure their baby while riding the car. There are three main aspects that this study will be cover as to make the convertible booster middle rear seat of a car. There are letting kids and short adult wear a seatbelt at the middle rear seat. In this study, it will cover the decrease fatality and severity rate during an accident. In sinking the fatality and severity rate, the ride will be more comfortable and safer for kids and short adult. Malaysia national car (Perodua Myvi) middle rear seat mechanism will be used in designing the attached booster mechanism.

The awareness on safety while riding in a motor vehicle is very vital and its significance is remarked in various of studies [8][9][10][11]. It is because the problem that occupants faced could endangered and might affect their entire life. The importance of this study is this study could be a guidance to some certain research community and automotive industry who manage in the field of safety and transportation. The data of this study is one of the crucial parts where it acts as an evidence to proof that safety in transportation could affect one's life, whether in positive or negative aspects. Identifying the real problem in this study might help occupants have a safe and comfortable ride. Therefore, Solidworks 2018 is used to design the convertible booster seat and define the convertible booster seat's strength analysis. Different loads are put to measure the strength that mechanism can afford to hold.

2. Materials and Methods

Solidworks 2018 is used for designing the mechanism moreover analyze the strength for the mechanism. The method used in this study was discussed in detail. This consists of the dimension of rear car seat, mechanism used, joining method, materials for the whole mechanism, problem justification, scoring concept and screening concept.

2.1 Dimension of car seat

The middle rear seat of Perodua Myvi is used as references in designing the convertible seat. Thus, a fieldwork had been done to measure the dimension of the middle rear seat. The width of Perodua Myvi's rear seat is about 320 mm, and the length of the seat is 460 mm. The convertible booster will be located under the seat on the other hand, the height is about 160 mm from the bottom of car. The convertible booster will be implemented on the car`s chassis. Figure 1 shows the dimension of Perodua Myvi`s middle rear seat.

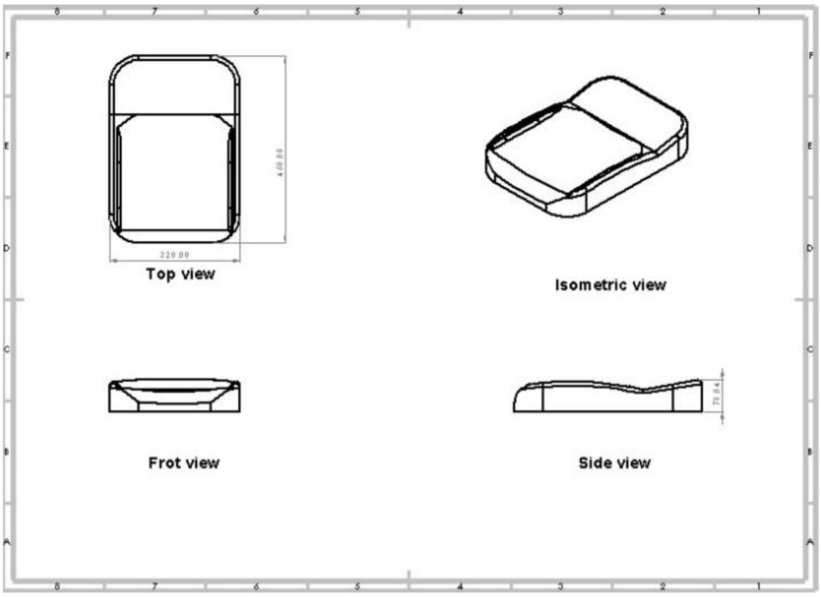

Figure 1: Dimension of Perodua Myvi's Middle Rear Seat

2.2 Problem justification

Problem justification is known as variance that we change the part or material used to produce the design. In this context, problem justification contains three parts: joining method, mechanism used for booster, and the material. Table 1 shows the suitable variance for all mechanism.

Table 1: Problem Justification

Joining Method	Mechanism	Materials
Bolts and Nuts and Washers	Gear	Aluminum Alloy
Screw and Pins	Rack	Iron
		Steel

Based on the table 1, there will possibly have 12 variances. The variances are all shown in Table 2 below:

Table 2: Variance for Assemble

V1	nuts and bolts and washers + gear + aluminum alloy
V2	nuts and bolts and washers + gear + steel
V3	nuts and bolts and washers + gear + iron
V4	nuts and bolts and washers + rack + aluminum alloy
V5	nuts and bolts and washers + rack + steel
V6	nuts and bolts and washers + rack + iron
V7	bolts and pins + gear + aluminum alloy
V8	bolts and pins + gear + steel

V9	bolts and pins + gear + iron
V10	bolts and pins + rack + aluminum alloy
V11	bolts and pins + rack + steel
V12	bolts and pins + rack + iron

Figure 2 displays the gear mechanism as they assemble with hinge connected to the seat that may help increase the seat height. The mechanism basically will be located under the seat. Figure 3 shows the rack mechanism when it is completely assembled. The rack is located the right side of the middle rear seat as it assembles with the front compartment of the seat.

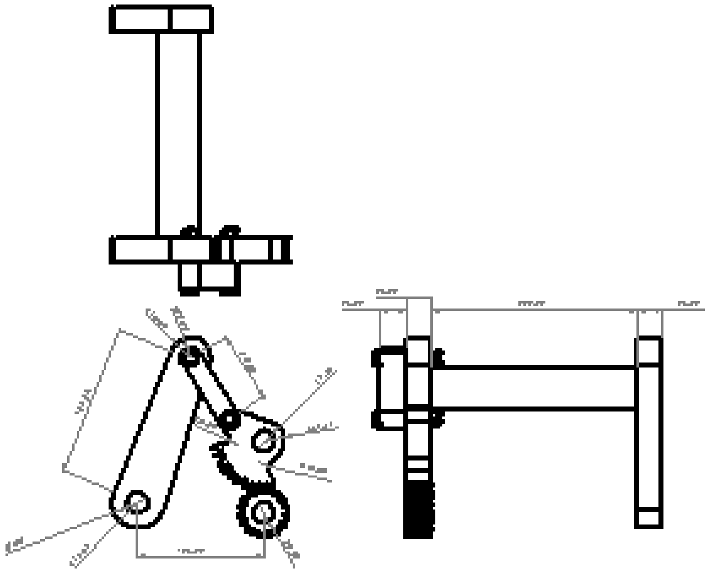

Figure 2: Full Assemble for Gear Mechanism

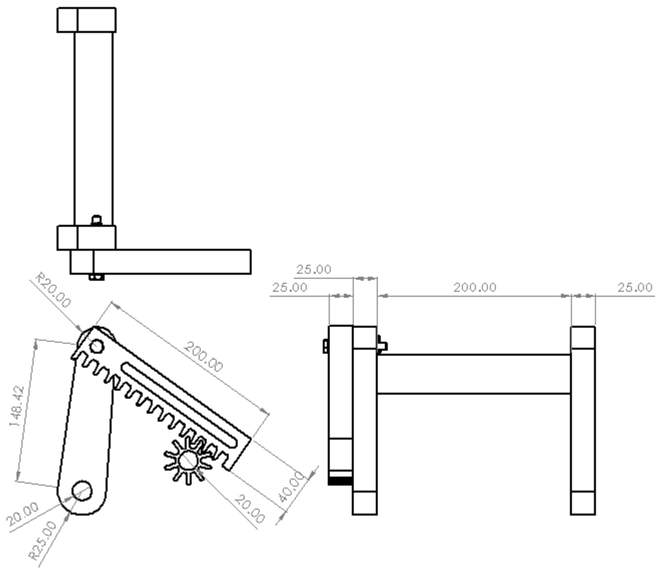

Figure 3: Full Assemble for Rack Mechanism

2.3 Mechanism

Mechanism is known as system of parts that working together. In this context, the mechanism is system that allow the movement to change the height of car seat. There are two types of mechanism that be found suitable in the process of changing the height of the rear car seat. Figure 4 shows the gear mechanism that being used in this study. The diameter used is about 100 mm with width 25 mm. Figure 5 shows the rack mechanism with 200 mm length and 30 mm height.

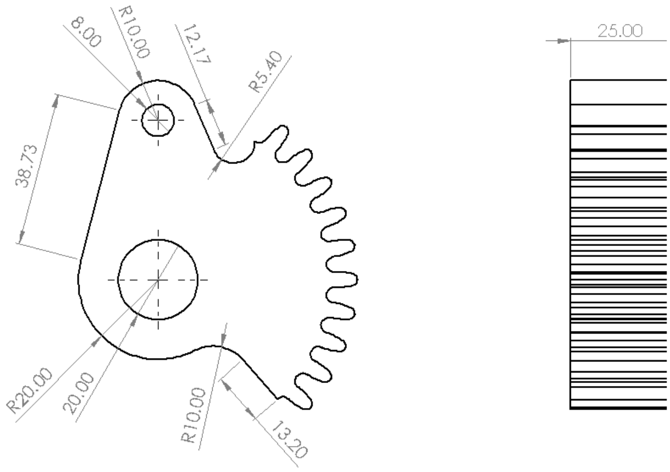

Figure 4: Gear Mechanism

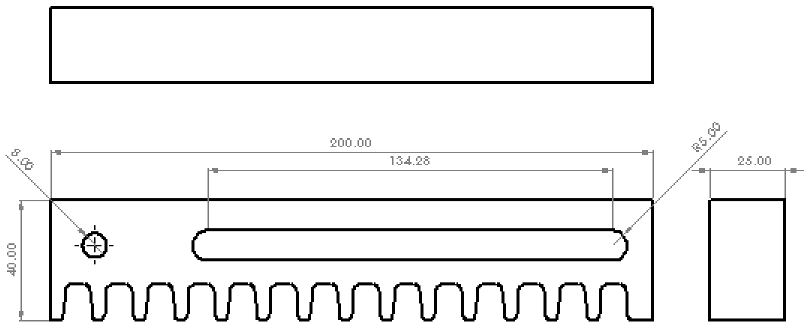

Figure 5: Rack Mechanism

2.4 Joining method

Joining method refers to ways to combine the materials to make it permanent or semi-permanent. The example of permanent joining methods such as welding, soldering and rivet. In this study, semi-permanent joining is used to ensure the mechanism is easy to be maintenance and service. Figure 6 shows bolts, nuts and washers were joined using its mechanism. The diameter of the bolt used is 8 mm same goes to the nut. While the length of the bolt is 60 mm. While Figure 7 displays the screw and pin joining that being used as variables in the mechanism. The diameter of the pins is 1 mm. The screws have the same length with bolts which is 60 mm. The bolts are standardized as taken from Solidworks library with diameter stat M8. Nut also is taken from Solidworks library with inner diameter is 8 mm and outer diameter is 10 mm. Screw is just same as bolts, but it is modified at the end of the screw to put the pin.

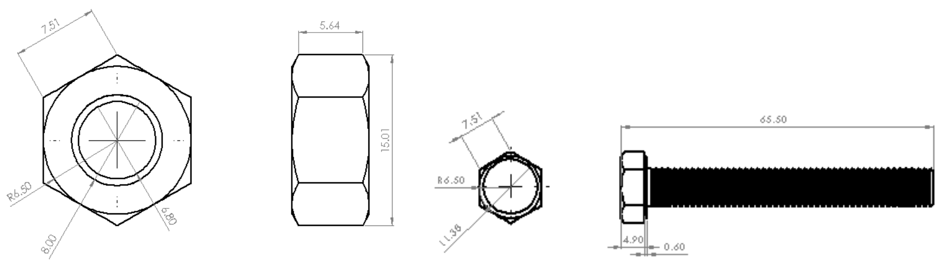

Figure 6: Bolt, Nut and Washer Joining

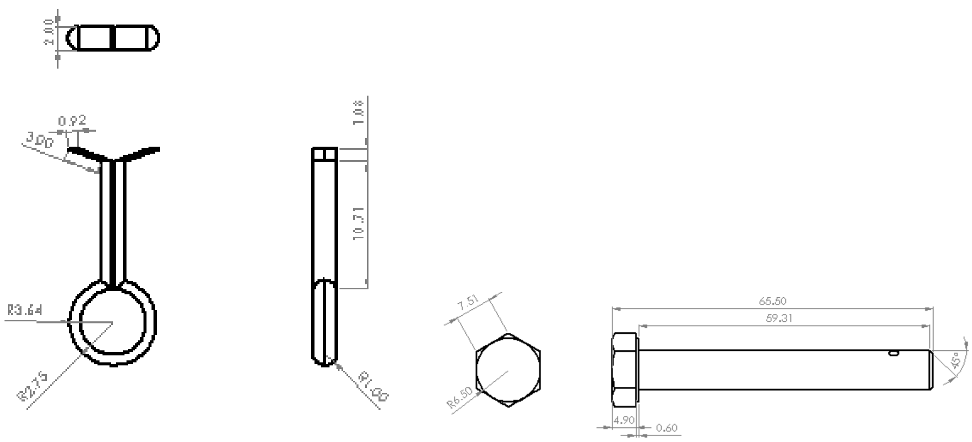

Figure 7: Screw and Pin Joining

2.5 Materials

Materials is the most important thing that must be considered before designing a product. Every material used should have their own characteristics that make them special. Table 3 displays the material used in this study. There is a description of the material characteristic, such as tensile strength, yield strength, and mass density. The metal used in this study is AISI 4340 Steel, normalized while the iron used is Ductile iron and aluminum used is 1345 Alloy.

Table 3: Materials Used in Study

	Steel	Ion	Aluminum
Elastic Modulus (N/m^2)	2.05×10^{11}	1.2×10^{11}	6.9×10^{10}
Mass Density (kg/m^3)	7850	7100	2700
Tensile Strength (kg/m^2)	1110000000	861695000	82722700
Yield Strength (kg/m^2)	710000000	551485000	27574200

2.6 Screening Concept

Concept screening is based on a method developed by the late Stuart Pugh in the 1980s and is often called Pugh concept selection [12]. The purposes of this stage are to narrow the number of concepts quickly and to improve the concepts. We rated the concepts against the reference concept using a simple code (H for "better than," M for "same as," L for "worse than") to identify some concepts for further consideration. Criteria such stress concentration, displacement and deformation, are chosen as the selection criteria.

The criteria will be marked for each design concept. This marking system will give a broad view of the cons and pros of each design study. A revision can be done and combine the design concept to make it a better design concept. For example, the design concept that has "0" or "same as" mark for its criteria can have the criteria itself change to a better one. This revise thing can make the design concept become better and theory also it makes it remove the need to find a new design concept.

Table 4: The Concept Screening Matrix

Y	**YES**
N	**NO**
R	**REVISE**
(r)	**reference**

	Concept											
Selection Criteria (V)	1	2	3	4	5	6	7	8	9	10	11	12
Stress Concentration	M	H	L	H	M	H	M	M	M	H	H	M
Displacement	L	M	H	L	M	H	L	M	H	L	M	H
Deformation	L	M	H	L	M	H	L	M	H	L	M	H
Sum H`s	0	1	2	1	0	3	0	0	2	1	1	2
Sum M`s	1	2	0	0	3	0	1	3	1	0	2	1
Sum L`s	2	0	1	2	0	0	2	0	0	2	0	0
Net score	-2	1	1	-1	0	3	-2	0	2	-1	1	2
Rank	11	4	4	9	7	1	11	7	2	9	4	2
Continue	N	R(r)	R	N	N	Y	N	N	Y	N	R	Y

2.7

2.7 Scoring concept

Concept scoring was used when the increased resolution will result with better differentiate among competing concepts. The relative importance of the selection criteria and focuses on more refined comparisons with respect to each criterion is weighted. As in the screening stage, it is generally easiest for me to focus its discussion by rating all of the concepts with respect to one criterion at a time. Because of the need for additional resolution to distinguish among competing concepts, a finer scale is now used, the recommended scale is from 1 to 5:

Table 5: Scale of Rating and Relative Performance

Relative Performance	Rating
Much worse than reference	1
Worse than reference	2
Same as reference	3
Better than reference	4
Much better than reference	5

Table 6: The Concept-Scoring Matrix

	Concepts		
	Variance 6	Variance 9	Variance 12

Selection criteria	weight	Ranking	Weight score	Ranking	Weight score	Ranking	Weight score
Stress Concentration	33.33%	3	0.6	2	0.4	2	0.4
Displacement	33.33%	5	1	4	0.8	4	0.8
Deformation	33.33%	5	1	4	0.8	4	0.8
Total score		2.6		2.0		2.0	
Rank		1		2		2	
Continue		Yes		No		No	

3. Results and Discussion

The data obtained from this research results from the full simulation of the mechanism using Solidworks simulation 2018. The simulation was run using different load variables which is 20, 40, 60 and 80 kg. The simulation datas were divided into several parts that included stress, displacement and strain. In comparison, the data were separated into the gear mechanism and the rack mechanism. From the simulation, materials are written in short form such as \`Al\` represent to aluminium alloy while \`Ir\` represent to iron and \`St\` represent to steel. \`1\` and \`2\` represent to joining method which is bolts-nuts and pin respectively.

3.1 Stress

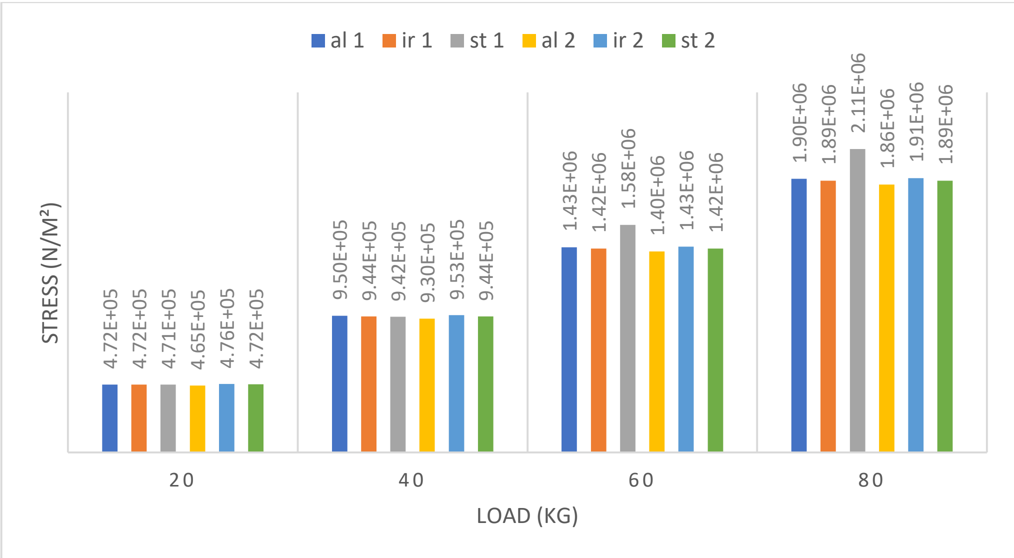

Figure 8: Stress Against Load for Gear Mechanism

Figure 8 depicts the graph of stress data for the gear mechanism. The graph is directly proportional. Data gained is nearly the same among other variances. Steel with bolts and nuts and washers joining differ its value since 60 kg load attached on it. The line for the graph is overlap since the value difference between each variance is smaller and the value stress for 20 kg load and 80 kg load is bigger. Since the stress formula is force over area [13], steel with bolt, nut and washer joining has more stress than other variance because force from the load is added to the steel which might have heavy weight compared to iron and aluminum. Even though the material used for bolts and nuts joining and pin joining are same, bolts and nuts joining have heavy weight compare to pin joining. Heavy weight from the material may add larger force to the load, causing total force acting on the body, leading to higher stress.

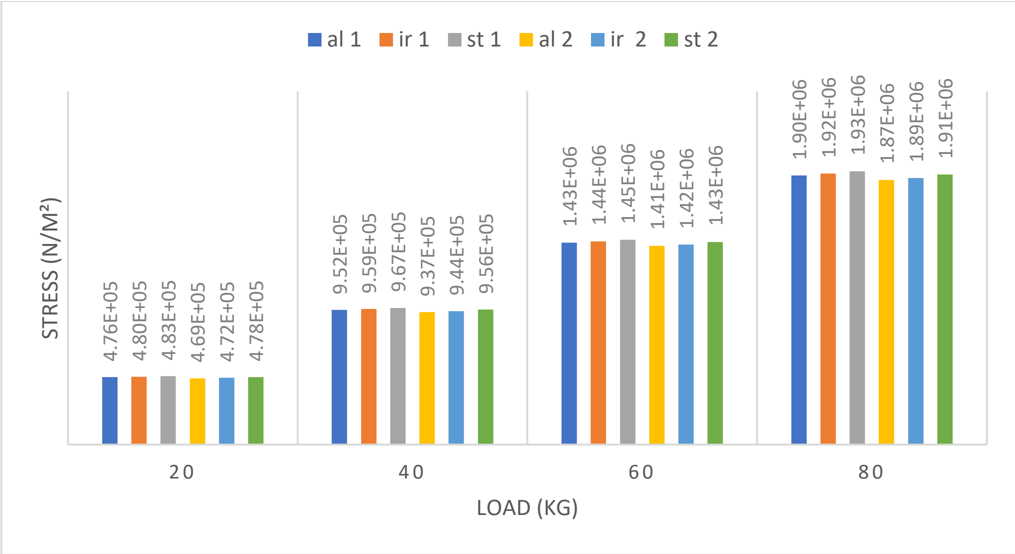

Figure 9: Stress Against Load for Rack Mechanism

Figure 9 displays graph of stress data for the rack mechanism. The graph is directly proportional. The data recorded are almost similar among other variances. Since the stress formula is force over area [13], aluminum with pins joining has less stress than other variance because force from the load is added to the steel which might have lighter weight compare to iron and steel. Even though the material used for bolts and nuts joining and pin joining are same, pins joining have lighter weight compare to bolts and nuts joining. Smaller weight from the material may add a smaller force to the load. This will cause total force acting on the body when run the simulation is less.

3.2 Displacement

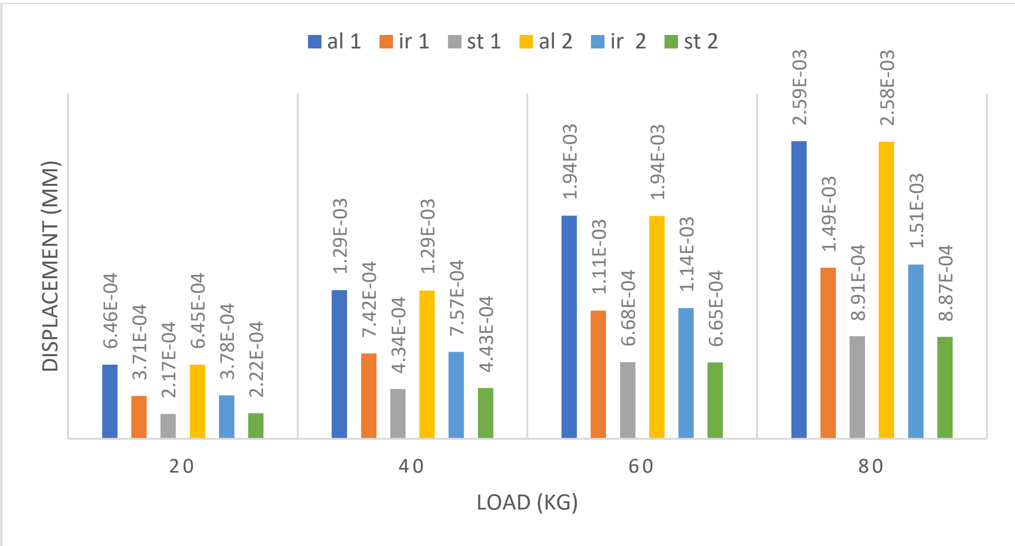

Figure 10: Displacement Against Load for Gear Mechanism

Figure 10 displays a graph of displacement for gear mechanism. The graph is directly proportional. The data is similarly according to their materials. Aluminum indicates the highest displacement travel against the load. Steel plotted the lowest among iron and aluminum. Displacement stand for changing the location of the object [14] after the load being put on it. The density of aluminum is the lowest compare to iron and steel. The more the density of a material, the more strength of the material. So, the lowest density could make larger displacement of the object because the object is not strong enough to hold the force. The displacement between aluminum with bolts and nuts joining method is larger than aluminum with pins joining method because the force is added by weight of joining. Bolts and nuts have more weight compare to pins since the size is already bigger.

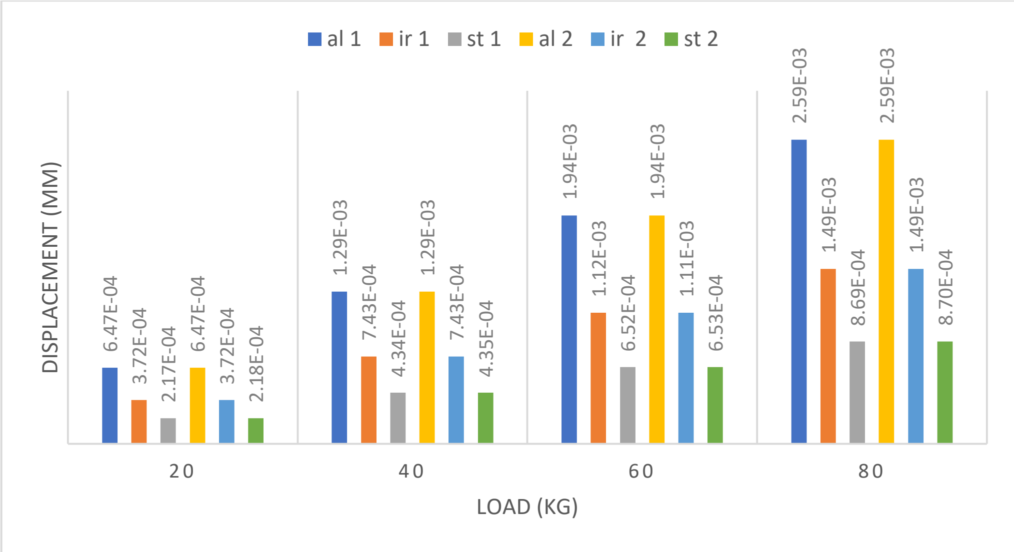

Figure 11: Displacement Against Load for Rack Mechanism

Figure 11 displays the graph of displacement against load for rack mechanism. The graph is plotted directly proportional. The data is nearly the same according to its materials. Steel indicates the lowest displacement travel when load is put on it. The line looks overlap since there is no difference in the same materials and only differ by 0.01 mm. Displacement stand for changing of location of the object [14] after the load being put on it. The density of steel is the highest compare to iron and aluminum. The less the density of a material, the less strength of the material. The higher density could make smaller displacement of the object because the object is strong enough to hold the force. The displacement between steel with pins joining method is smaller than aluminum with bolts and nuts joining method because the force is added by weight of joining is less. Pins is obviously having lighter weight compare to bolts and nuts since the size is already smaller.

3.3 Strain

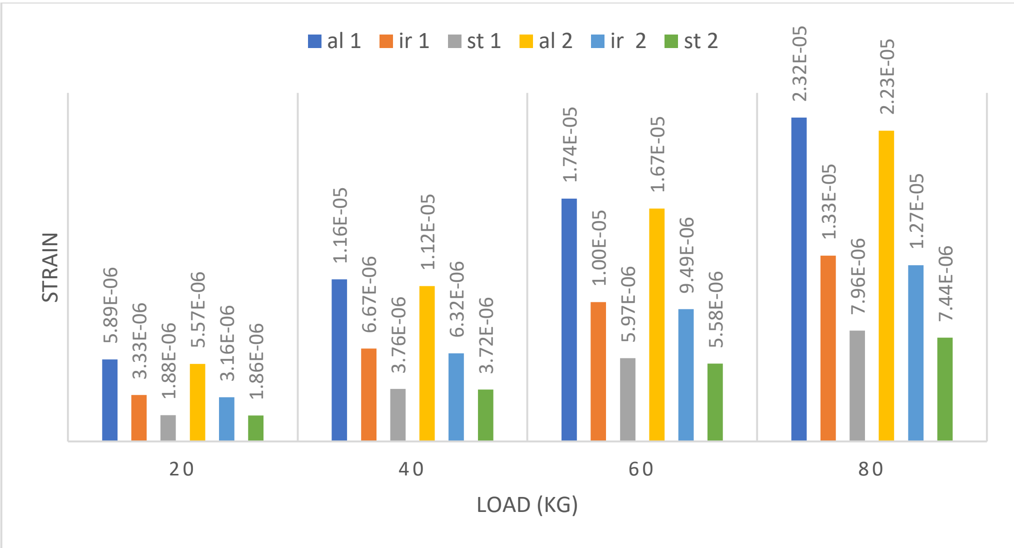

Figure 12: Strain Against Load for Gear Mechanism

Figure 12 depicts a graph of strain data for the gear mechanism. The graph is plotted directly proportional. Aluminum recorded the highest strain value among other materials with 2.32×10^{-5} for aluminum with bolts nuts and washers. Iron plotted in the middle between steel and aluminum in the graph. Strain can be defined as deformation of a solid due to stress [13]. Since the stress data for all variances are nearly the same, there are a big difference in the material's yield strength. Yield strength is the maximum stress that can be applied before it begins to change shape permanently [15]. Steel used as materials in this simulation has yield strength of 710.000 MN/m². While iron used has yield strength 551.485 MN/m² and for aluminum is 27.500 MN/m². This shows that steel has larger yield strength compared to iron and aluminum. Therefore, steel has less strain value compare to iron and aluminum since steel is difficult to deform.

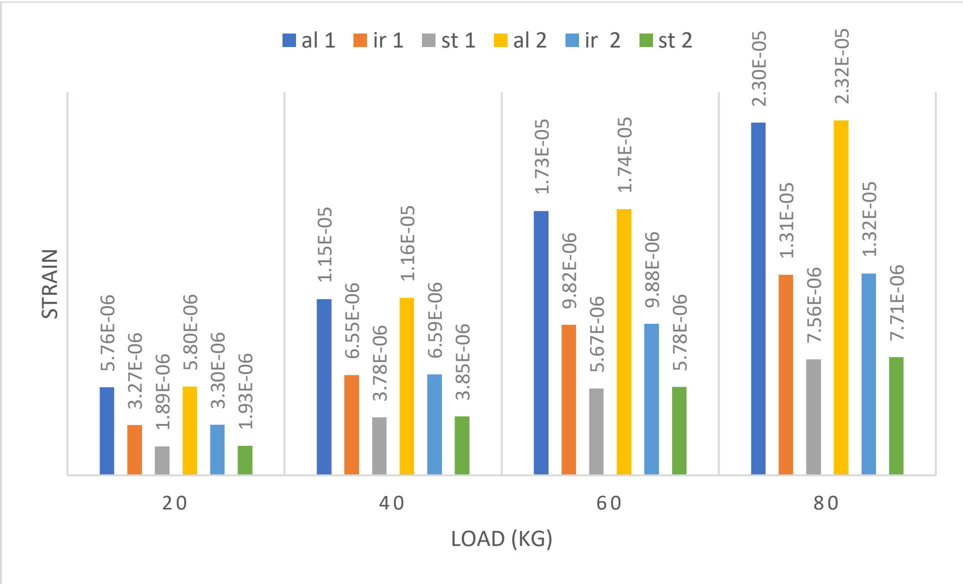

Figure 13: Strain Against Load for Rack Mechanism

Figure 13 shows the graph of strain data for rack mechanism. The graph is directly proportional. As for the maximum load attached to it, the strain value is 7.71×10^{-6} for rack mechanism and $7.56\times10^{-6}$for gear mechanism. The value is nearly the same according to materials but has big differences compared to other materials. The line plotted look overlap since the difference value is less among the same materials. Strain can be defined as deformation of a solid due to stress [13]. Since the stress data for all variances are nearly the same, there are a big difference in the material's yield strength. Yield strength is the maximum stress that can be applied before it begins to change shape permanently [15]. Aluminum used as materials in this simulation has yield strength of 27.5MN/m². While iron used has yield strength 551.485MN/m² and for steel is 710MN/m². This indicates that aluminum has smaller yield strength compared to iron and steel. Therefore, aluminum has more strain value compare to iron and steel since aluminum is easy to deform.

4. Conclusion

In conclusion, this research was done using Solidworks 2018 to design the convertible booster seat mechanism. The strength analysis also used the Solidworks simulation 2018. The mechanism's sizing is referred to as Perodua Myvi middle rear seat as references and validated by simulating the variance at various loads attached on it. The simulations were intended to compare the strength of design mechanisms. The stress concentration, displacement and strain are recorded in the simulations.

The result of the simulation shows that steel is the highest strength obtain when loads are put on it compare to iron and aluminum. But for the displacement and deformation, steel recorded the lowest vice versa to aluminum. The analysis indicates that steel with pin joining method and gear mechanism is most suitable and effective for a booster mechanism. Even though the stress is the second highest among other variance, the displacement and strain are the lowest. The joining method selected is the pin. The pin has less mass that causes it to give less force to the mechanism compare to bolts and nuts. The material selected is steel which makes the mechanism stronger than iron and aluminum. The proper way to apply the load is needed to be determined in the simulation for future research recommendation. The challenge with this study is the hardware itself. Computer with appropriate specifications is very important to run the simulation; otherwise, it will be time-consuming or cannot be running. The diameter for the pin also needs to increase as to make the joining method stronger so that it can afford more force.

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