

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**DESIGN AND DEVELOPMENT OF MONO-BLOCK
COMPOSITE STRUCTURE TO REDUCE WEIGHT OF THE
CONVENTIONAL BUS BODY**

TANSEL AKSOY
A THESIS SUBMITTED FOR THE DEGREE OF
MASTER OF SCIENCE
DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING

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ASSOC. PROF. DR. AHMET SİNAN ÖKTEM

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T.C.
GEBZE TEKNİK ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

KONVANSİYONEL OTOBÜS
GÖVDELERİNDE AĞIRLIK AZALTMAK
İÇİN MONO-BLOK KOMPOZİT YAPI
TASARIMI VE GELİŞTİRİLMESİ

TANSEL AKSOY
YÜKSEK LİSANS TEZİ
MALZEME BİLİMİ VE MÜHENDİSLİĞİ ANABİLİM DALI

DANIŞMANI
DOÇ. DR. AHMET SİNAN ÖKTEM

GEBZE
2019

GEBZE TEKNİK ÜNİVERSİTESİ	YÜKSEK LİSANS JÜRİ ONAY FORMU
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GTÜ Fen Bilimleri Enstitüsü Yönetim Kurulu'nun 03/07/2019 tarih ve 2019/30 sayılı kararıyla oluşturulan jüri tarafından 17/07/2019 tarihinde tez savunma sınavı yapılan Tansel AKSOY'un tez çalışması Malzeme Bilimi ve Mühendisliği Anabilim Dalında YÜKSEK LİSANS tezi olarak kabul edilmiştir.

JÜRİ

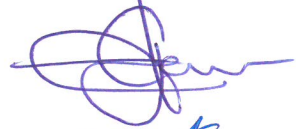
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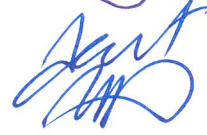
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SUMMARY

Main scope of this thesis is to present advantages of composite materials with their application examples and detailed structural analyses of the MonoBlock carcass structure compared to the conventional old carcass model in the frame of calculated and defined load cases. These structural analyses are completed on a commercial software that uses finite element method.

Under the defined load cases, structural analyses of the MonoBlock carcass structure and the conventional old carcass model have been concluded with two different materials (structural steel and e-glass) and different stack-up models.

First analysis set-up was modelled with structural steel material for the conventional old carcass structure under the defined load cases. The following analysis models are for the MonoBlock composite structure with e-glass composite material prepared with different angled layers under the same load cases.

It has been observed that, the distribution of the stress and the total deformation results on carcass structures are relatively high on the conventional old carcass model compared to the MonoBlock carcass structure and using MonoBlock composite structure is cost efficient and time saving due to lower prices of parts and high production rate of composites.

Key Words: Composite Materials, Finite Element Analysis of Composite Structures, Finite Element Analysis Comparison.

ÖZET

Bu tezin ana amacı, kompozit malzemelerin avantajlarını örneklerle göstermek, belirlenmiş ve hesaplanmış yükler altında geleneksel karkas yapısının MonoBlock karkas yapıya kıyasla detaylı sonlu elemanlar analiz sonuçlarını karşılaştırmaktır. Bu yapısal analizler, sonlu elemanlar yöntemi kullanan ticari bir yazılım ile tamamlanmıştır.

İki farklı malzeme (yapısal çelik ve cam fiber) ve farklı fiber serim açıları için, belirlenmiş yük koşulları altında MonoBlock ve geleneksel karkas yapılarının sonlu elemanlar analizleri sonuçlandırılmıştır.

İlk analiz modeli eski geleneksel karkas modeli için yapısal çelik malzeme ile belirlenmiş olan yük koşulları altında modellendi. Takip eden analiz modelleri ise farklı açılarda hazırlanmış olan cam fiber malzemeden yapılma kompozit MonoBlock yapısı için aynı yük koşulları altında modellenmiştir.

Analiz sonuçlarından yapılan çıkarımlara göre, gerilme ve toplam deformasyon sonuçları, geleneksel karkas yapısında MonoBlock karkas yapısına kıyasla daha yüksek çıkmıştır ve MonoBlock kompozit yapısının kullanımı, düşük maliyetli ve yüksek üretim hızından dolayı zaman kazandırıcıdır.

Anahtar Kelimeler: Kompozit Malzemeler, Kompozit Yapıların Sonlu Elemanlar Analizleri, Sonlu Elemanlar Analizi Karşılaştırması.

ACKNOWLEDGEMENTS

I would like to express my deep and sincere gratitude to my supervisor, mentor and also a good friend Assoc. Prof. Dr. Ahmet Sinan ÖKTEM, who not only shared his profound scientific knowledge with me but also taught me great lessons of life. His support, suggestions and encouragement gave me the drive and will to complete this work.

I wish to express my warm and sincere thanks to Anadolu ISUZU R&D team, specially to people who shared their experience and knowledge, but most important their precious time for this project. I would like to thank individually to Arif ÖZER, Cengizhan BİLGİN, Emre İLERİ, Hayri EREN as my director, managers and supervisors for their guidance and suggestions.

I am grateful to my family for their love and support.

Finally, I want to thank Nazenin GÜRE, who showed me the art of humanity, love and kindness and for her immortal friendship.

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LIST of ABBREVIATIONS and ACRONYMS

<u>Abbreviations</u> <u>and Acronyms</u>	<u>Explanations</u>
σ	: Stress, MPa
τ	: Shear Stress, MPa
E	: Elastic Modulus, MPa
ε	: Strain, mm/mm
ρ	: Density, ton/mm ³
F	: Force, N
t	: Thickness, mm
L	: Length, mm
%	: Percent
Kg	: Kilograms
FEM	: Finite Element Model
FEA	: Finite Element Analysis
OEM	: Original Equipment Manufacturer
NABI	: North American Bus Industries
GTU	: Gebze Technical University
IRF	: Inverse Reserve Factor
LC	: Load Case

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1. INTRODUCTION

The usage of composite materials in different industry fields such as transportation, marine, aerospace, defense industries, is increasing due to durability, strength, stiffness and low-weight properties of composites [1].

In transportation, including the automotive industry, weight is one of the most important parameters [2]. A higher weight means more energy to travel distances. Since resources are not infinite in our planet, alternative options for traveling have been started for lowering the costs [3]. Reducing the weight of the transporting vehicles is one of the alternative options.

Composite materials are widely used in transporting since their properties are more suitable for most of the transportation industry. Composites are the materials that can provide the same strength and rigidity with extra damage absorbing ability that structural steel materials can [4]. These properties of composites can differ due to the scope and the purpose of the application field and the manufacturing process [5].

In the automotive industry, designs of the transportation vehicles are changed first to fuel conservation but, the incapacibilities of revisioning the designs start to lead the industry to change materials. The importance of the composite applications for the automotive industry is increasing and composite materials being widely used in transportation vehicles since the composite materials have lower density, faster manufacturing process, and better corrosion resistance compared to steel materials [1].

The weight reduction and increasing the rate of the manufacturing process by keeping the same strength of the materials are the starting point of the composite MonoBlock carcass structure [6]. As a result of having low weight, fuel consumption and the emission rate of the carbon dioxide of the vehicles will decrease [5].

The MonoBlock structure consists of two parts, inner and outer blocks. The details inside of the vehicle (such as glovebox, instrument and dashboard panel, inner trims, etc.) are included in inner block and the rest of the outer parts (such as vehicle body, vehicle headlights, engine hatch, and hood, etc.) are in the outer block part of the MonoBlock structure.

The definition of a composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and the other constituent

that is embedded in is called the matrix. The reinforcing phase material may be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous. Examples of composite systems include concrete reinforced with steel and epoxy reinforced with graphite fibers, etc. [7].

Advanced composites are composite materials that are traditionally used in the aerospace industries. These composites have high performance reinforcements of a thin diameter in a matrix material such as epoxy and aluminum. Examples are graphite/epoxy, kevlar/epoxy, and boron/aluminum composites. These materials have now found applications in commercial industries as well [7].

In many cases, using composites is more efficient. For example, in the highly competitive airline market, one is continuously looking for ways to lower the overall weight of the aircraft without decreasing the stiffness and strength of its components. This is possible by replacing conventional metal alloys with composite materials. Even if the composite material costs is higher, the reduction in the number of parts in an assembly and the savings in fuel costs make them more preferable. Reducing 0.453 kg of weight in a commercial aircraft can save up to 1360 litres of fuel per year; Fuel expenses are 25% of the total operating costs of a commercial airline [7].

Composites offer several other advantages over conventional materials. These may include improved strength, stiffness, fatigue and impact resistance, thermal conductivity, corrosion resistance, etc. [7].

In this thesis, the advantages of composite applications are presented, and as an example, detailed finite element analysis results of composite MonoBlock carcass structure and old conventional steel carcass structure are compared.

1.1. Literature Review

Composite applications in the transportation industry have been started to spread since the first full fiberglass body of first-generation Corvettes in 1953. The idea of using the glass fiber material for the body of the car was driven from the light weight design, corrosion resistance property of the structure as well as it has economical advantages for mass production [8]. Similar to this work, in 1963, a full body glass fiber vehicle idea was born in Turkey too. After years of research and hard work, in

1966, the first Turkish automobile Anadol hit the marketplace as a full body glass fiber composite vehicle, Anadol A1 [9].

Manufacturing composite structures for the transportation industry did not restrict to the automobiles of the automotive industry, besides this trend became a rising need in conventional transportation vehicles, buses. The production facility of North American Bus Industries (NABI) located in Kaposvar, Hungary, built full composite city buses from 2002 to 2013 for American cities, including Los Angeles, Phoenix, Tampa and others and in the last quarter of 2013, METYX Composites has acquired this facility of NABI [10]. These full body composite buses imported to the American cities are passed the specific series of tests prepared and subjected by the Altoona Bus Research Center [11].

Another good example of the rising demand for composite applications in bus transportation is Modulo Bus [12]. It is designed and developed by The Russian Nanotechnology Center of Composites and a Hungarian company, EvoPro Group [13]. Modular construction idea was adopted for the manufacturing and due to its modular construction, Modulo Buses are produced in different dimensions and types within the customers' need. Modulo Bus is 100% Hungarian development and the bus body made of glass fiber composite has around 20% weight reduced [13]. JEC World 2016 Innovation Award winner Modulo Bus is currently in use in Budapest [14].

Besides automotive industries, Sazcilar Automotive Industry in Turkey produces exterior and interior front bumper/driver cabin structures for railway industries [15]. Bombardier (Flexity 2-Basel) model interior and exterior composite parts are made for Austria [15].

1.2. Contributions and Scope of the Thesis

This thesis is an answer to the question of why we should use composite materials in the transportation industry.

In the past, composite structures have been used in the transportation industry in various ways and one of these ways is the automotive industry. Creating a new composite made front geometry design for old carcass structure of a conventional bus body and evaluating a finite element analysis results in this thesis, is a proof for the similar studies and works have been done so far.

The main objective of this thesis is achieving a weight reduction and simplifying the old complex design to a robust design with lowering the manufacturing costs. With less weight of the bus body, emission values and fuel consumption will decrease, the manufacturing and assembly process will be faster and due to composite material properties, composite structure will have better corrosion resistance [1]. In finite element analysis results, the old conventional carcass model and new MonoBlock composite model have been compared within the same boundary conditions and load cases. The new MonoBlock composite carcass structure is lowering the weight without compromising the strength properties of the old steel structure and the consequent objectives come with it too.

2. MONOBLOCK STRUCTURE

Anadolu ISUZU, is one of the biggest automotive OEM companies in Turkey that manufactures and provides transportation vehicles and solutions to the automotive industry not only in our country but also in foreign countries. The idea of using composite technology in their products, which is a radical decision, is the reason for compensating increasing demand in the automotive industry. This is the starting point of the MonoBlock composite structure that is compatible with most vehicle types.

Since ISUZU Citiport vehicle (Figure 2.1) has been chosen as the prototype, current situation and disadvantages of old conventional steel carcass structure can be listed as;

- The front side of the vehicle consist of metallic and plastic parts,
- These metallic and plastic parts are assembled one by one by the workers, and this affects the labor costs and manufacturing time,
- Life of the structure is being affected negatively due to the cataphoresis process which fails to penetrate the carcass structure fully for corrosion resistance,
- In carcass body structure of the vehicle, using a different variation of parts including sheet metals with different thickness instead of using standard parts,
- The increasing weight of the vehicle due to using more metallic and plastic parts.

With the current problems listed above, we can list objectives for the composite structure compatible with vehicles as;

- The main objective of the project is achieving weight reduction,
- Fuel consumption will decrease due to weight reduction,
- The production rate will increase with the reason for faster manufacturing of composites than the conventional structure,
- Since composites have corrosion resistance, cataphoresis process is no longer needed,
- Due to the high strength property of composite materials, the structure will have extra scratch and dent resistance,



Figure 2.1: Image of the Citiport vehicle.



Figure 2.2: Image of the Mono-Block imported citiport vehicle.

2.1. Parts Used In Old Conventional Body

The metallic and plastic parts used in the classic conventional carcass body are shown below (Figure 2.3, Figure 2.4).

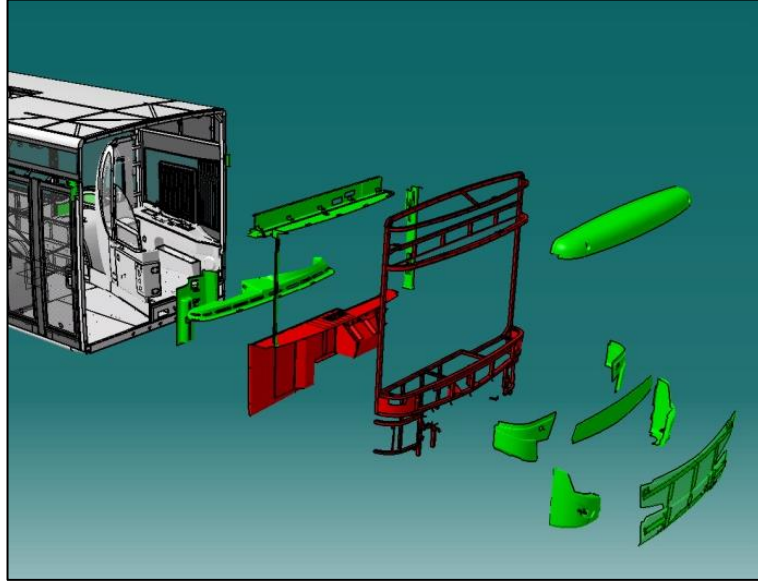


Figure 2.3: Drawings of the metallic and plastic parts in classic carcass structure.

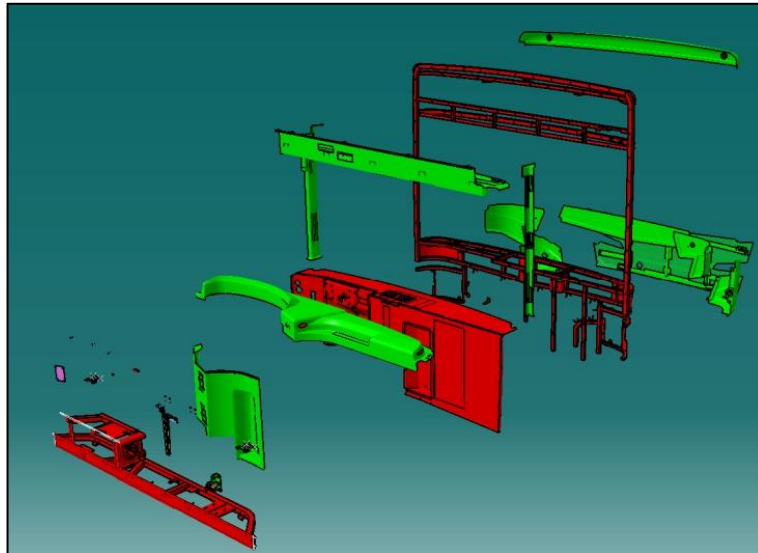


Figure 2.4: Drawings of the metallic and plastic parts in classic carcass structure.

2.2. New Monoblock Body

The new MonoBlock composite structure that will replace the metallic and plastic parts in the current conventional carcass body is shown below (Figure 2.5, Figure 2.6).

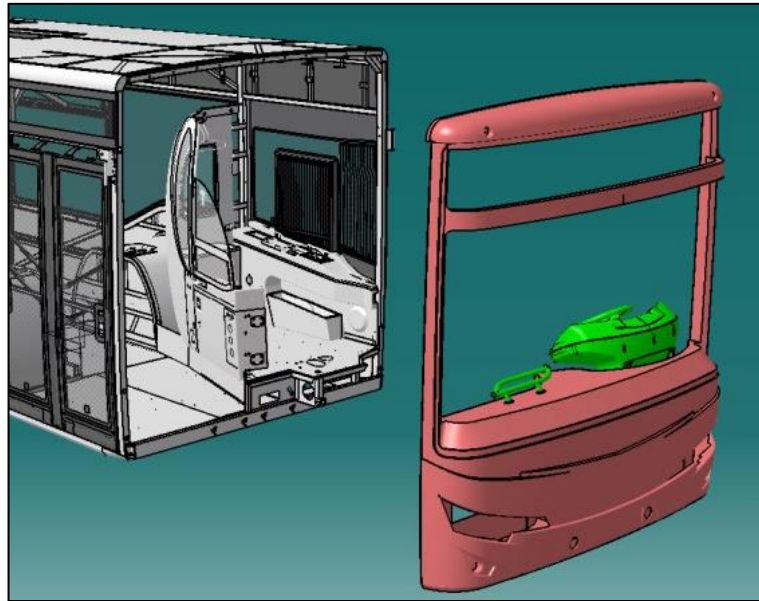


Figure 2.5: Drawings of the MonoBlock composite structure.

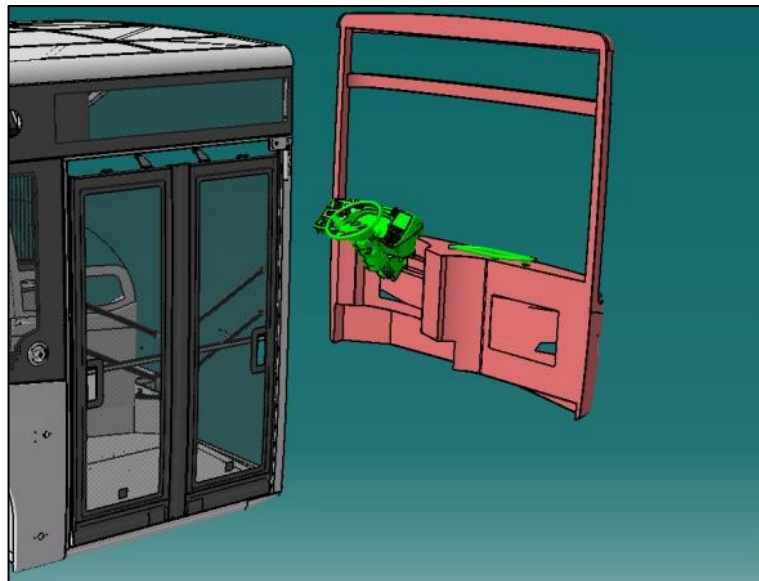


Figure 2.6: Drawings of the MonoBlock composite structure.

2.3. Advantages of Using New Composite Monoblock Structure

The main objective of changing the old classic carcass structure with a new composite MonoBlock structure is reducing the overall weight of the vehicle. The weight comparison of MonoBlock and old structure is shown in Table 2.1.

Table 2.1: Weight of the Old Carcass and MonoBlock Structures.

Name of the Complete Parts	Weight of the Parts (kg)	Weight of MonoBlock (kg)	Total Weight Reduction (kg)
Front Carcass Panel	71	109.45	110.55
Front Z Sheet Complete	50.5		
Low Front Bumper	15		
Inner Carcass Front Panel Complete	12.5		
Top Glovebox and Lower FRP	19		
FRP; Line Panel Cover	10		
ABS Left & Right A-Pillar	2		
Front Mask	40		
TOTAL	220	109.5	110.5

E-glass material (material properties are provided below) has been chosen as a composite material for the MonoBlock structure and the total weight of the MonoBlock composite carcass structure has been calculated as 109.45 kg. Since the total weight of the old carcass structure is 220 kg, almost 50 % weight reduction has been achieved.

For ISUZU Citiport vehicle, specific fuel consumption formula has been applied for both old conventional carcass model and new Mono-Block composite model. In the end of the comparison of the results of the fuel consumption datas for Citiport vehicle, with new MonoBlock structure Citiport vehicle has lower weight and this situation conserves fuel 0.075 % to 0.11 % (min and max values) by the fuel consumption formula.

The time needed for the manufacturing and the assembling processes of a conventional bus body is a lot due to the steps on this processes and to complete these processes well trained workers and engineers (men power) should work together in production line. For the Citiport vehicle on the production line, it takes around 328 mins to complete manufacturing and assembling and cataphoresis process takes around 150 mins to complete, in a total of 478 mins. As a result of the researches done for composite manufacturing and assembling to compare two different methods, for two different composite manufacturing methods (hand lay-up and RTM molding), it would have taken 8 to 25 mins to produce a prototype MonoBlock structure depending on how complex geometry it is and the manufacturing method that has been chosen. Thus, we can say that the production rate is increasing drastically comparing to the old carcass structure manufacturing and assembling process time.

For the unit prices and mold costs comparison, the budget required to produce Mono-Block composite structure is lower than the old conventional carcass structure. For the unit prices of the individual parts, Mono-Block composite structure has around 63 % and 58 % lower prices for the hand lay-up and RTM molding manufacturing techniques, respectively. For the mold costs, choosing Mono-Block composite structure is more profitable than the old conventional carcass structure since mold prices of Mono-Block are around 68 % and 61 % lower for the hand lay-up and RTM molding manufacturing techniques, respectively.

In the end of the basic comparison of MonoBlock structure and old conventional model, most of the objectives listed above are achieved so far. For the comparison of strength properties of the old and new structures can be viewed in the Analysis Results section.

3. FINITE ELEMENT ANALYSIS MODEL

Finite elements methodology is a technique that divides the model into small bodies and calculated the overall deformation and stress values. This process is called discretization [16]. The finite element model discretized into nodes and small elements and for every element and node, calculations are carried on by the system software [17]. These calculations and formulas are prepared in matrix form and the software program solves it and evaluates the results after the boundary conditions are defined to the matrix.

Finite element models of the composite MonoBlock carcass structure and the conventional old carcass model were generated according to geometry provided. Linear static analyses are performed under the defined load cases and the results are evaluated.

Analyses are executed by ANSYS v19.3 software. Ansys Mechanical, ACP pre-processor and ACP post-processor are used for pre-processing and post-processing.

3.1. Coordinate System

Model global axis convention;

- X-axis: Longitudinal axis
- Y-axis: Transverse axis
- Z-axis: Vertical axis

The global axis convention of the model is shown in figures below.

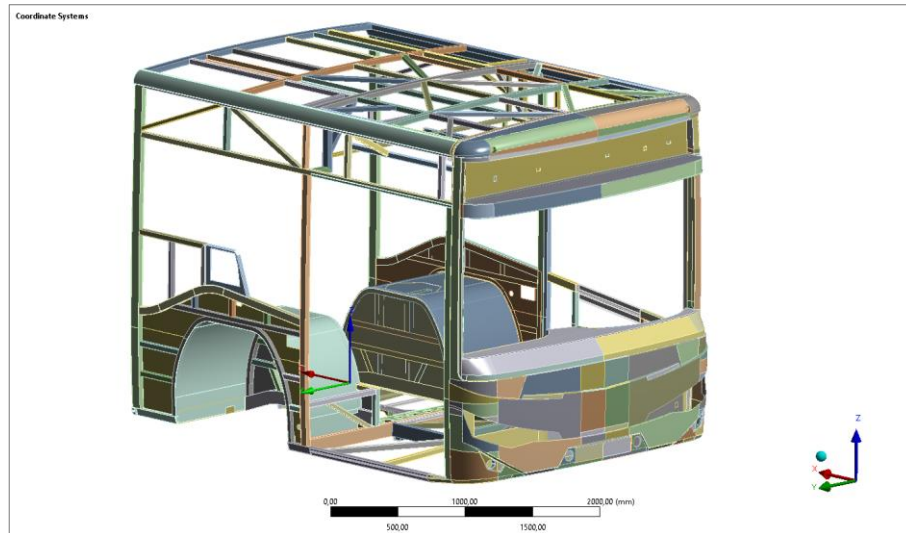


Figure 3.1: Coordinate system of the classic carcass structure.

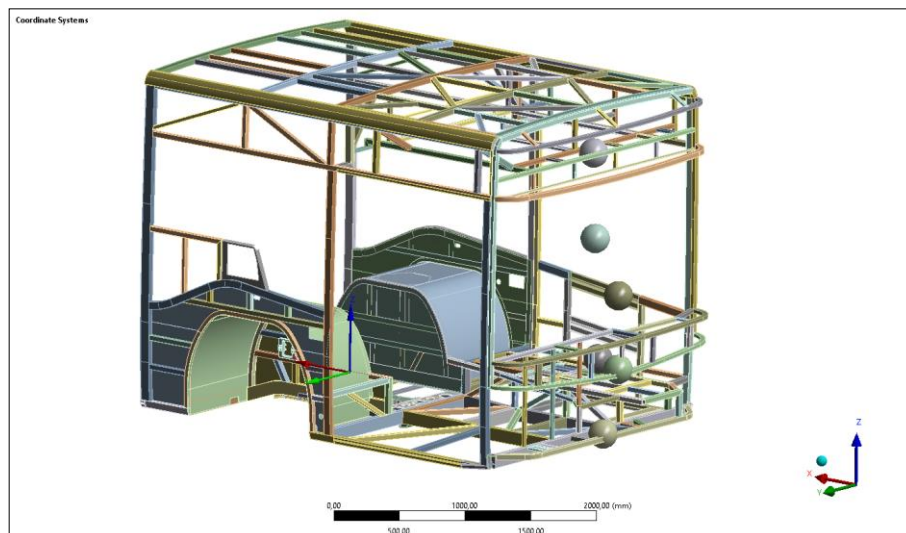


Figure 3.2: Coordinate system of the Mono-Block carcass structure.

3.2. Material Properties

Structural steel and e-glass materials are used in this analysis and ANSYS engineering data library contains these material properties. Material properties defined in the software are shown in Table 3.1 and Table 3.2. Also, the polar properties of e-glass material are shown in Figure 3.3.

Table 3.1: Material properties of structural steel.

Property	Value	Unit
Density	7850	kg.m ⁻³
Young's Modulus	2E+05	MPa
Poisson's Ratio	0.3	-
Tensile Yield Strength	250	MPa
Compressive Yield Strength	250	MPa
Tensile Ultimate Strength	460	MPa

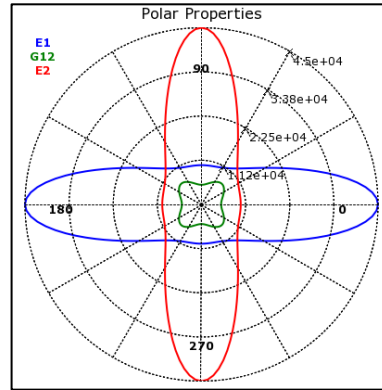


Figure 3.3: Polar properties of e-glass.

Table 3.2: E-glass material properties.

Property	Value	Unit
Density	2E-9	tonne.mm ⁻³
Young's Modulus X Direction	45000	MPa
Young's Modulus Y Direction	10000	MPa
Young's Modulus Z Direction	10000	MPa
Poisson's Ratio XY	0.3	-
Poisson's Ratio YZ	0.4	-
Poisson's Ratio XZ	0.3	-
Shear Modulus XY	5000	MPa
Shear Modulus YZ	3846.2	MPa
Shear Modulus XZ	5000	MPa
Tensile Stress Limit X Direction	1100	MPa
Tensile Stress Limit Y Direction	35	MPa
Tensile Stress Limit Z Direction	35	MPa
Compressive Stress Limit X Direction	-675	MPa
Compressive Stress Limit Y Direction	-120	MPa
Compressive Stress Limit Z Direction	-120	MPa
Shear Stress Limit XY	80	MPa
Shear Stress Limit YZ	46.154	MPa
Shear Stress Limit XZ	80	MPa

3.3. Mesh Settings

Finite element models of the MonoBlock carcass structure and the conventional old carcass model are generated by the 3D model and they consist of quadratic solid and shell elements. Shell elements are used in composite parts, solid elements are used in the rest of the model. For the MonoBlok structure, the total element number is 282365 and the total node number is 1036493. For the old conventional structure, the total element number is 257578 and the total node number is 1039026. Global FEA models of structures are given below (Figure 3.4, Figure 3.5).

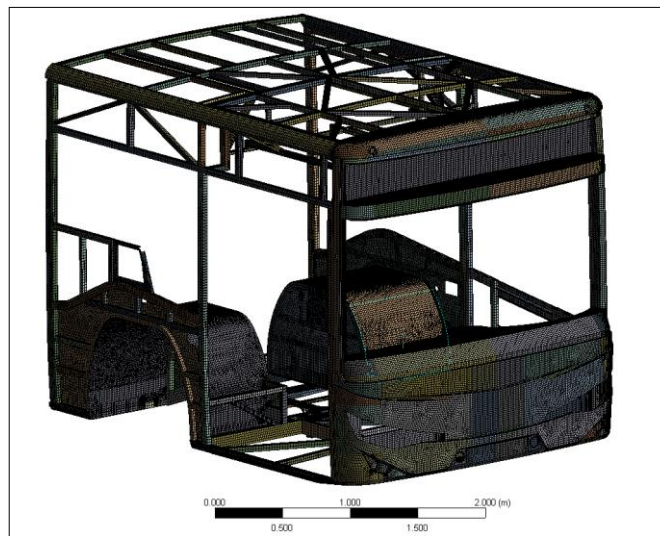


Figure 3.4: FEM of MonoBlok structure.

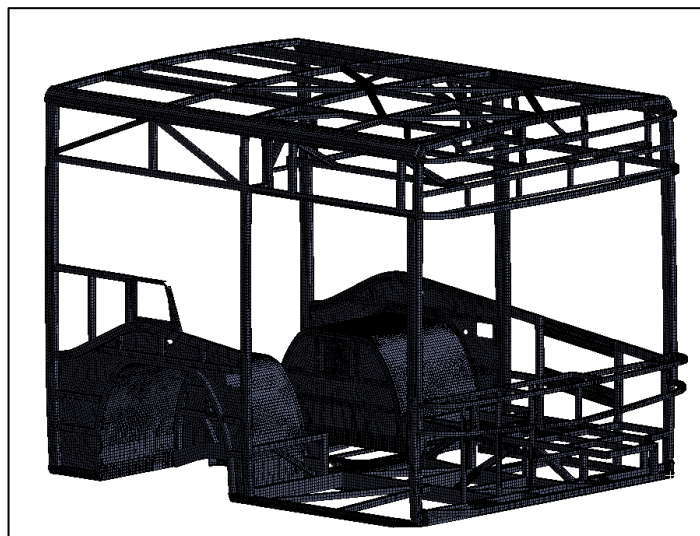


Figure 3.5: FEM of classic structure.

3.4. Composite Modelling

MonoBlock Structure is modeled with the E-Glass composite material and four different lamination options have been set. The thickness of each ply is 0.25mm and the total thickness of the structure is 4mm. As manufacturing difficulties for hand lay-up technique, fiber angles are suggested as below for the stack-up models;

- 4 stack-ups (16 layers in total): 45/-45
- 4 stack-ups (16 layers in total): 0/90
- 4 stack-ups (16 layers in total): 90/90
- 4 stack-ups (16 layers in total): 0/0

These stack-up options are applied with different angles to the structure and these modeling groups are shown below (Figure 3.6).

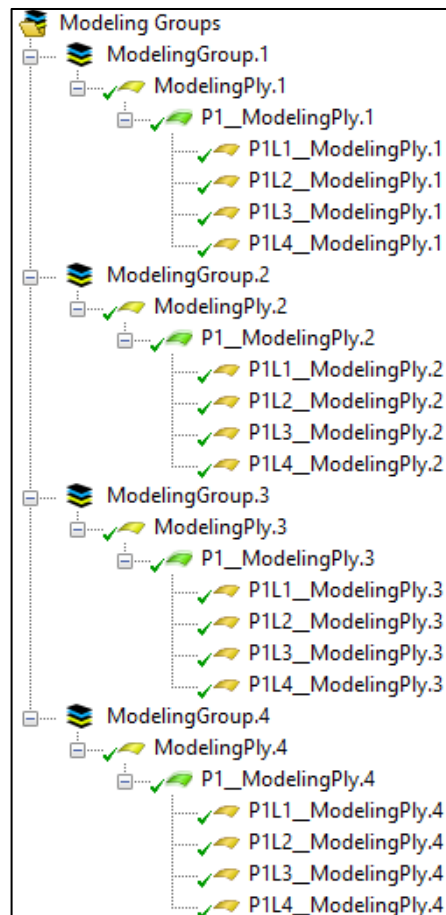


Figure 3.6: Modelling groups.

3.5. Contacts

Contact features are defined between related surfaces and bodies. One type of contact is used in the model which is **bonded contact**, and the definition of bonded contact is no penetration, no separation and no sliding between faces or edges.

3.6. Point Mass

The old conventional carcass model has point masses defined on its front mask parts since the MonoBlock composite structure has the end-design geometry data including the inner and the outer parts. To equalize the old and new carcass models in the analyses, parts implemented to the MonoBlock structure have been applied as point masses to shorten the time of the analyses. These point masses are shown in Figure 3.7. Properties of these 6 point masses are shown in table below (Table 3.3).

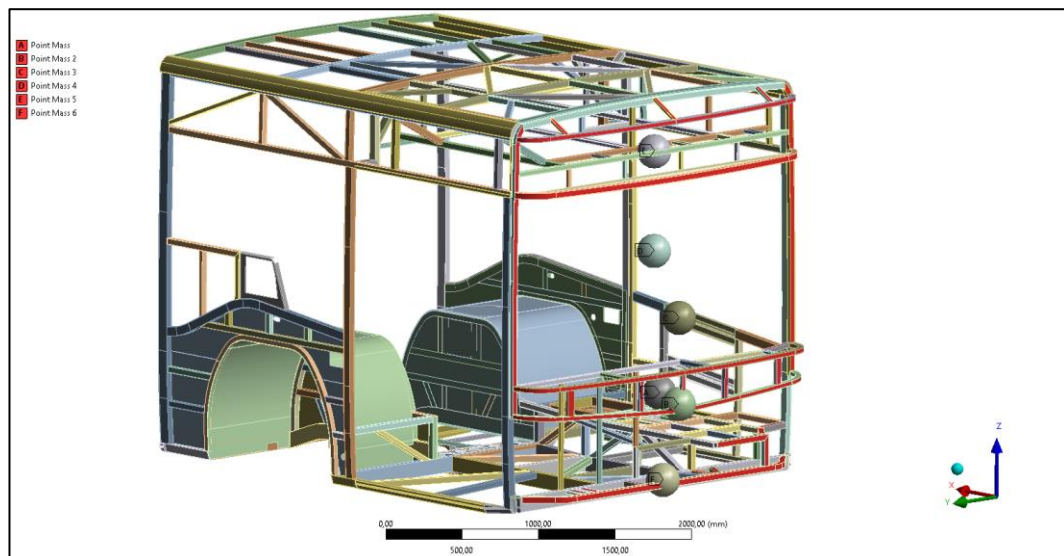


Figure 3.7: Applied point masses on old model.

Table 3.3: Properties of the point masses.

	Weight	X Coordinate	Y Coordinate	Z Coordinate
Point Mass 1	69.5 kg	-2382.3 mm	-31.59 mm	465.71 mm
Point Mass 2	12.5 kg	-2603.2 mm	-1.649E-5 mm	421.49 mm
Point Mass 3	40 kg	-2570.4 mm	-30.431 mm	985.15 mm
Point Mass 4	4 kg	-2360 mm	-3.9572E-6 mm	1405 mm
Point Mass 5	10 kg	-2251.9 mm	-100.15 mm	2039.4 mm
Point Mass 6	15 kg	-2510.7 mm	53.635 mm	-87.007 mm

3.7. Load Cases

Since a conventional bus body is subjected to external loads under the defined conditions, these conditions have been calculated and evaluated as results of concluded tests by Anadolu ISUZU R&D team.

The old conventional bus body has been developed and produced under these load cases. Thus, analyses in this document are performed under the three load cases namely which are “Bump”, “Braking” and “Cornering” cases.

These load cases are applied to both the old conventional bus model and the new MonoBlock carcass structure as an acceleration load to the whole body and fixed from the axle connection places (Figure 3.8). In addition to these load cases, an extra analysis for a load case has been performed with only gravitational force applied. Overall analyses results are compared at the end.

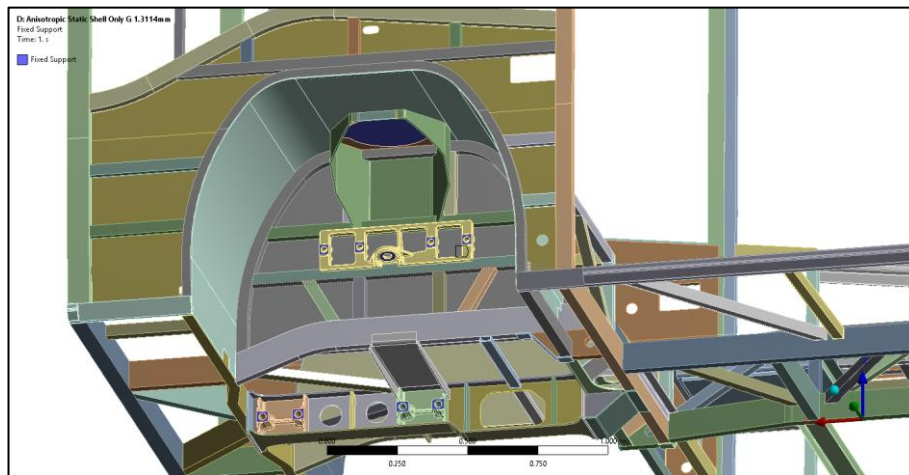


Figure 3.8: Fixed supports.

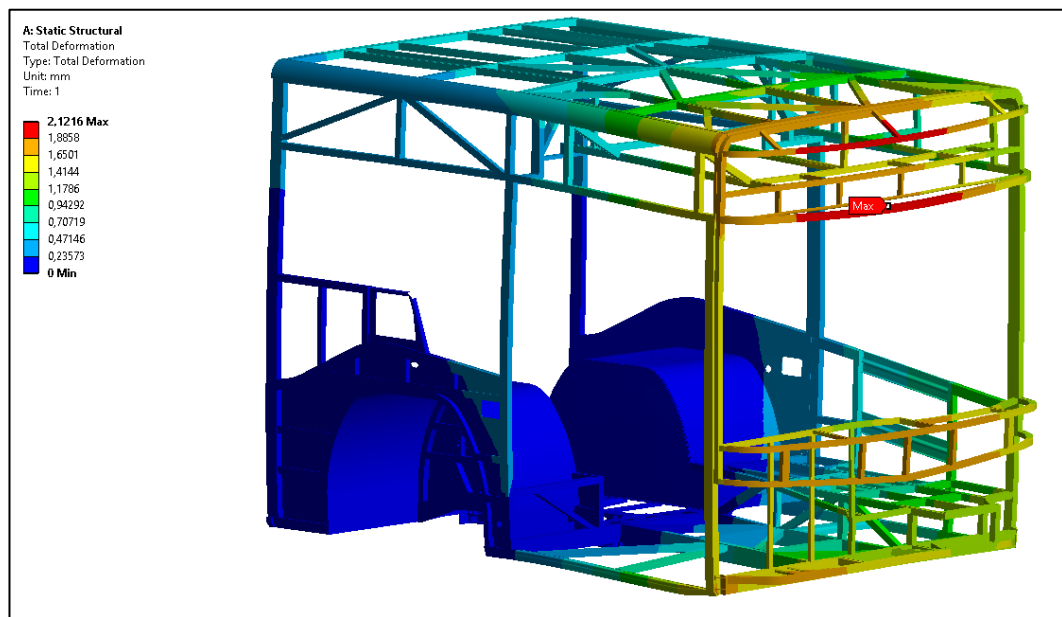
4. ANALYSIS RESULTS

Finite element analyses for the old conventional model and new MonoBlock carcass structure are performed under the defined load cases. The results are evaluated and compared below for the old and new carcass models.

4.1. Static Analysis Results for The Old Conventional Carcass Model

Linear static analyses are performed for the old conventional carcass model under the defined gravitational load and acceleration loads.

4.1.1. Load Case – Gravitational Acceleration Only



4.1.2. Load Case – Bump

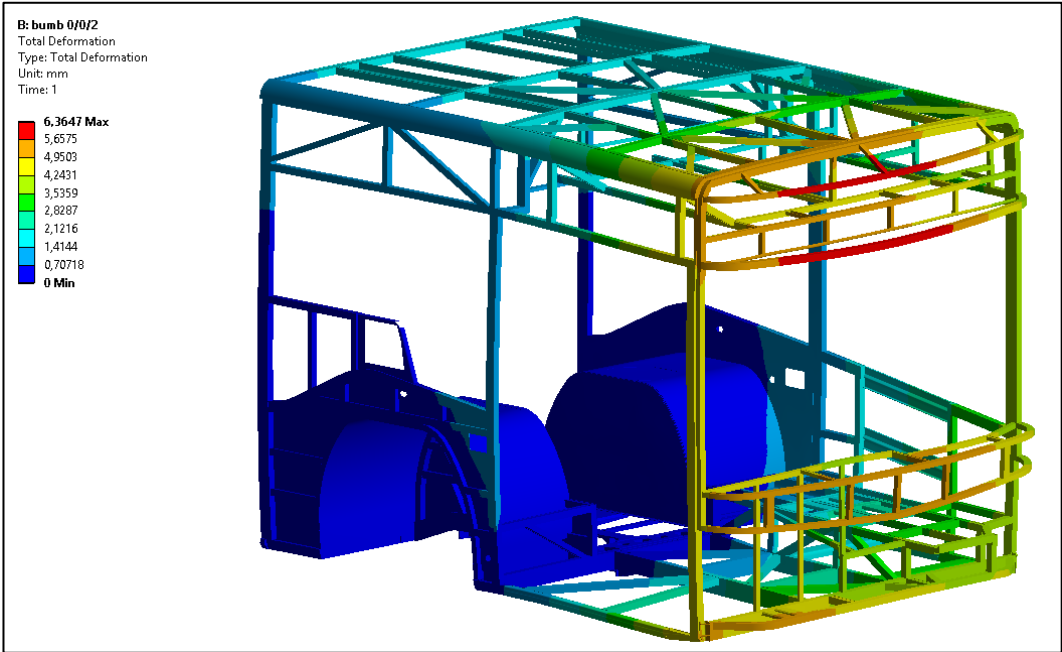


Figure 4.2: Total deformation results.

4.1.3. Load Case – Braking

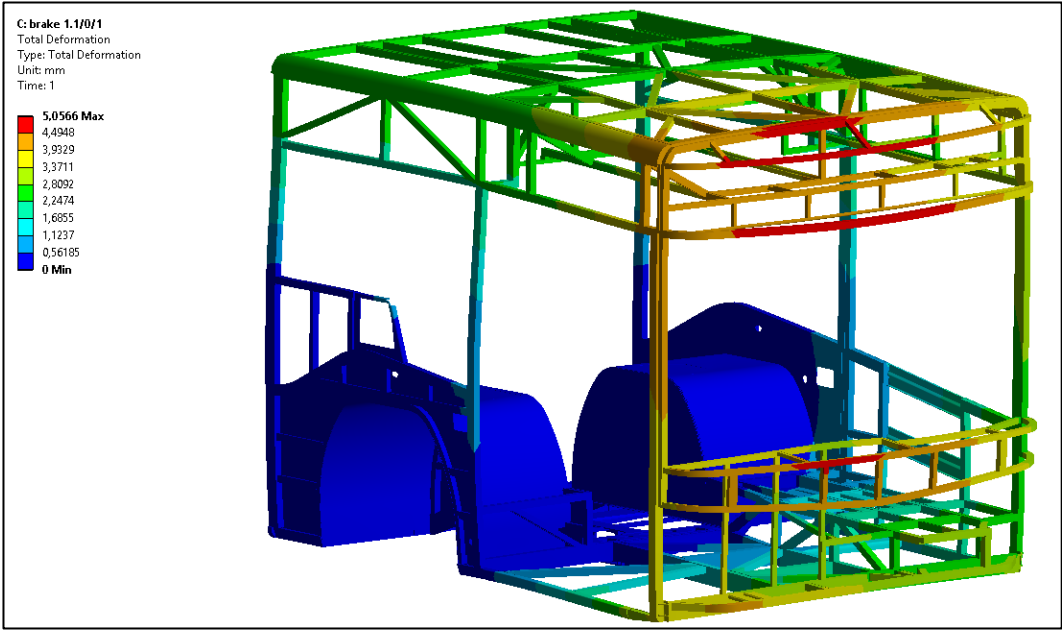


Figure 4.3: Total deformation results.

4.1.4. Load Case – Cornering

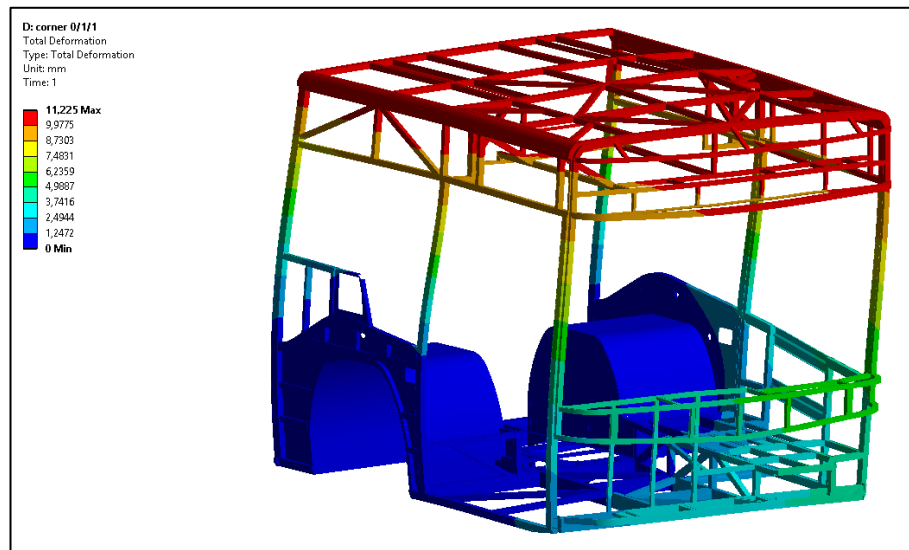


Figure 4.4: Total deformation results.

4.2. Static Analysis Results for The New MonoBlock Carcass Model

Linear static analyses are performed for the new MonoBlock carcass model under the defined gravitational load and acceleration loads.

4.2.1. Load Case - Gravitational Acceleration Only

4.2.1.1. Fiber Direction [0/0/0/0]

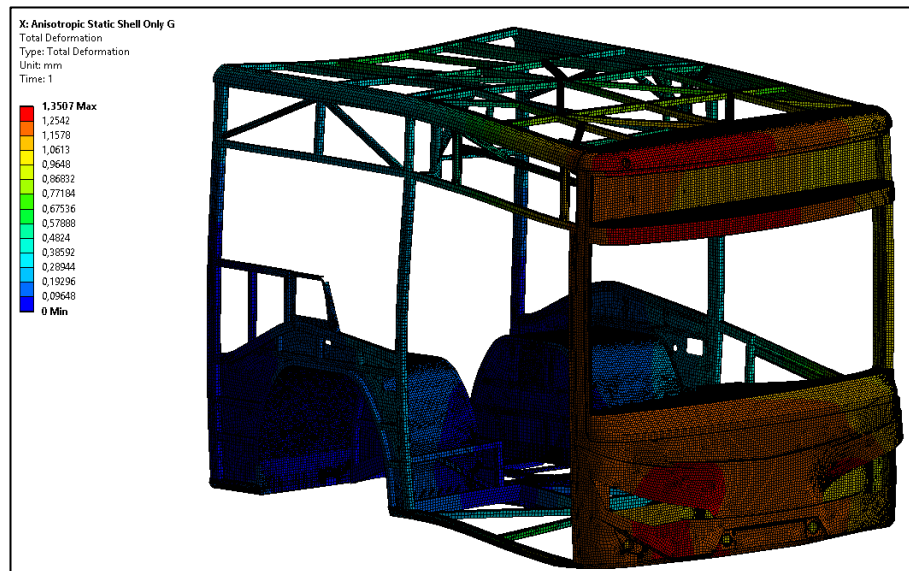


Figure 4.5: Mono-Block structure - total deformation results.

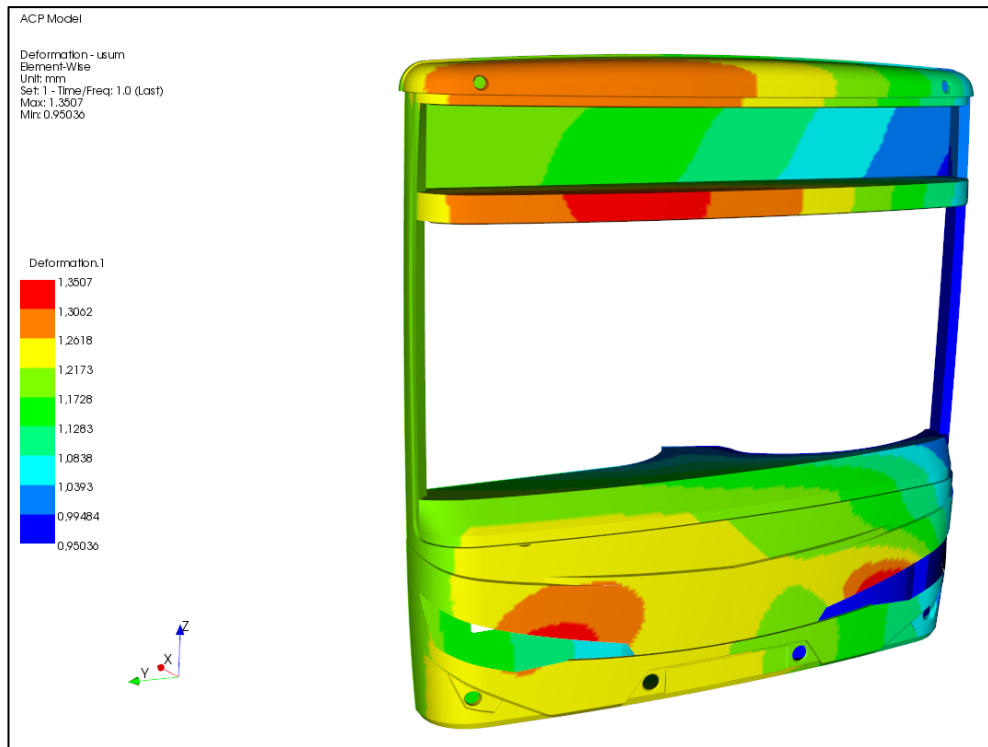


Figure 4.6: Mono-Block structure - total deformation results.

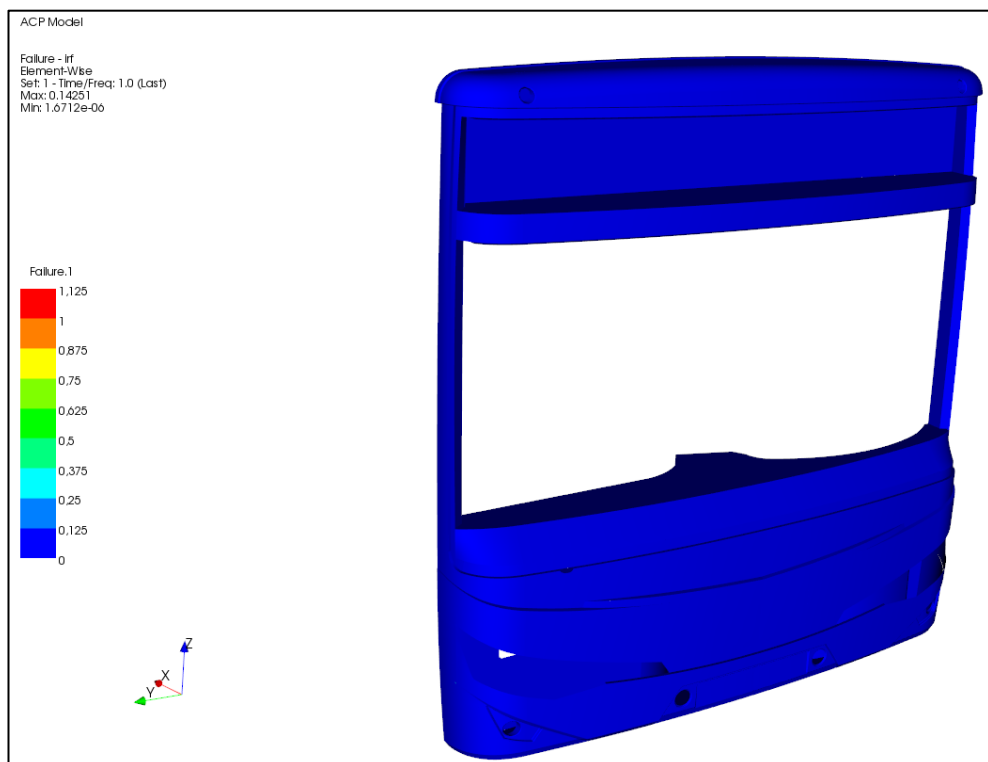


Figure 4.7: Mono-Block structure - inverse reserve factor results.

4.2.1.2. Fiber Direction [0/90/0/90]

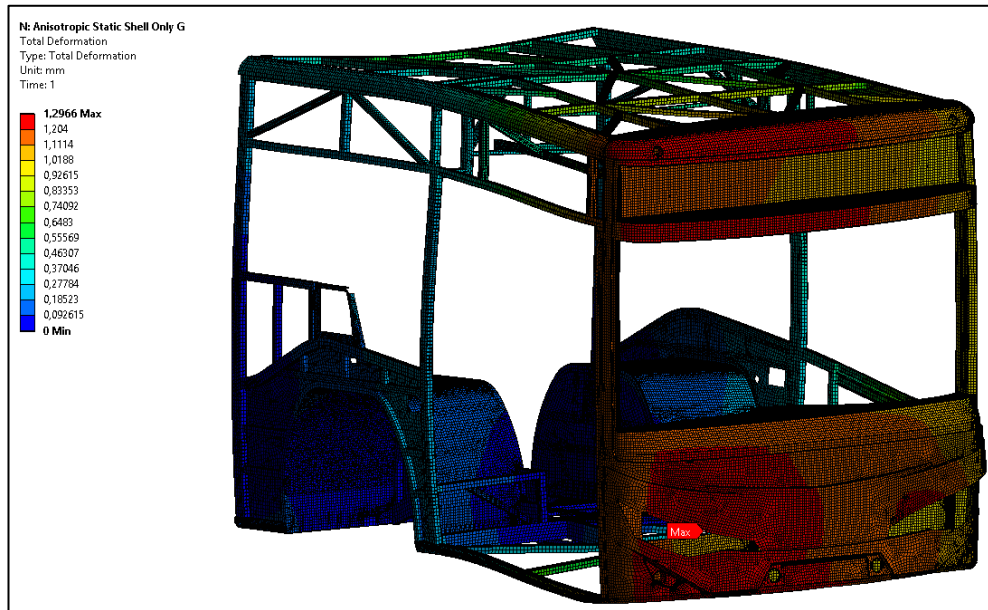


Figure 4.8: Mono-Block structure - total deformation results.

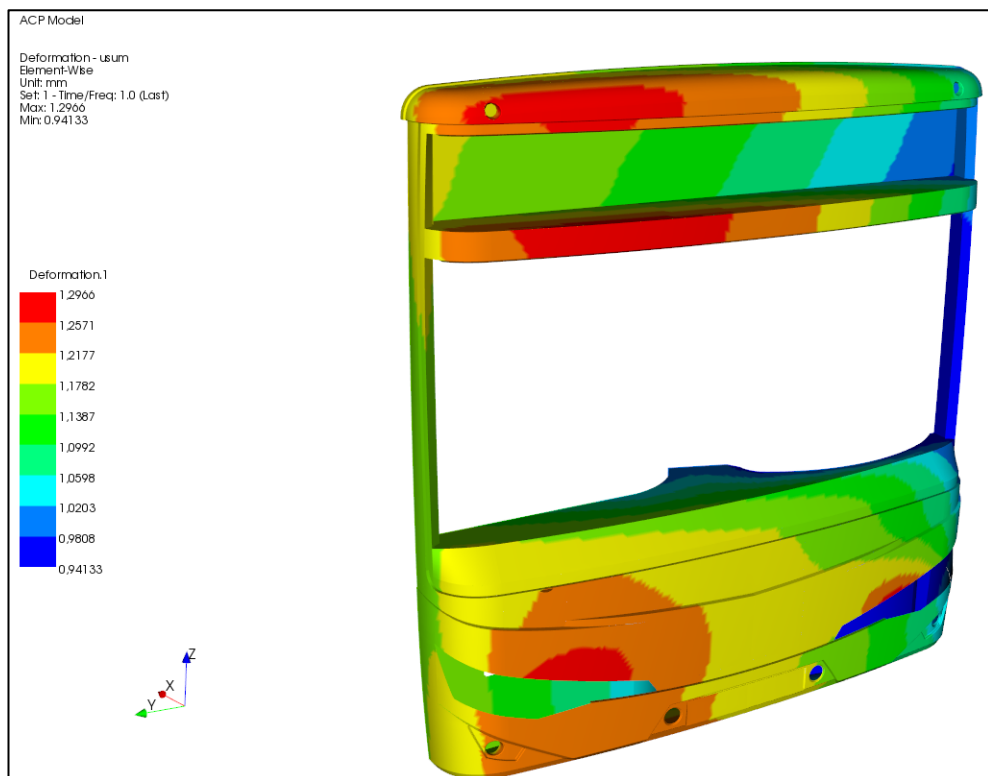


Figure 4.9: Mono-Block structure - total deformation results.

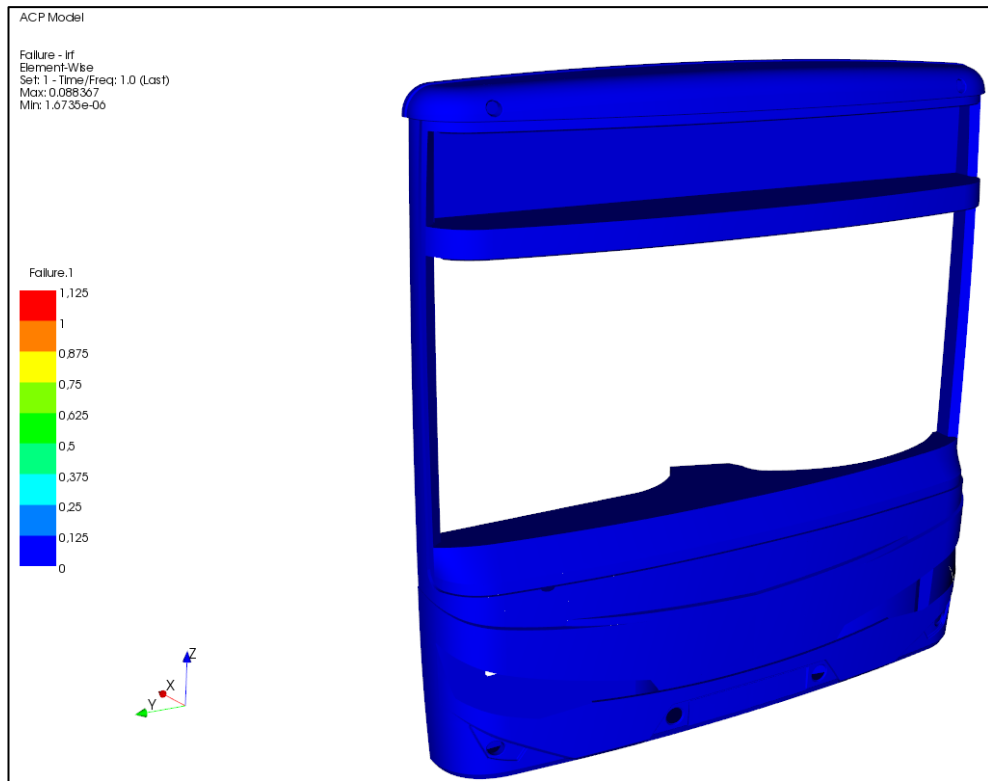


Figure 4.10: Mono-Block structure - inverse reserve factor results.

4.2.1.3. Fiber Direction [45/-45/45/-45]

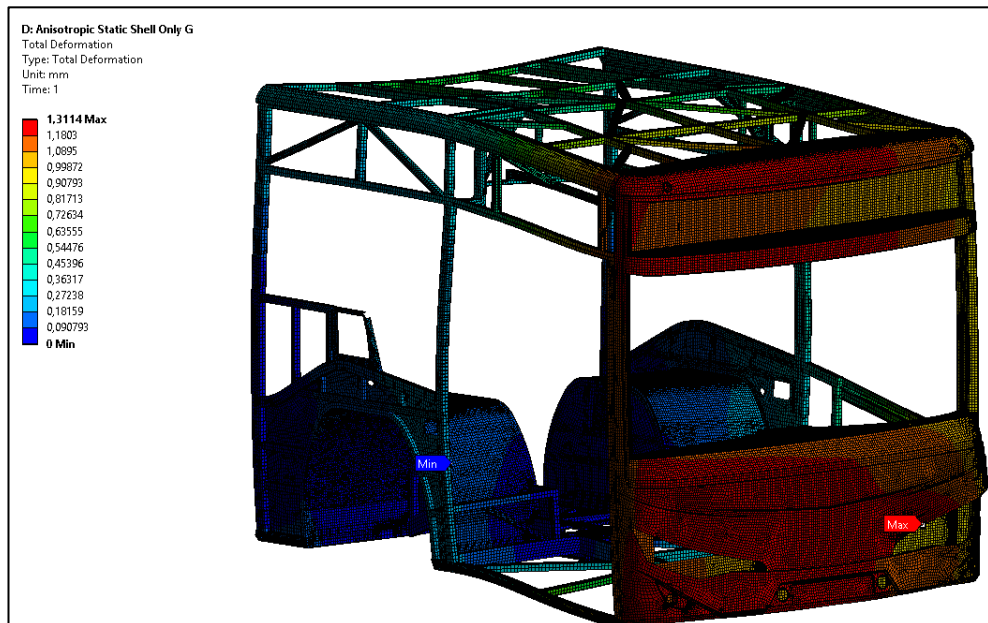


Figure 4.11: Mono-Block structure - total deformation results.

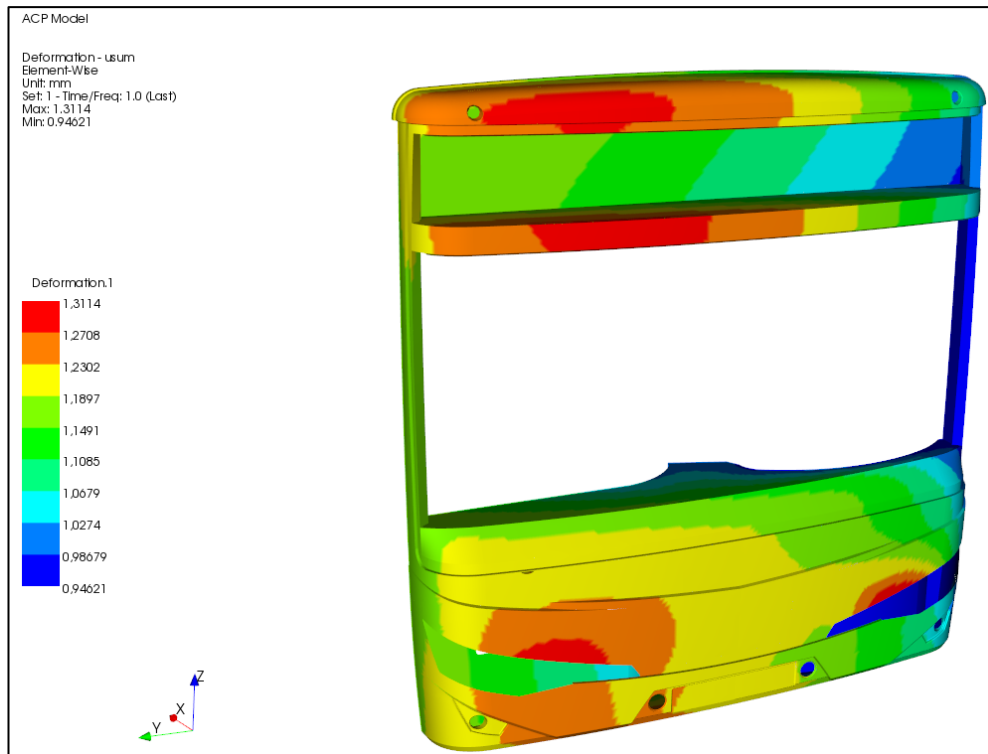


Figure 4.12: Mono-Block structure - total deformation results.

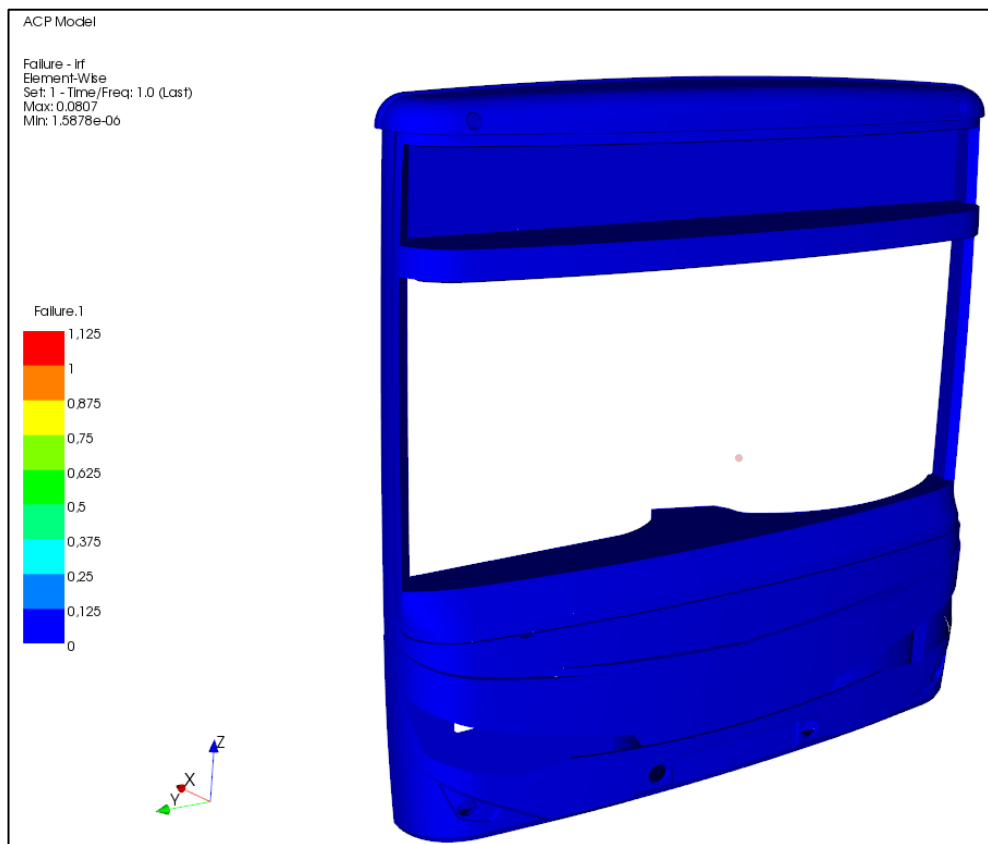


Figure 4.13: Mono-Block structure - inverse reserve factor results.

4.2.1.4. Fiber Direction [90/90/90/90]

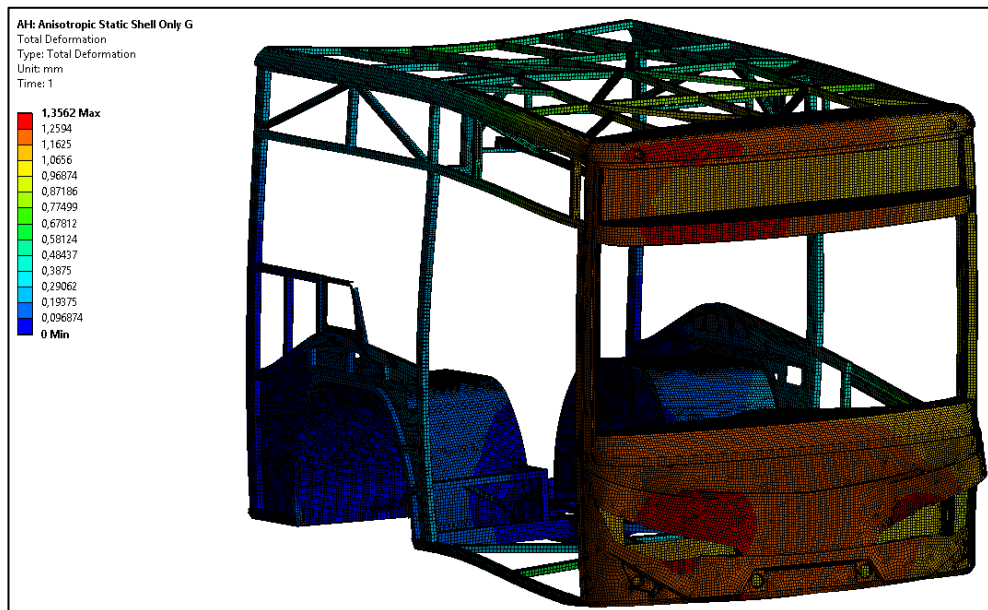


Figure 4.14: Mono-Block structure - total deformation results.

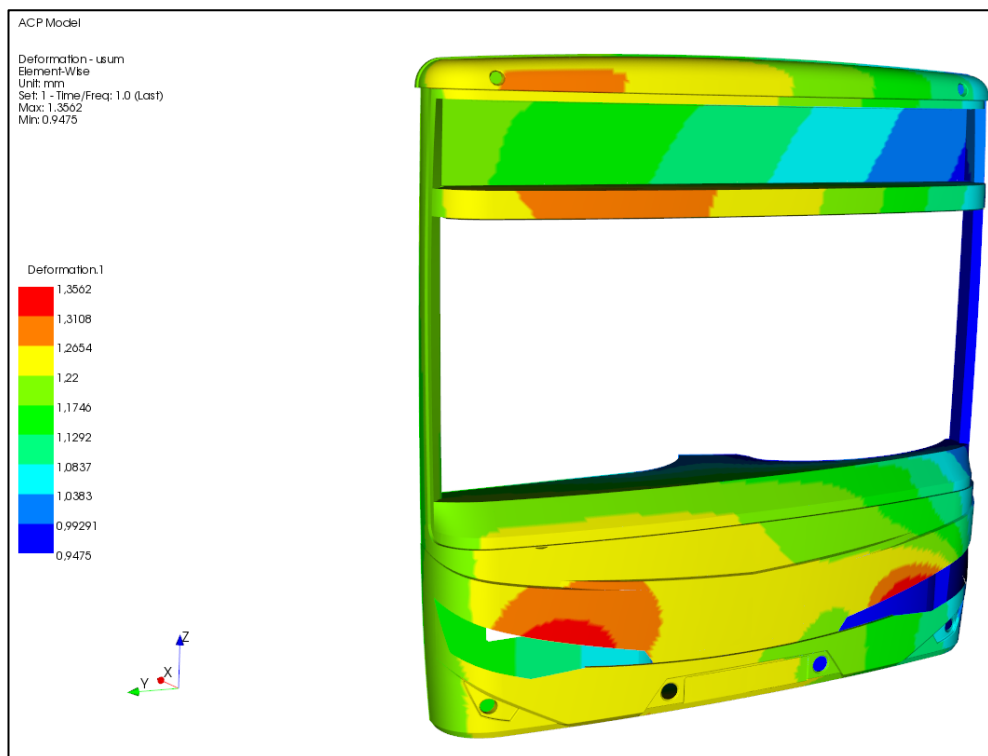


Figure 4.15: Mono-Block structure - total deformation results.

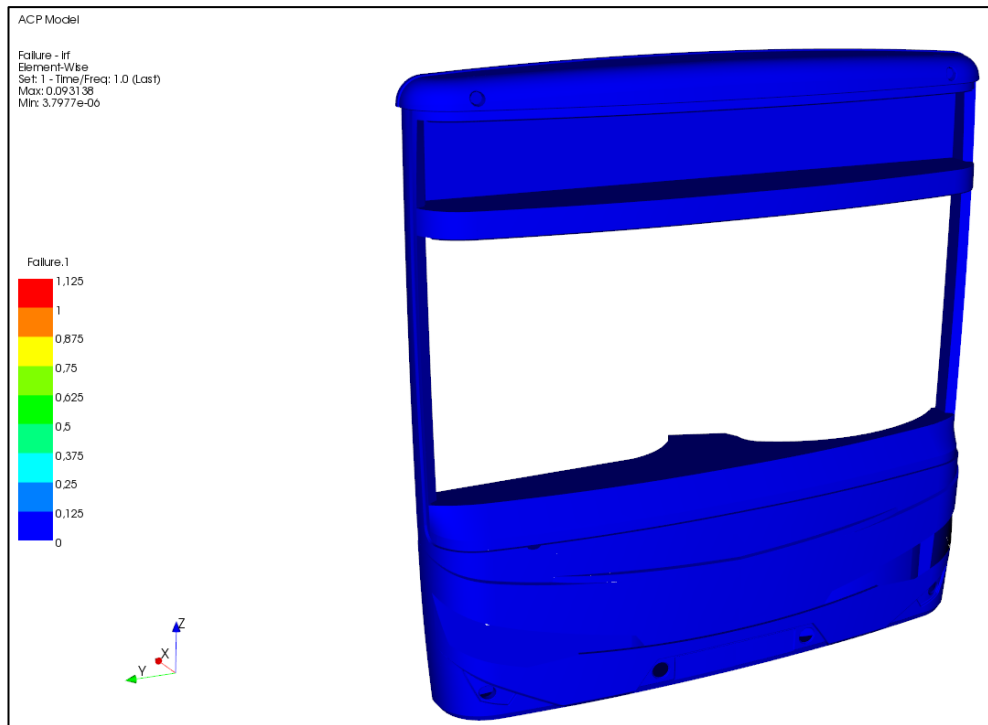


Figure 4.16: Mono-Block structure - inverse reserve factor results.

4.2.2. Load Case – Bump

4.2.2.1. Fiber Direction [0/0/0/0]

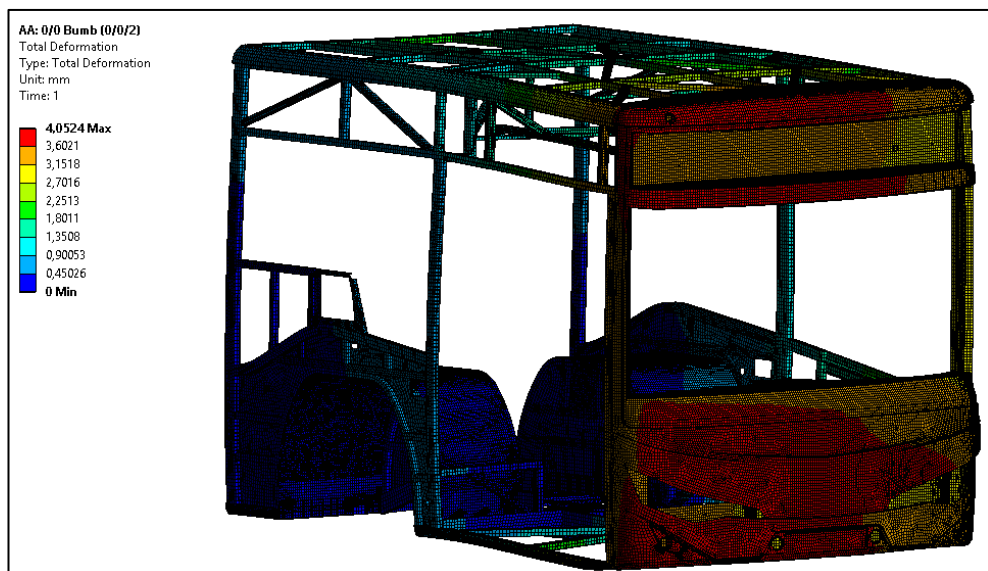


Figure 4.17: Mono-Block structure - total deformation results.

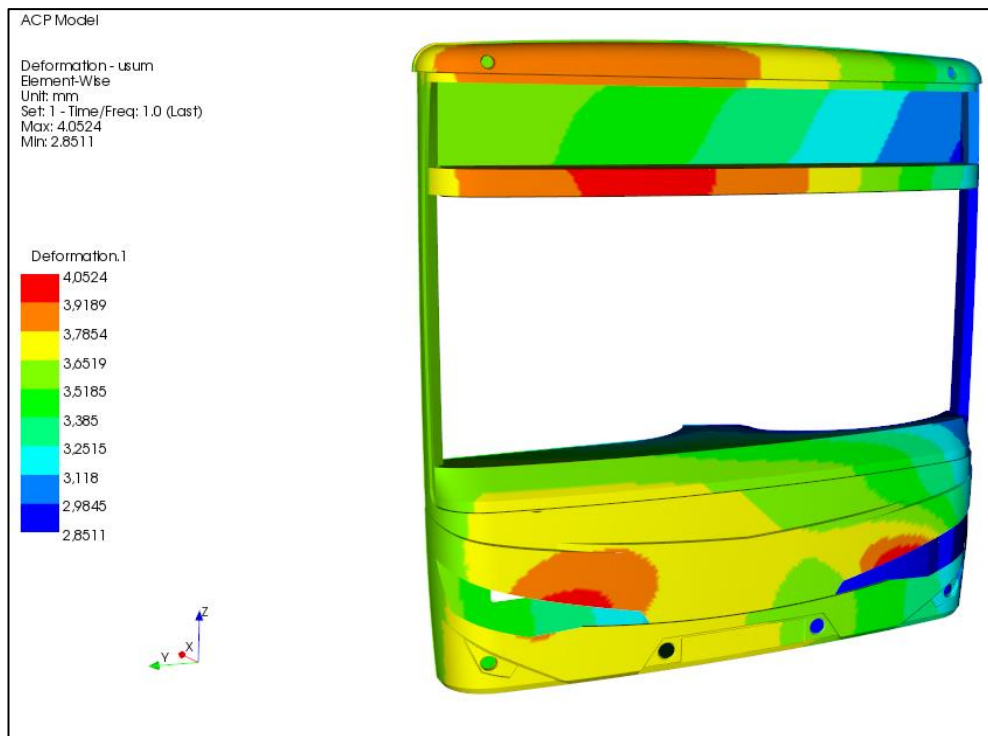


Figure 4.18: Mono-Block structure - total deformation results.

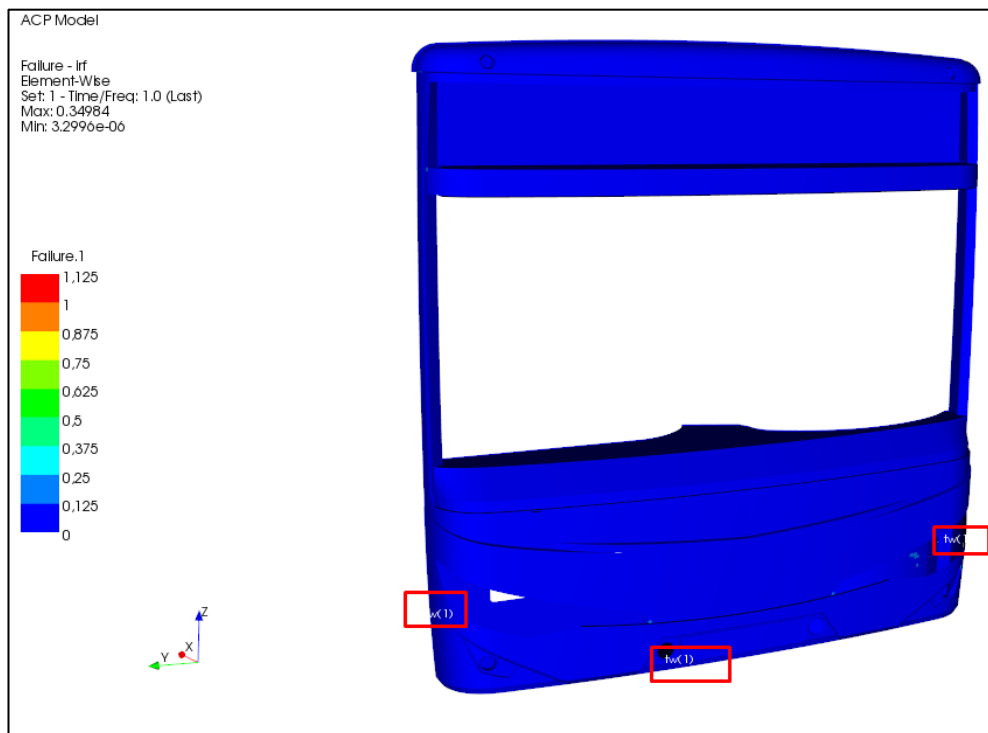


Figure 4.19: Mono-Block structure - inverse reserve factor results.

4.2.2.2. Fiber Direction [0/90/0/90]

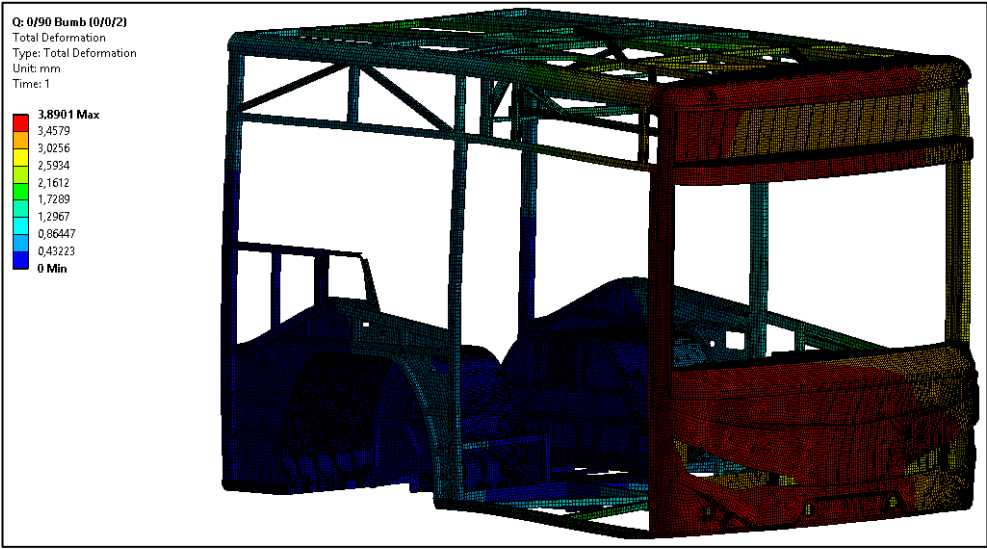


Figure 4.20: Mono-Block structure - total deformation results.

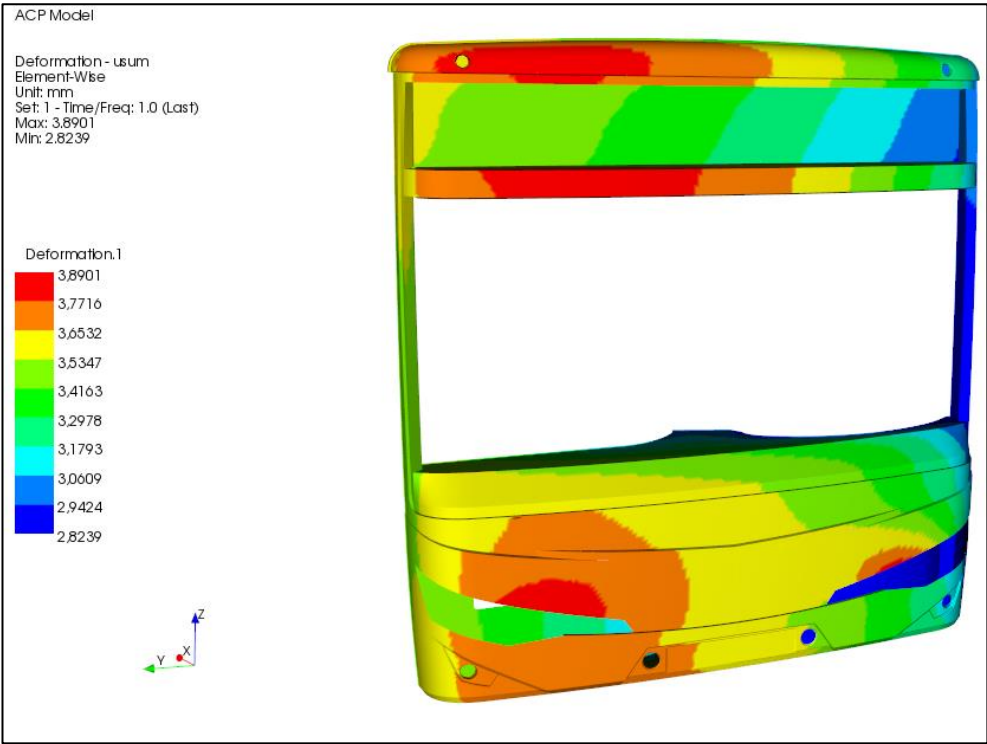


Figure 4.21: Mono-Block structure - total deformation results.

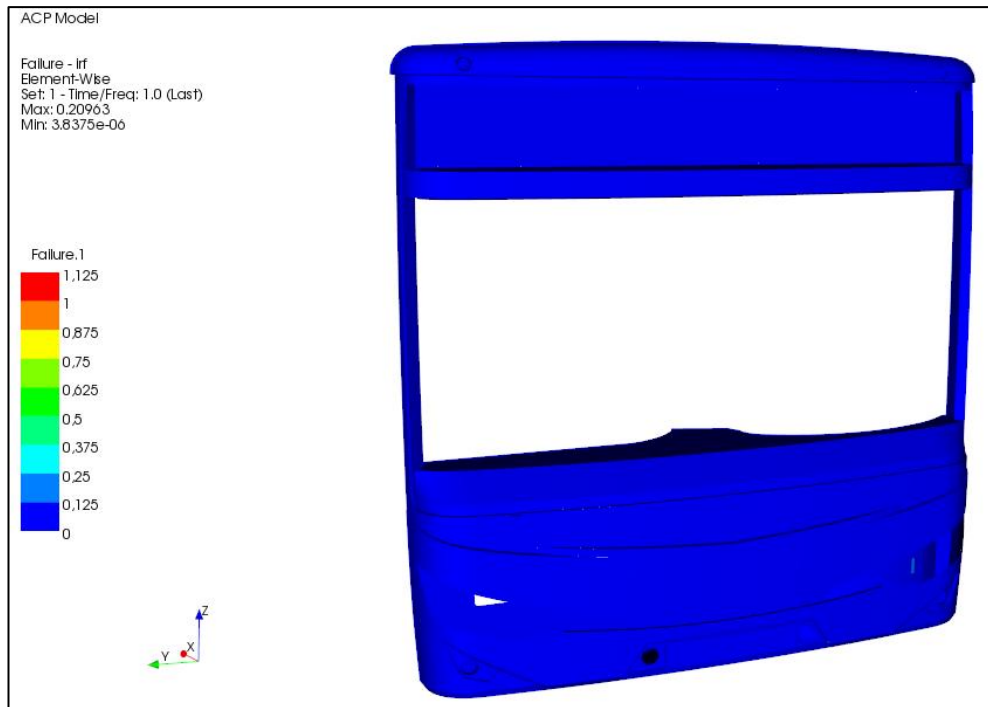


Figure 4.22: Mono-Block structure - inverse reserve factor results.

4.2.2.3. Fiber Direction [45/-45/45/-45]

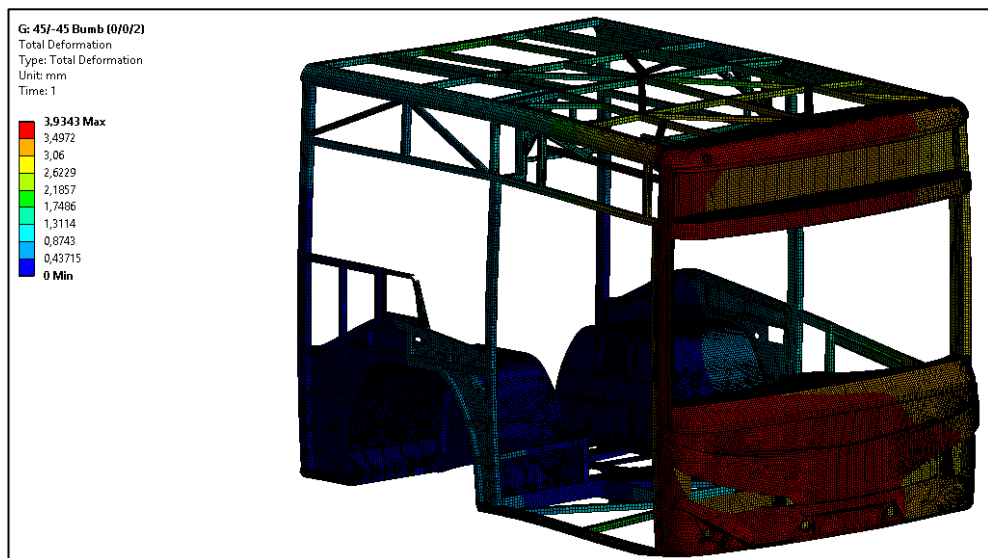


Figure 4.23: Mono-Block structure - total deformation results.

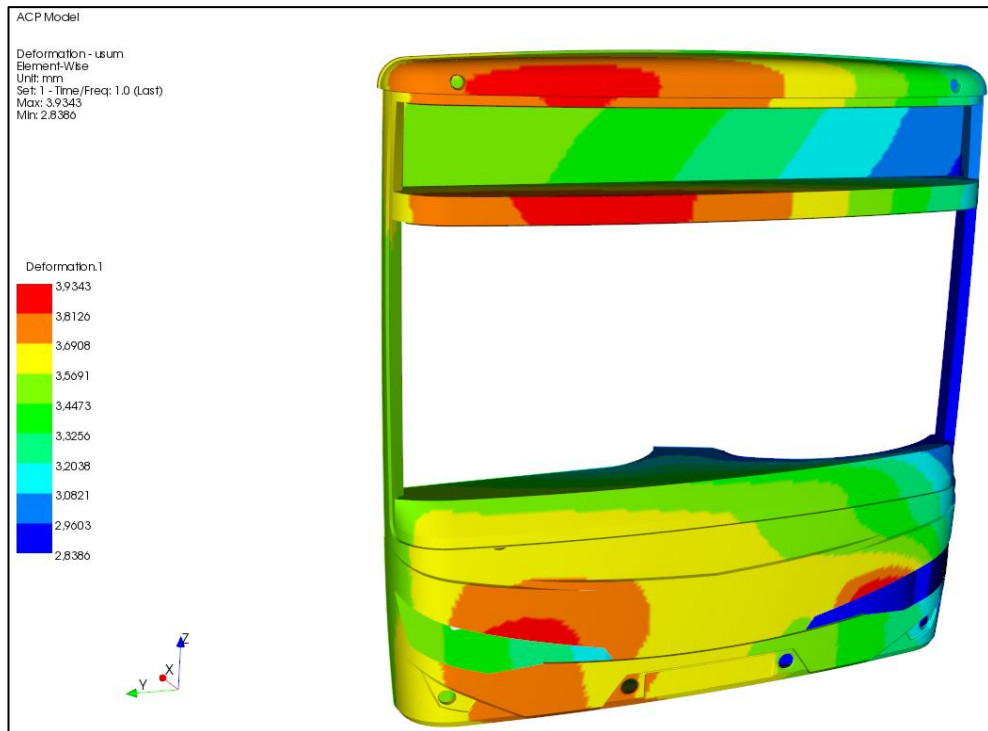


Figure 4.24: Mono-Block structure - total deformation results.

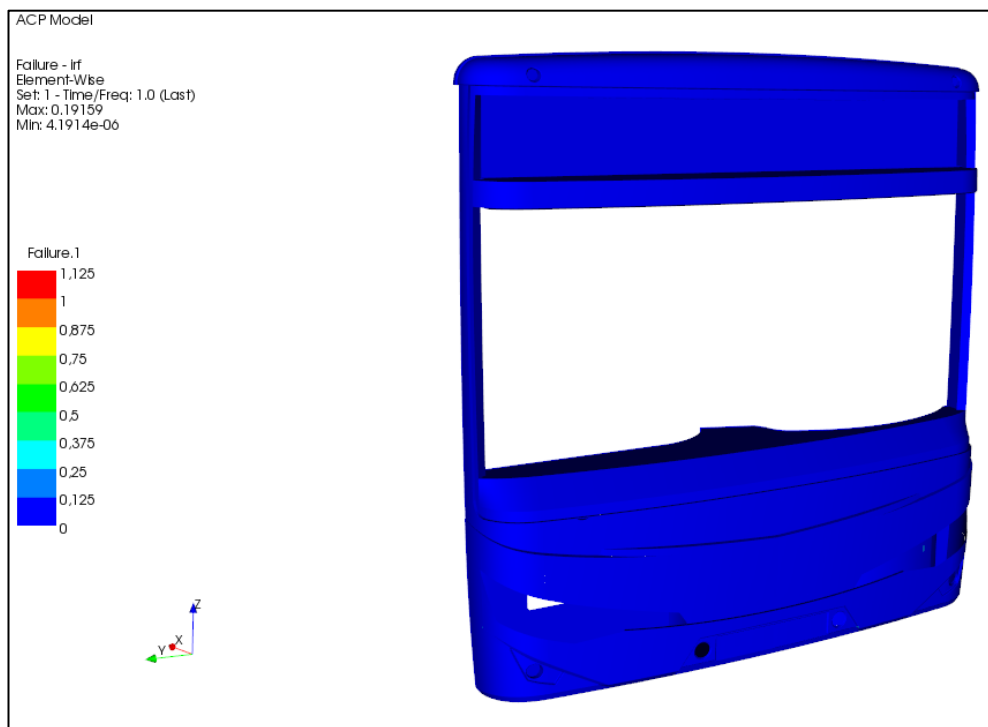


Figure 4.25: Mono-Block structure - inverse reserve factor results.

4.2.2.4. Fiber Direction [90/90/90/90]

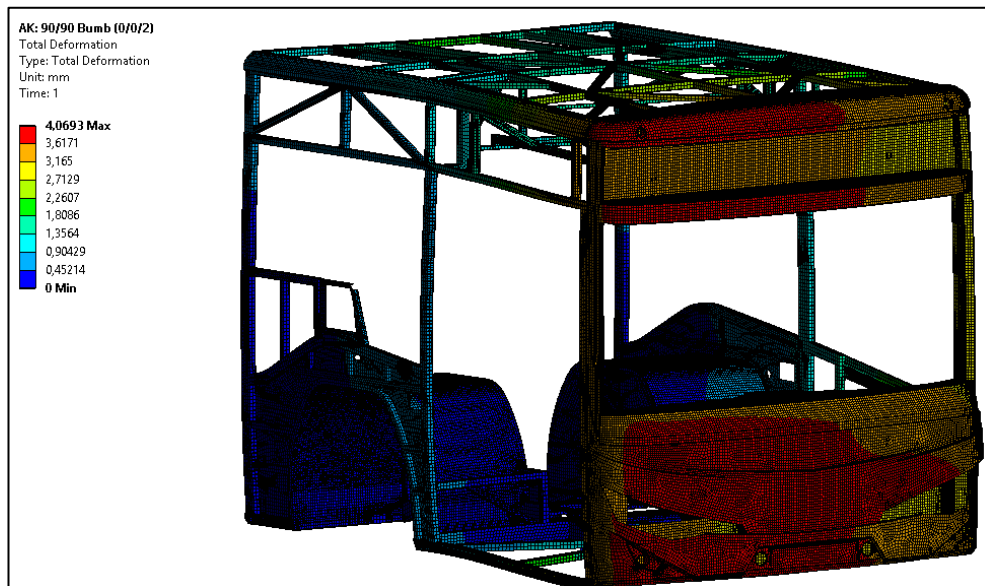


Figure 4.26: Mono-Block structure - total deformation results.

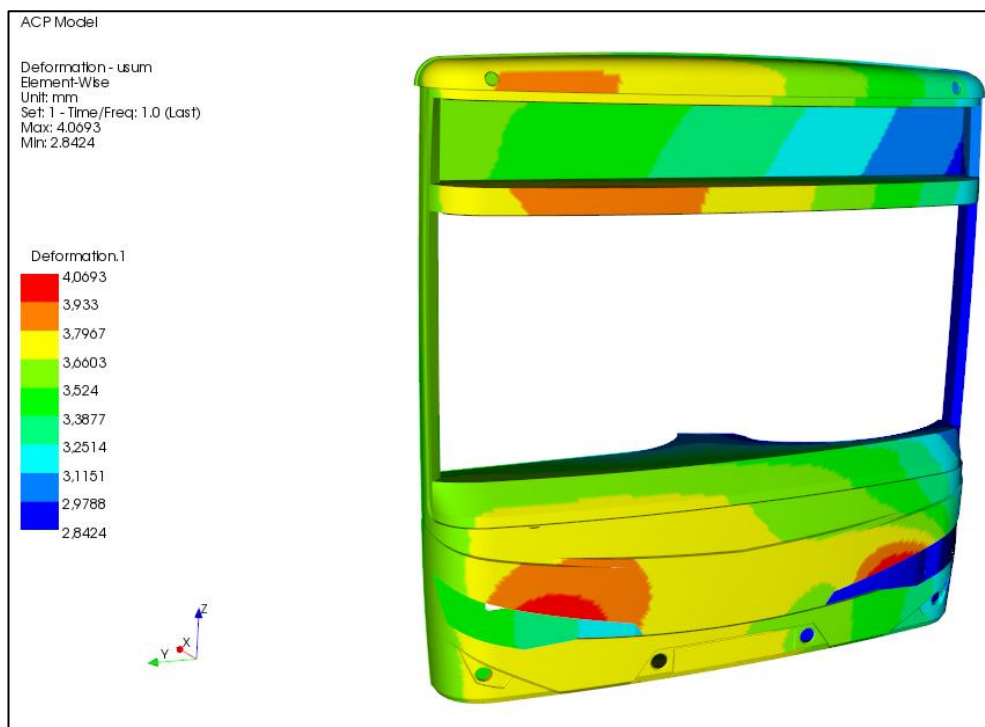


Figure 4.27: Mono-Block structure - total deformation results.

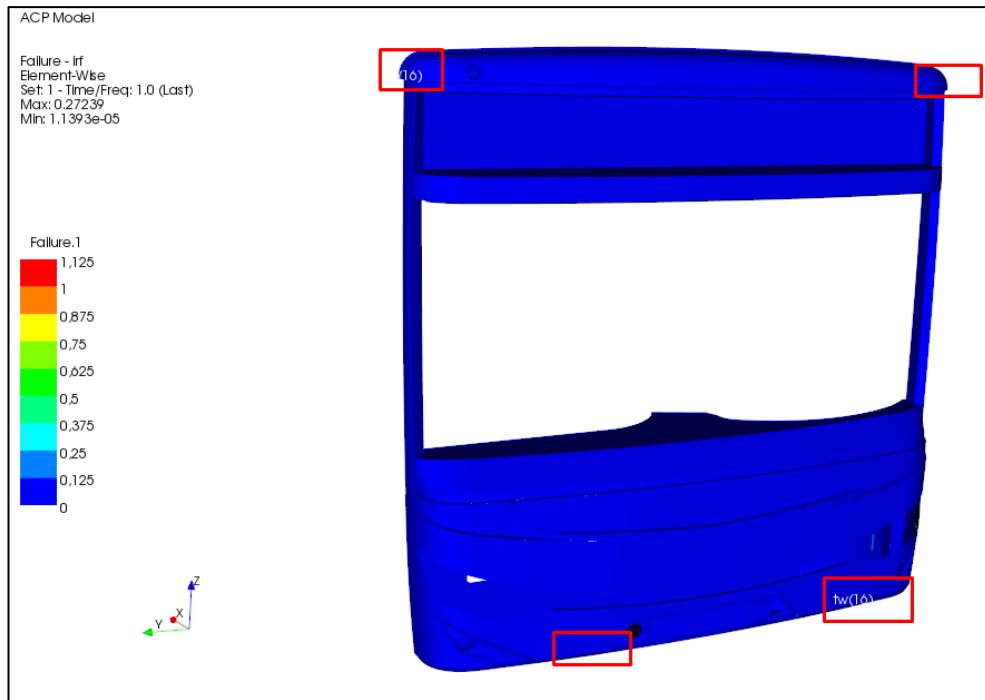


Figure 4.28: Mono-Block structure - inverse reserve factor results.

4.2.3. Load Case – Braking

4.2.3.1. Fiber Direction [0/0/0/0]

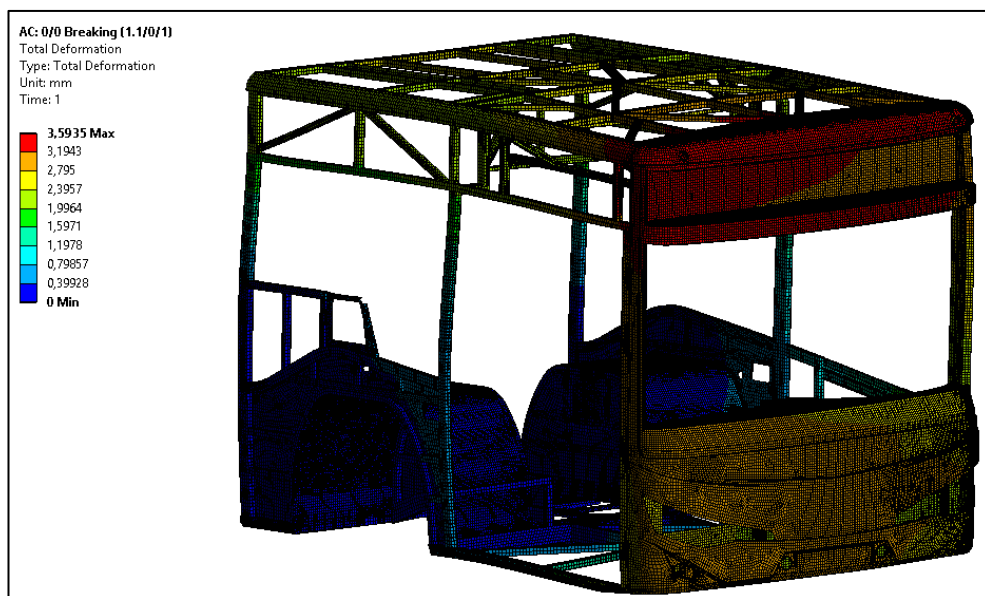


Figure 4.29: Mono-Block structure - total deformation results.

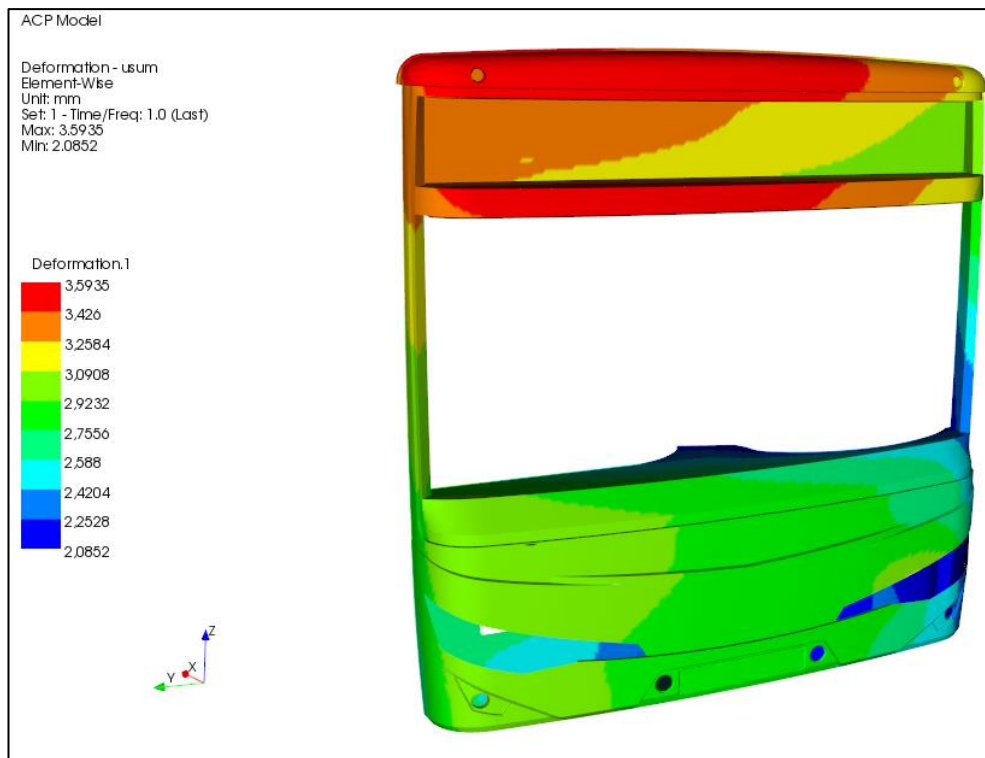


Figure 4.30: Mono-Block structure - total deformation results.

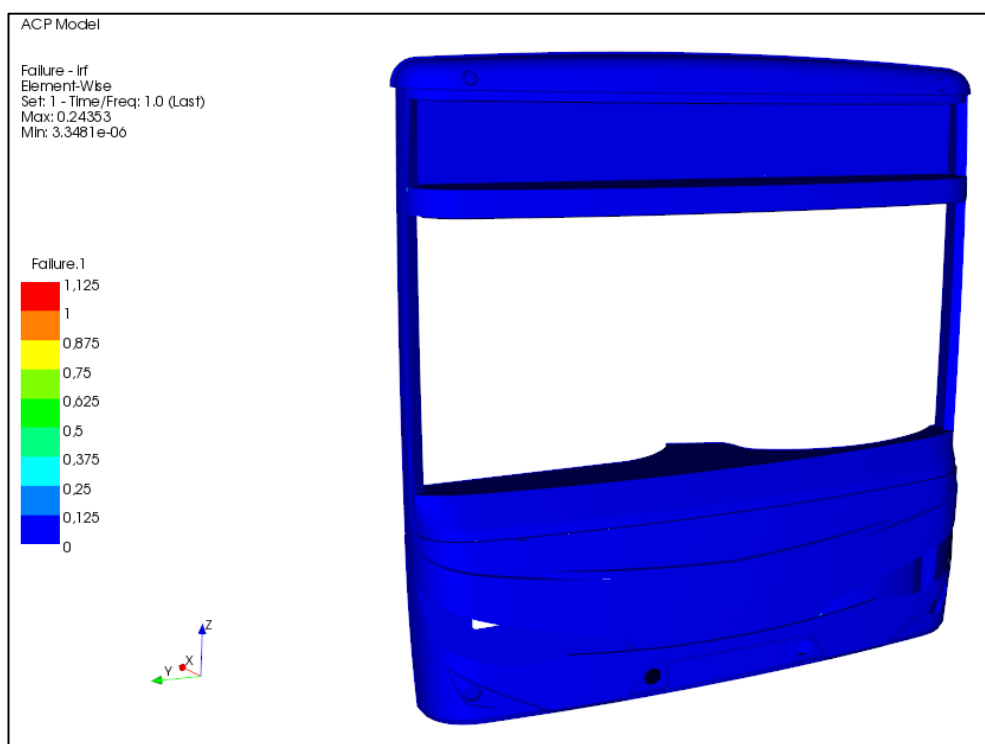


Figure 4.31: Mono-Block structure - inverse reserve factor results.

4.2.3.2. Fiber Direction [0/90/0/90]

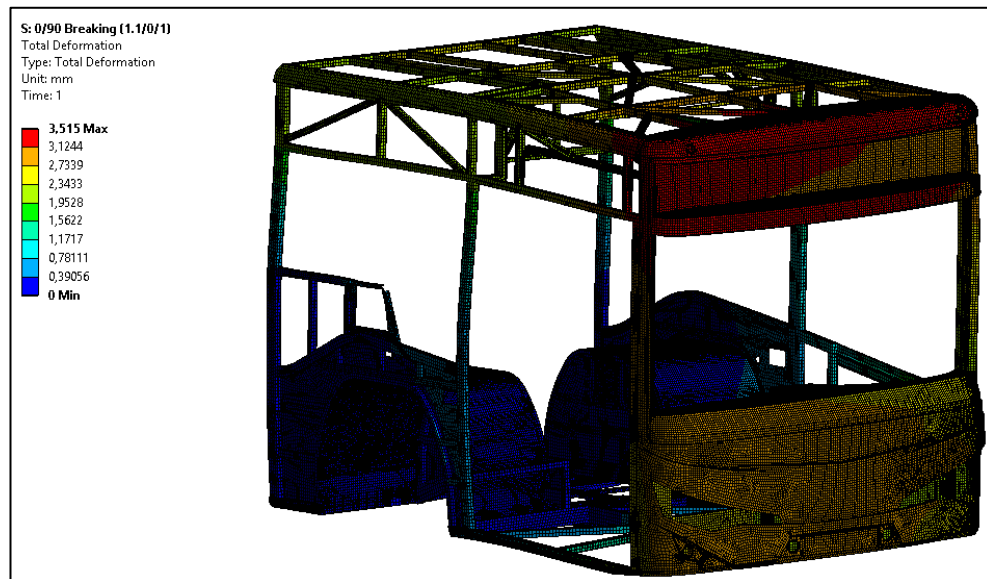


Figure 4.32: Mono-Block structure - total deformation results.

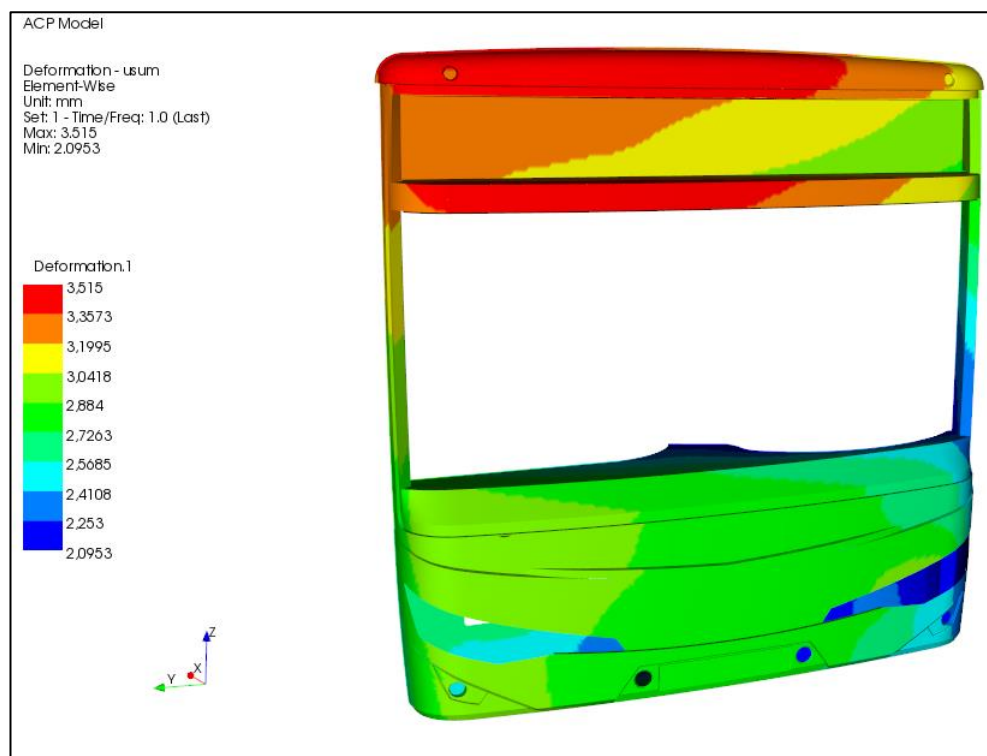


Figure 4.33: Mono-Block structure - total deformation results.

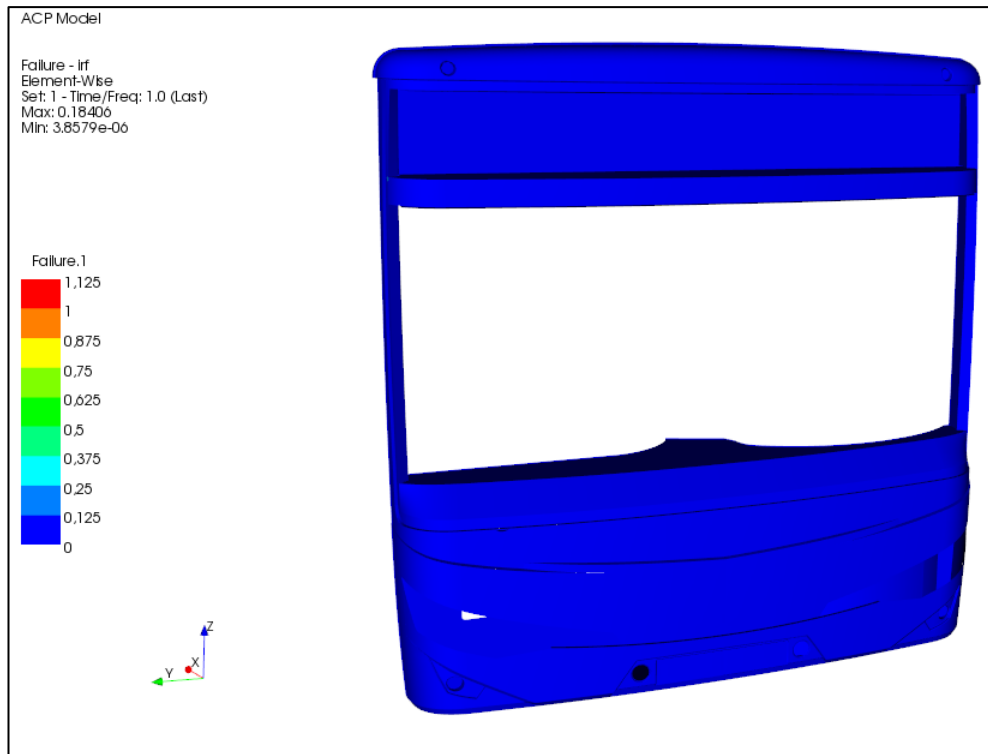


Figure 4.34: Mono-Block structure - inverse reserve factor results.

4.2.3.3. Fiber Direction [45/-45/45/-45]

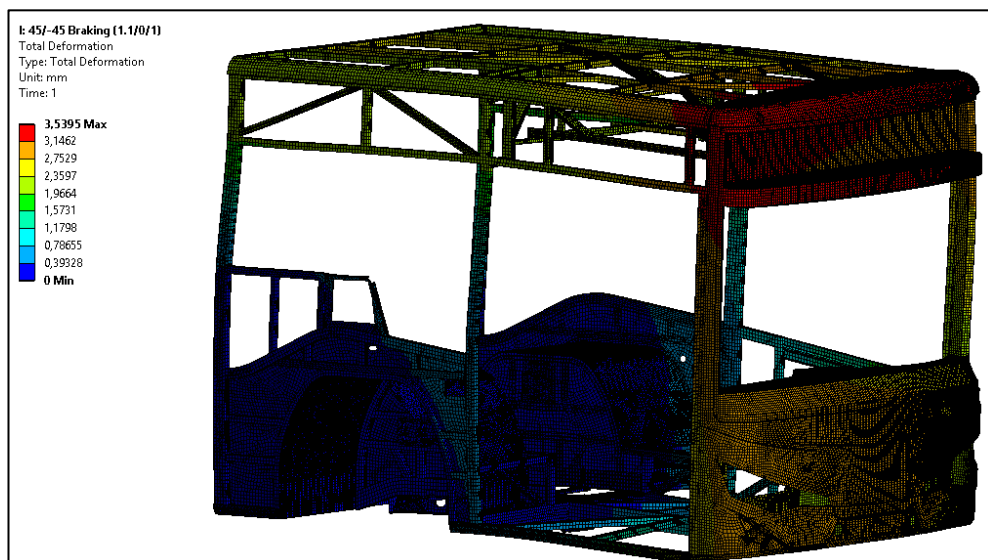


Figure 4.35: Mono-Block structure - total deformation results.

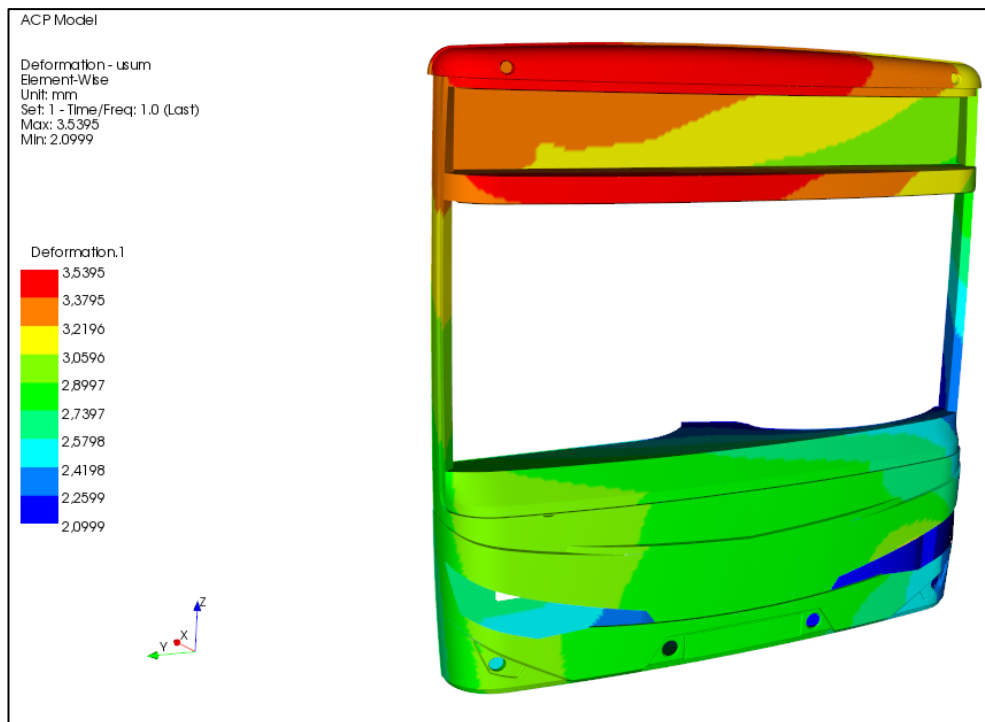


Figure 4.36: Mono-Block structure - total deformation results.

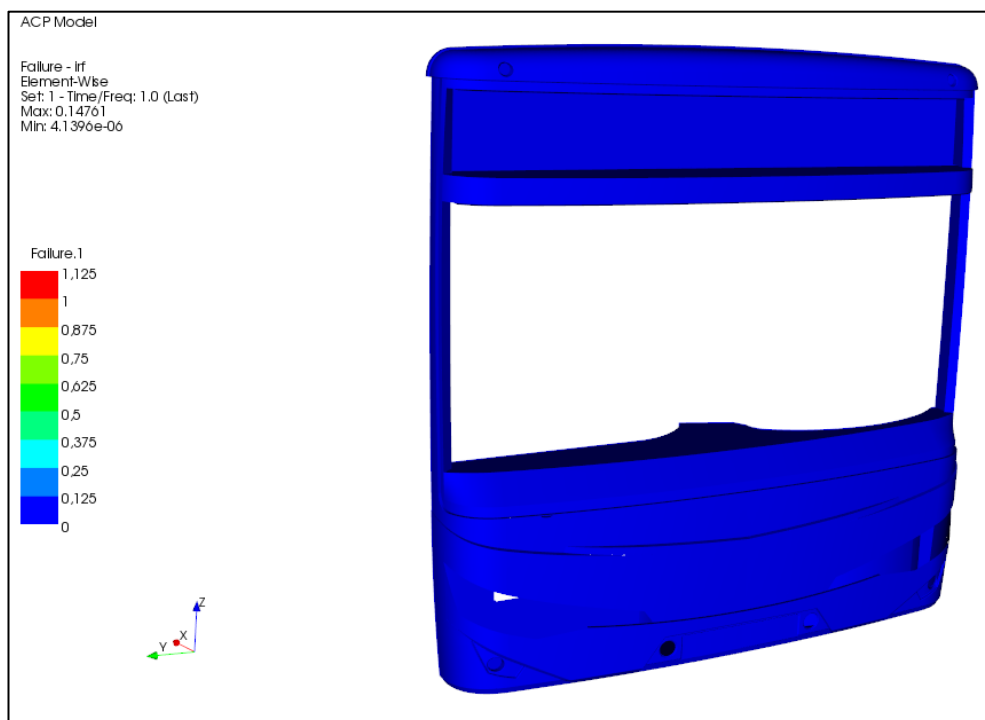


Figure 4.37: Mono-Block structure - inverse reserve factor results.

4.2.3.4. Fiber Direction [90/90/90/90]

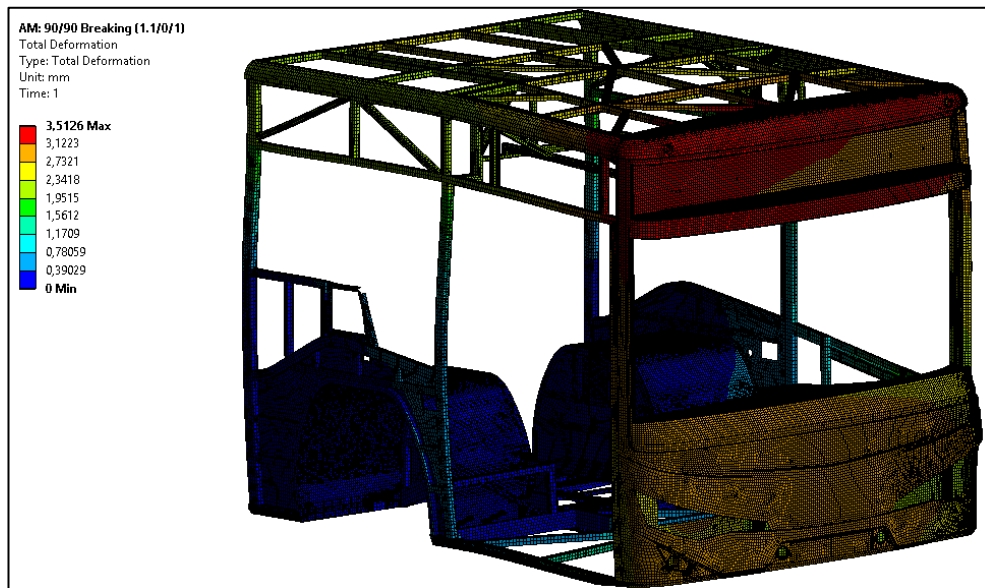


Figure 4.38: Mono-Block structure - total deformation results.

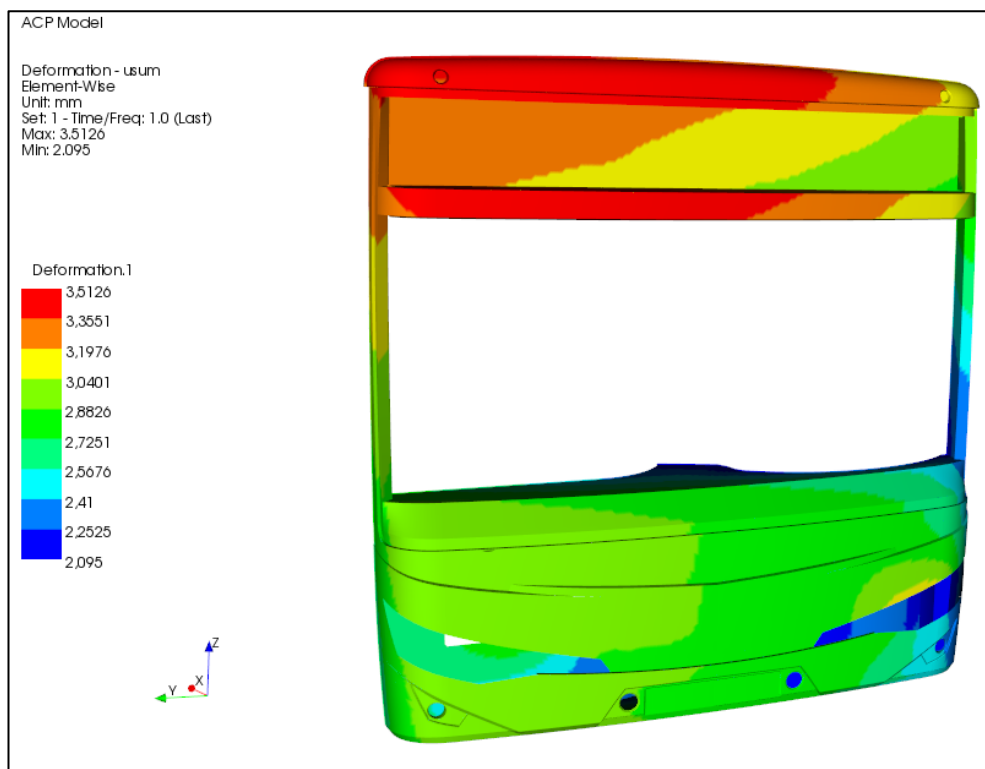


Figure 4.39: Mono-Block structure - total deformation results.

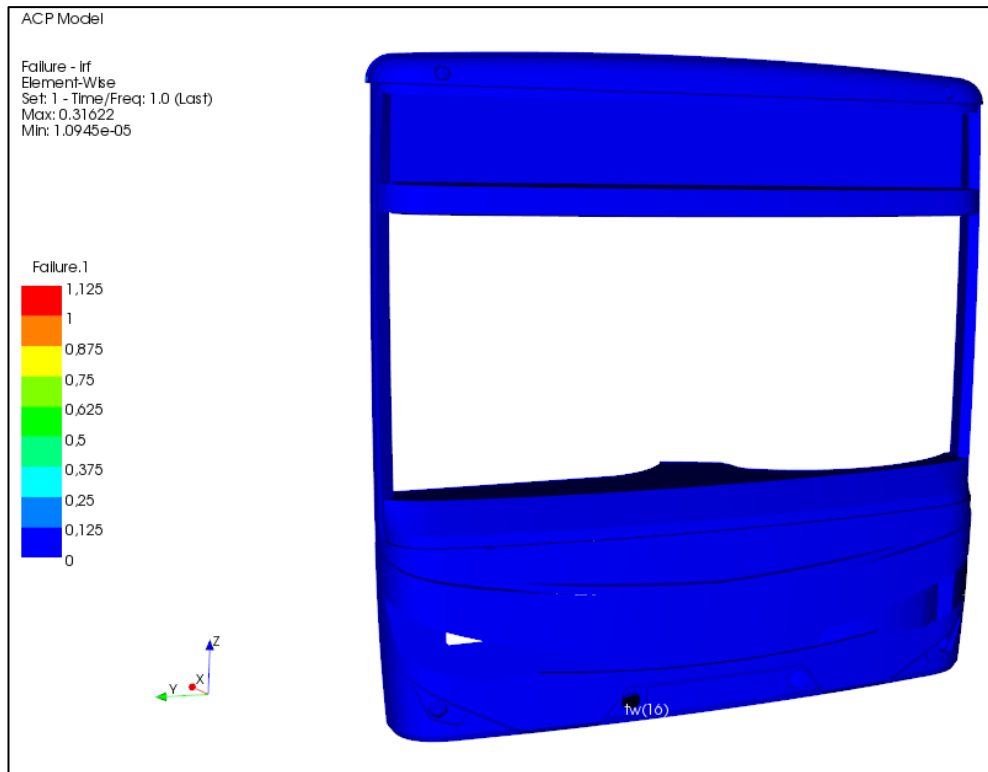


Figure 4.40: Mono-Block structure - inverse reserve factor results.

4.2.4. Load Case – Cornering

4.2.4.1. Fiber Direction [0/0/0/0]

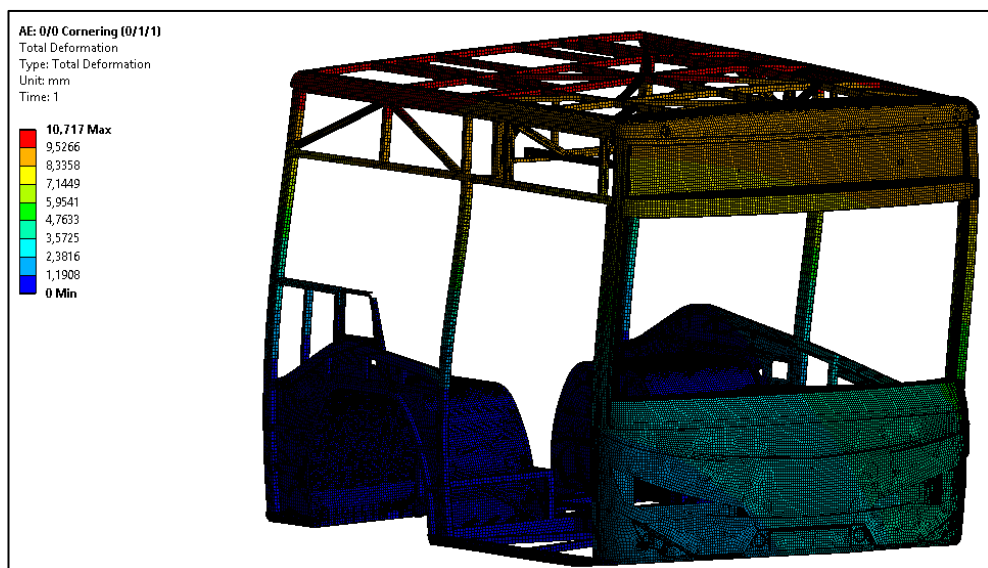


Figure 4.41: Mono-Block structure - total deformation results.

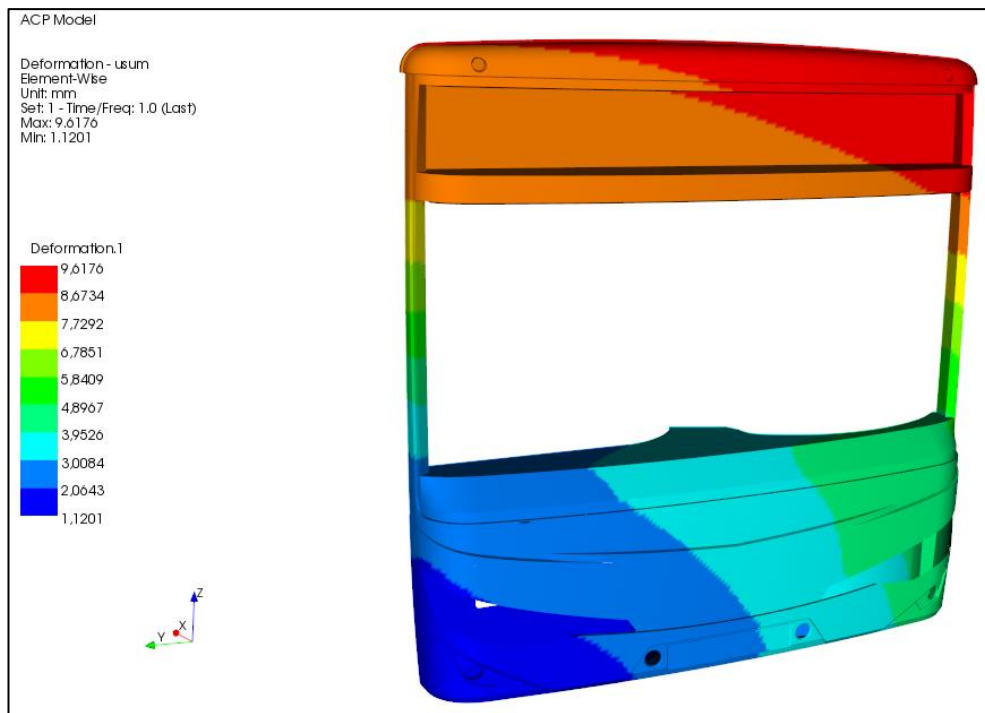


Figure 4.42 : Mono-Block structure - total deformation results.

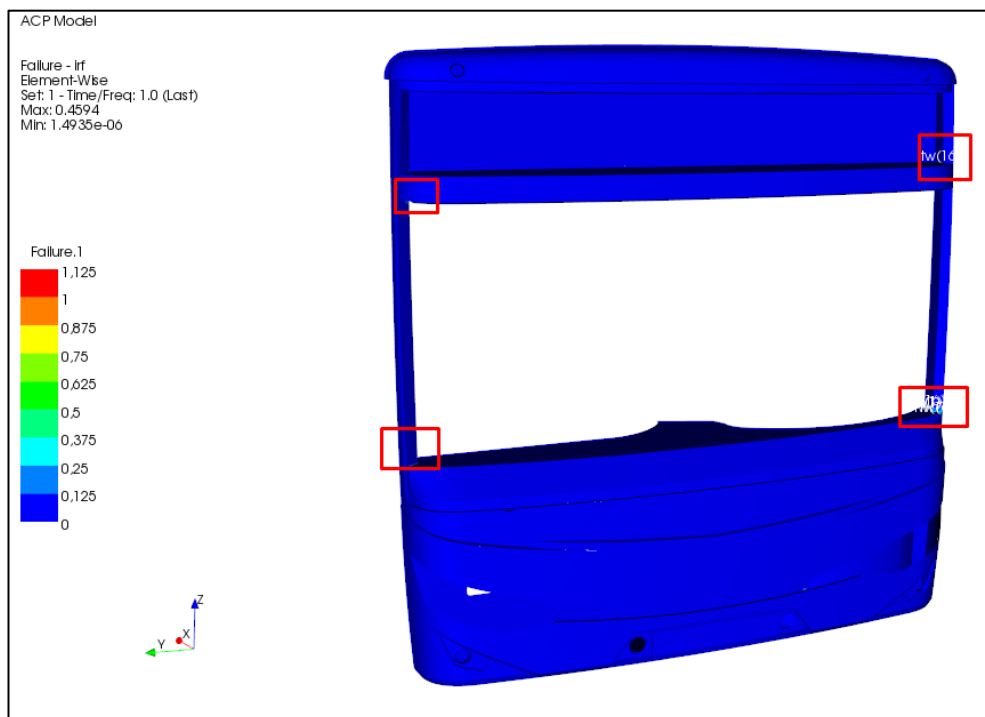


Figure 4.43: Mono-Block structure - inverse reserve factor results.

4.2.4.2. Fiber Direction [0/90/0/90]

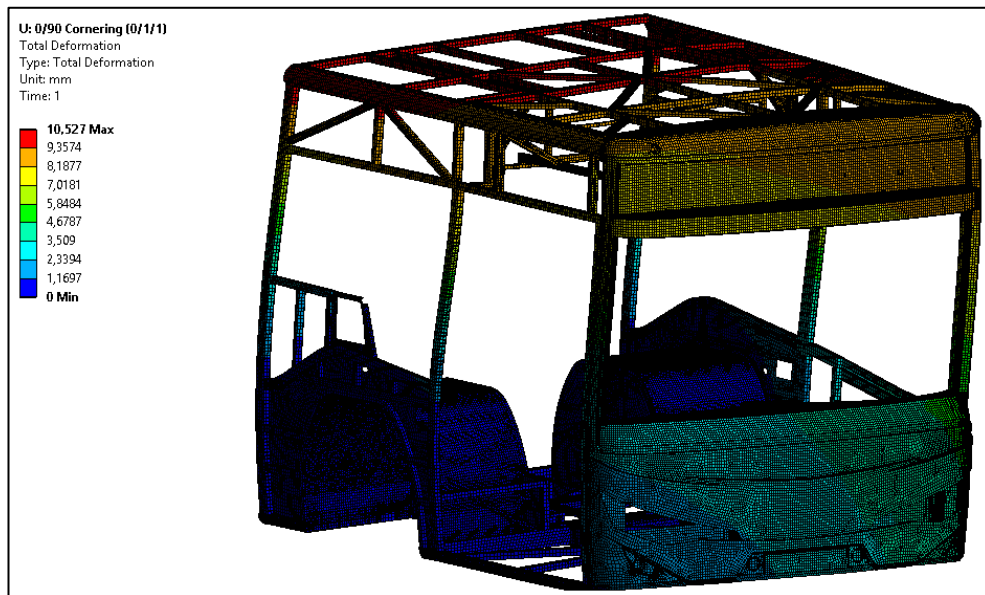


Figure 4.44: Mono-Block structure - total deformation results.

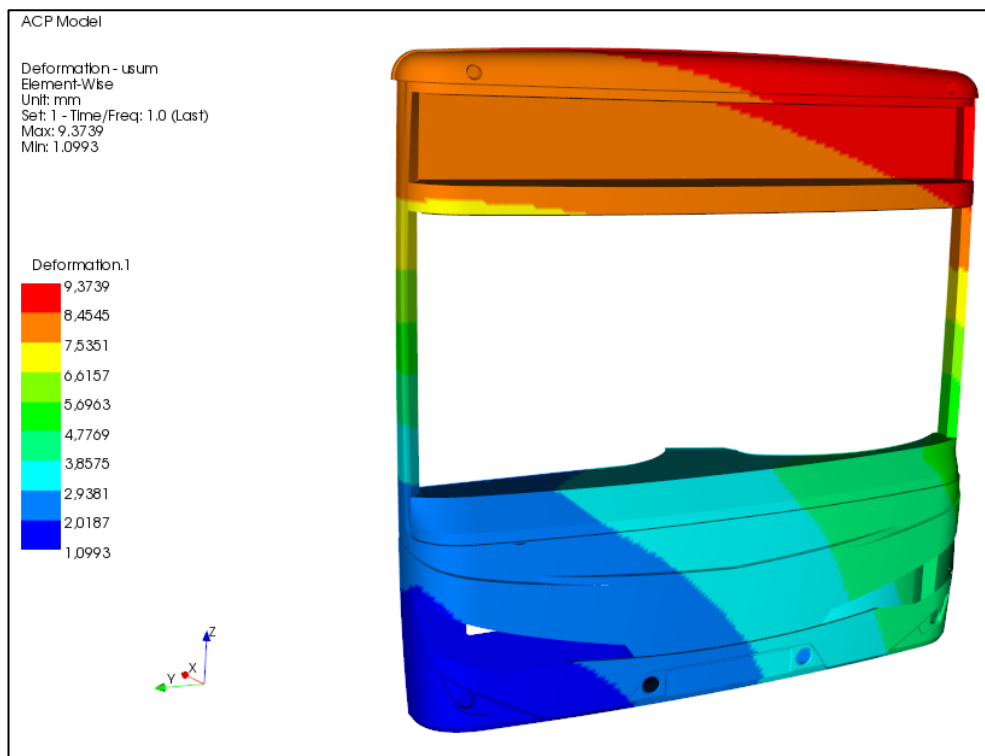


Figure 4.45: Mono-Block structure - total deformation results.

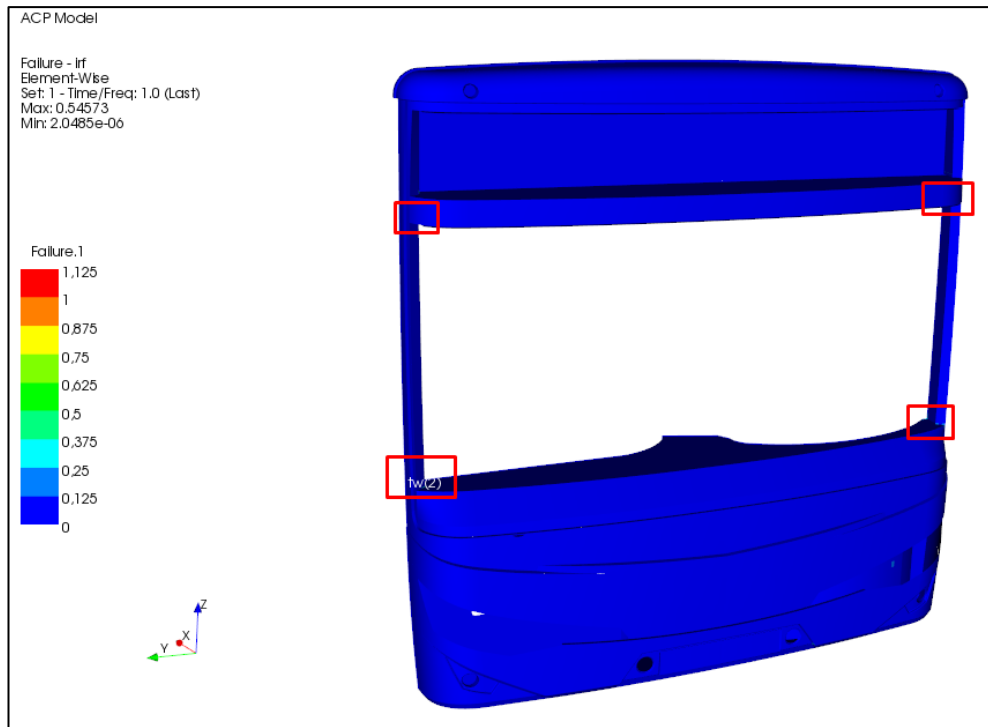


Figure 4.46 : Mono-Block structure - inverse reserve factor results.

4.2.4.3. Fiber Direction [45/-45/45/-45]

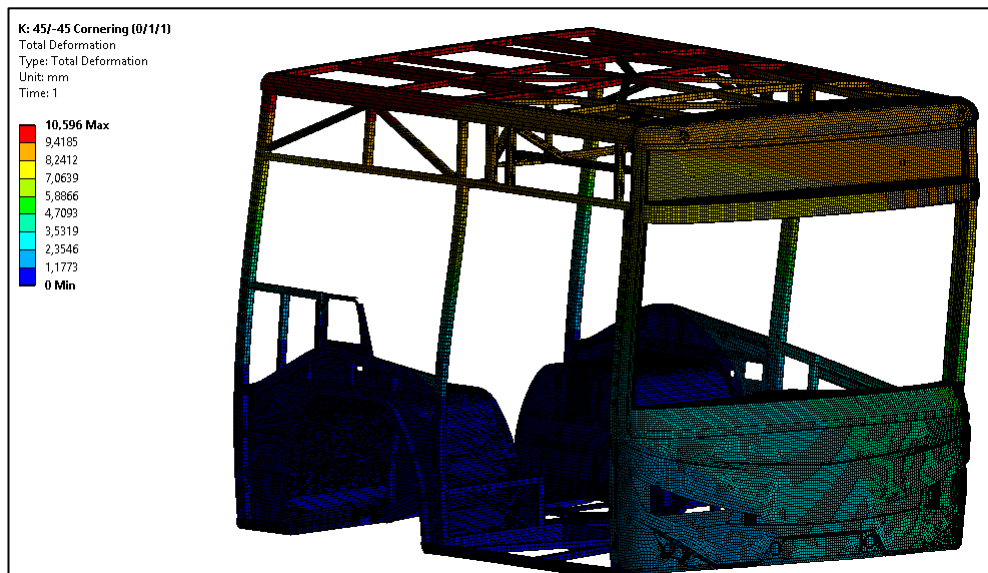


Figure 4.47: Mono-Block structure - total deformation results.

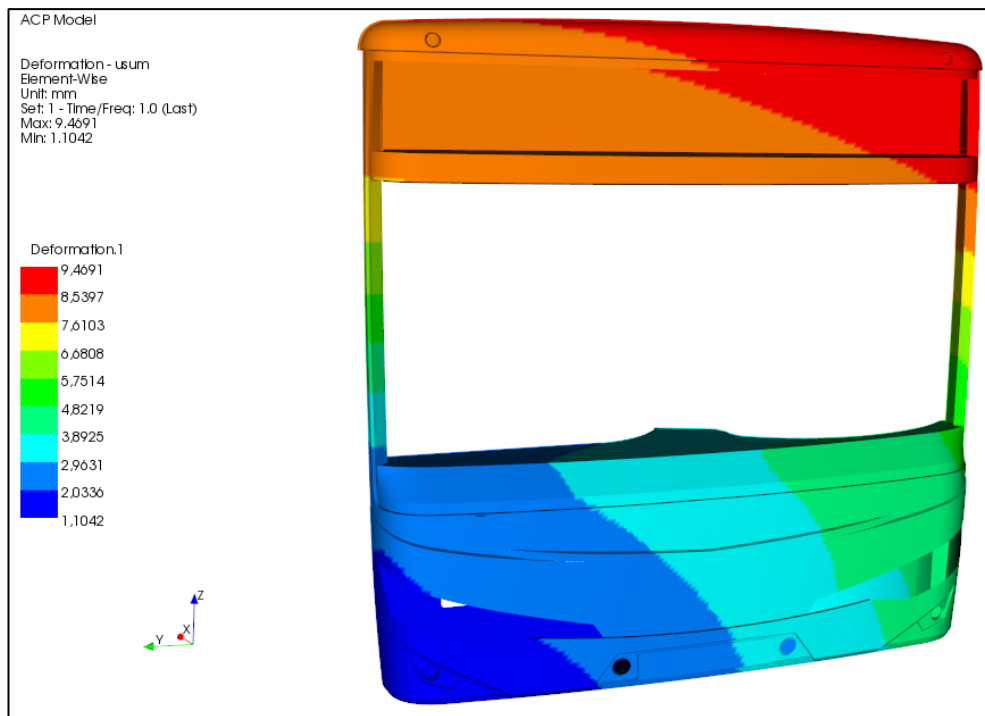


Figure 4.48: Mono-Block structure - total deformation results.

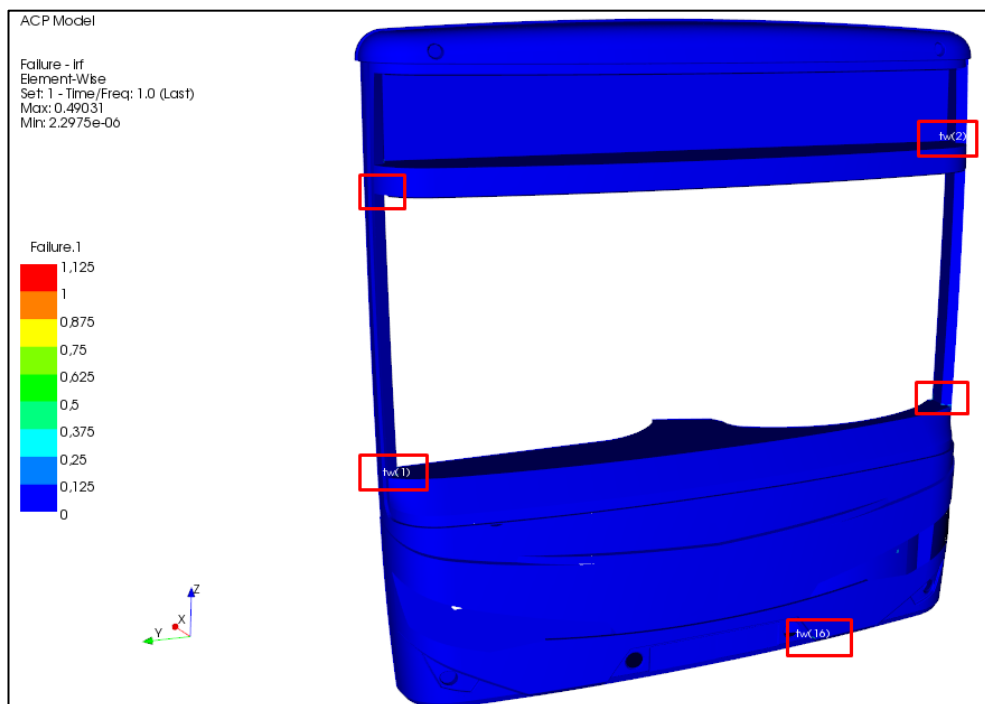


Figure 4.49: Mono-Block structure - inverse reserve factor results.

4.2.4.4. Fiber Direction [90/90/90/90]

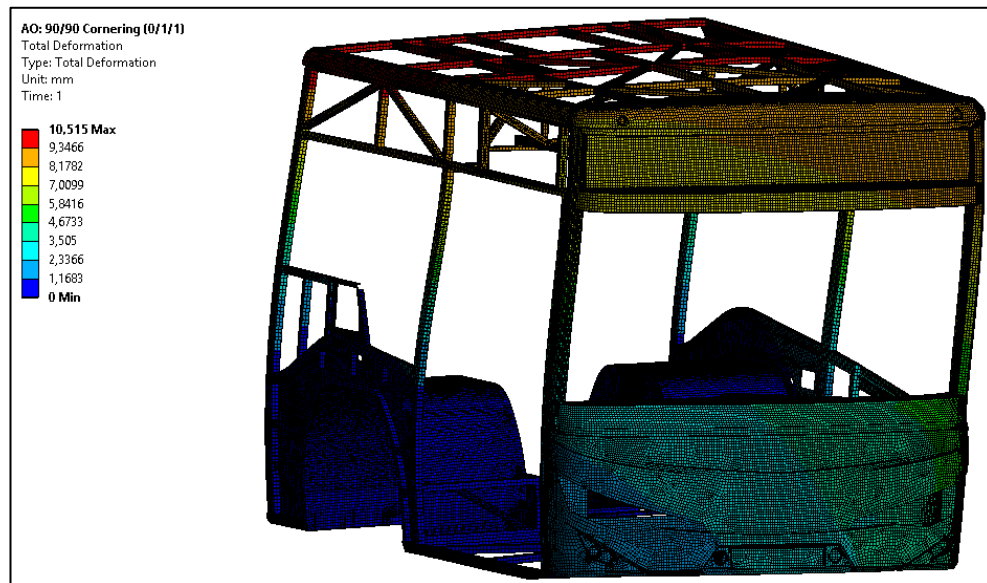


Figure 4.50: Mono-Block structure - total deformation results.

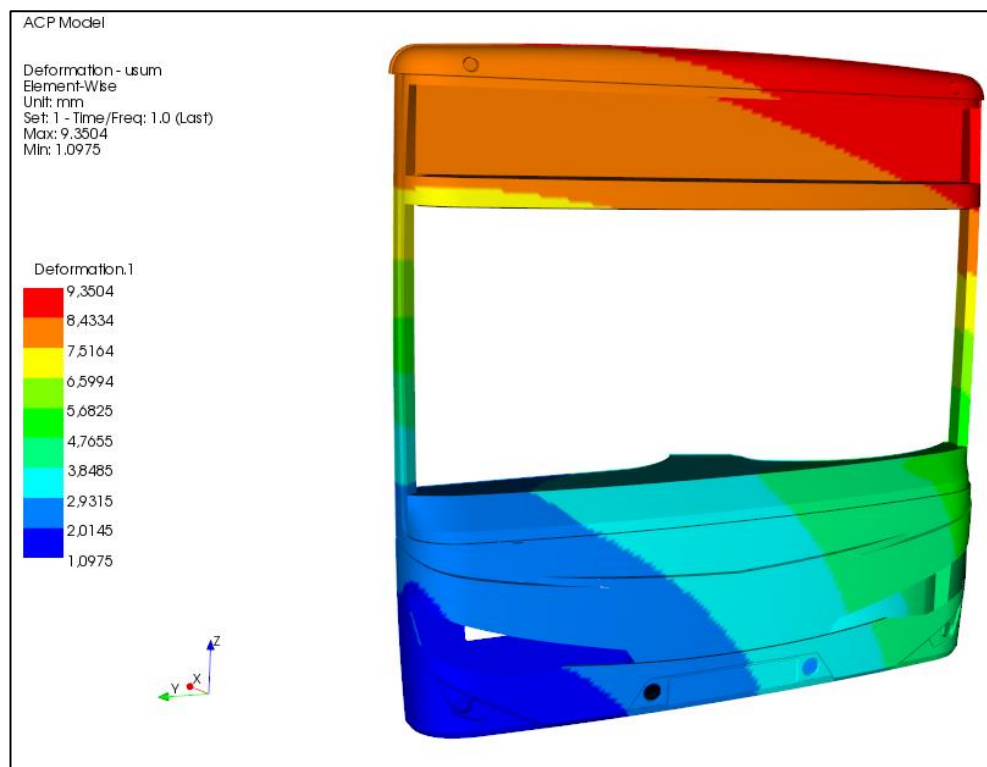


Figure 4.51: Mono-Block structure - total deformation results.

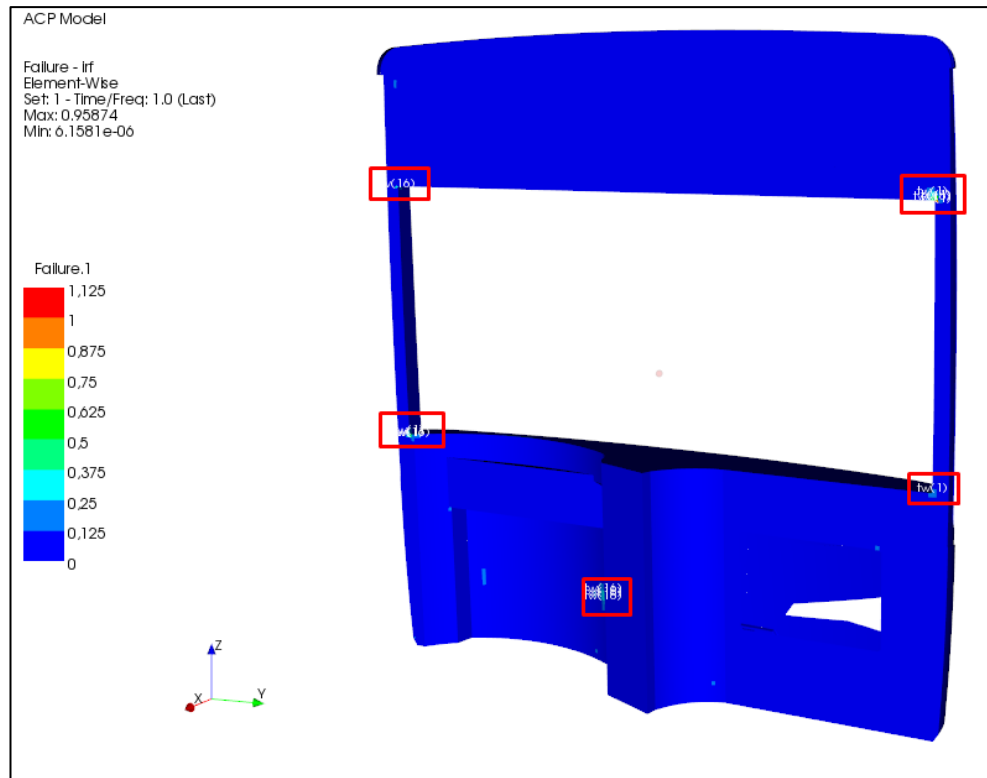


Figure 4.52: Mono-Block structure - inverse reserve factor results.

4.3. Comparison of Results

Under the four load cases, gravitational acceleration only, bump, braking and cornering, static analyses are performed for the old conventional carcass and new MonoBlock carcass models. Results are evaluated and given in the tables below.

In all models, at some points of the geometry data, there are singularity problems indicated in results figures due to design problems. Those singularity results are excluded from results and indicated with purple color on legend bars as independent top band.

For the MonoBlock composite structure, Tsai-Wu failure criteria has been chosen to post-process analysis results. The reason of choosing this failure criteria is the Tasi-Wu failure criteria is a widely used material failure method for anisotropic materials (such as composite materials) that have different properties in different global directions.

With conventional assumptions, such as homogeneity and linear elasticity up to failure, the Tsai-Wu criterion was originally proposed in the context generally anisotropic materials by using a quadratic polynomial expression of stresses with

tensorial coefficients as a simplified form from a more comprehensive but less practical form. The tensorial expressions employed enable its general applicability in terms of coordinate systems to be adopted to describe the problem [18].

The safety criteria of the materials can be evaluated differently for different approaches for different industries. For composite materials, mostly used safety criteria options are Reserve Factor, Inverse Reserve Factor and Margins of Safety in finite element analysis. The Reserve Factor (RF) indicates margins to failure. The applied load multiplied by the RF gives the failure load for the structure [19].

RF values greater than one indicate positive margin to failure and values less than one indicate negative margin. The values of RFs are always greater than zero [19].

The critical values of RF lie between zero and one, whereas the non-critical values range from one to infinity. Whether the results are shown in numeric form or as contour plots, the non-critical values tend to be emphasized in comparison to critical values. Therefore, the inverse reserve factor (IRF) is often preferred in practical use. The no-critical values of IRF range from zero to one and the critical values from that on [19].

The margins of safety (MoS) is an alternative for the RF in indicating margin to failure. The MoS is obtained from the corresponding RF with subtracting 1 from the values of RF. A positive MoS indicates the relative amount that the applied load can be increased before reaching the failure load. Correspondingly, a negative MoS indicates how much the applied load should be decreased. MoS is typically expressed as percentages [19].

In this thesis, IRF values are calculated and evaluated for the analysis results of the MonoBlock composite structure.

For the old conventional carcass model, the evaluated results are shown in Table 4.1.

Table 4.1: Results for the old carcass model.

The Old Conventional Carcass Structure				
Load Cases	Gravity Only	Bump	Braking	Cornering
Equivalent Stress Results (Mpa)	169,37	508,2	417,7	269,08
Equivalent Elastic Strain Results	8,80E-04	2,64E-04	2,17E-03	1,94E-03
Total Deformation Results (mm)	2,12	6,3647	5,0566	11,225

For the new MonoBlock Carcass Model, the evaluated results are shown in tables below (Table 4.2, Table 4.3, Table 4.4 and Table 4.5).

Table 4.2: Results for the monoblock structure – gravitational acceleration.

The New MonoBlock Carcass Structure				
Load Case	Gravitational Acceleration			
Fiber Directions	[0/0]	[0/90]	[45/-45]	[90/90]
Equivalent Stress (Mpa)	84,58	85,369	85,251	85,352
Total Deformation (mm)	1,3507	1,2966	1,3114	1,3562
Stress Results (S1, MPa)	-6,758	-6,6266	6,3414	-4,9908
Stress Results (S2, MPa)	-2,8142	-1,5822	-2,2413	-2,3604
Stress Results (S12, MPa)	1,8079	1,7731	-1,0967	-1,6561
Strain Results (E1)	-1,46E-04	-1,43E-04	1,33E-04	-1,08E-04
Strain Results (E2)	-2,83E-04	-1,34E-04	-1,95E-04	-2,19E-04
Strain Results (E12)	3,62E-04	3,55E-04	-2,19E-04	-3,31E-04
Inverse Reserve Factor	0,14251	0,88367	0,0807	0,093138

Table 4.3: Results for the monoblock structure – load case bump.

The New MonoBlock Carcass Structure				
Load Case	Bump			
Fiber Directions	[0/0]	[0/90]	[45/-45]	[90/90]
Equivalent Stress (Mpa)	253,74	256,11	255,75	256,06
Total Deformation (mm)	4,0574	3,8901	3,9343	4,0693
Stress Results (S1, MPa)	-20,274	-19,88	19,027	-14,974
Stress Results (S2, MPa)	-8,4492	-4,7467	-6,7241	-7,2129
Stress Results (S12, MPa)	5,4231	5,3181	-3,2899	-4,9676
Strain Results (E1)	-4,39E-04	-4,30E-04	3,98E-04	-3,23E-04
Strain Results (E2)	-8,48E-04	-4,01E-04	-5,83E-04	-6,70E-04
Strain Results (E12)	1,08E-03	1,06E-03	-6,58E-04	-9,94E-04
Inverse Reserve Factor	0,34984	0,20963	0,19159	0,27239

Table 4.4: Results for the monoblock structure – load case braking.

The New MonoBlock Carcass Structure				
Load Case	Braking			
Fiber Directions	[0/0]	[0/90]	[45/-45]	[90/90]
Equivalent Stress (Mpa)	203,87	196,36	198,72	196,12
Total Deformation (mm)	3,5935	3,515	3,5395	3,5126
Stress Results (S1, MPa)	-10,2	11,797	-21,086	-15,1
Stress Results (S2, MPa)	-6,722	-4,5738	-4,3948	-4,607
Stress Results (S12, MPa)	-3,8872	4,5992	2,749	-4,5004
Strain Results (E1)	-2,20E-04	2,47E-04	-4,63E-04	-3,31E-04
Strain Results (E2)	6,26E-04	-4,22E-04	-4,65E-04	-4,05E-04
Strain Results (E12)	-7,77E-04	9,20E-04	5,50E-04	-9,00E-04
Inverse Reserve Factor	0,24353	0,18406	0,14761	0,31622

Table 4.5: Results for the monoblock structure – load case cornering.

The New MonoBlock Carcass Structure				
Load Case	Cornering			
Fiber Directions	[0/0]	[0/90]	[45/-45]	[90/90]
Fiber Directions	247,73	240,72	244,12	239,77
Equivalent Stress (Mpa)	10,717	10,527	10,596	10,515
Total Deformation (mm)	-23,94	-38,216	41,793	34,116
Stress Results (S1, MPa)	-9,0013	-7,5519	-8,0623	-18,361
Stress Results (S2, MPa)	-6,7525	9,7913	6,1147	-9,5776
Stress Results (S12, MPa)	5,01E-04	-7,99E-04	9,22E-04	7,61E-04
Strain Results (E1)	-8,02E-04	7,04E-04	-7,76E-04	-1,68E-03
Strain Results (E2)	1,35E-03	1,96E-04	1,22E-03	-1,92E-03
Strain Results (E12)	0,4594	0,54573	0,49031	0,95874

5. CONCLUSIONS

In this study, a new composite structure design has been developed to replace the old conventional carcass structure and finite element analysis results are compared for both models. The following conclusions obtained from the study;

- The MonoBlock carcass structure has far better results compared to the old conventional carcass structure since stress, strain and total deformation values occurred on the model under the defined load case conditions are lower.
- Almost 50 % weight reduction has been achieved for the MonoBlock composite structure compared to the old conventional model. For this reason, stress distribution on the carcass body has lower values for the MonoBlock model and also this model has smaller deformation under the acceleration loads as expected.
- In a detailed examination of results for the MonoBlock composite part of the model, different fiber laminations are used for achieving optimum angles for stack-ups. Since the over-all equivalent stresses and the local stresses with their deformation results are similar to each other stack-up angle options for the same load cases, it is difficult to compare them. The real difference is on the inverse reserve factor values of these options. All IRF values of stack-up options are lower than 1, and this shows all composite models are on the safe side. It can be determined through the results tables (Table 4.2, Table 4.3, Table 4.4, Table 4.5) that the most appropriate option among these lay-up options is the [45/-45/45/-45] angled stack-up option since the IRF values are the lowest in this setup.
- Within the fuel consumption formula for the ISUZU Citiport vehicle, 0.075 % to 0.11 % (min and max values) fuel conservation has been achieved if the new MonoBlock composite structure replaces the old conventional carcass model.
- Production rate is increased drastically since the manufacturing and assembling process of the old carcass structure is way much slower than the new MonoBlock composite structure. (478 mins for old model, 8 to 25 mins for MonoBlock)
- Since glass fiber composite materials have corrosion resistance, after replacement of the MonoBlock structure with the old conventional structure, the cataphoresis process is no longer needed for the front part of the Citiport vehicle.

- For the unit prices of the individual parts, Mono-Block composite structure has around 63 % and 58 % lower prices for the hand lay-up and RTM molding manufacturing techniques, respectively.
- For the mold costs, choosing Mono-Block composite structure is more profitable than the old conventional carcass structure since mold prices of Mono-Block are around 68 % and 61 % lower for the hand lay-up and RTM molding manufacturing techniques, respectively. Thus, creating a new production line for the MonoBlock structure is not hard as it was for the conventional carcass structure and this is a lucrative business.
- Weight reduction of the body will certainly lower the exhaust emissions values of the vehicle which is the one of the most important requirements of future.

6. SUGGESTIONS AND FURTHER STUDIES

Fiber layer stack-up angle options are restricted to four cases since the prototype of the MonoBlock structure will be manufactured by hand lay-up technique and this method has limitations for fiber angles. For prototype, it might be acceptable but for mass production, the RTM molding technique should be selected.

Since only 4 options of fiber angles are analyzed and results are compared, more fiber angle options should be analyzed to achieve better and optimum structure. An optimization software might pre-connected to the analysis and one of the parameters should be the angles of the fibers.

In this thesis, only static linear analysis is completed. The rest of the load cases should be defined and results should be evaluated. For further approaches, more analysis systems should join the project. Modal analysis results should be evaluated first, then crush and roll-over analyses should be performed. After all analyses are done and results are evaluated, the final model should be optimized for better results if necessary.

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BIOGRAPHY

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