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MÁSTER UNIVERSITARIO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

Composite Monocoque FS Chassis: Design of co-cured or bonded-in metallic inserts

Autor: Jesús López Menéndez

Director: Ignacio Granell Heredero

Madrid

Julio de 2024

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

Composite Monocoque FS Chassis: Design of co cured or bonded-in metallic inserts

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EL DIRECTOR DEL PROYECTO

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COMPOSITE MONOCOQUE FS CHASSIS: DESIGN OF CO CURED OR BONDED-IN METALLIC INSERTS

Autor: López Menéndez, Jesús.

Director: Granell Heredero, Ignacio.

Entidad Colaboradora: ICAI – Universidad Pontificia Comillas.

RESUMEN DEL PROYECTO:

Palabras clave: inserto metálicos, monocasco, elementos finitos, simulación, normativa adhesivo estructural, coste de fabricación y materiales compuestos.

1. **Introducción:**
   Este proyecto tiene como objetivo el diseño y desarrollo de los insertos metálicos necesarios para el primer monocasco de fibra de carbono del equipo ISC Formula Student. Formula Student es una competición donde equipos procedentes de universidades de todo el mundo compiten desarrollando prototipos de vehículos tanto de combustión, como híbridos y eléctricos. Los eventos se dividen en dinámicos y estáticos, evaluando no solo el rendimiento del coche, sino también la ingeniería que existe detrás de su diseño. Con este proyecto se busca sentar las bases de diseño para que puedan ser empleadas durante la fabricación del primer chasis monocasco del equipo.

Ilustración 1: ISC Racing Team [1]

La industria de la automoción se basa en la mejora continua y la incesable búsqueda de los límites del diseño. Desde el punto de vista estructural, esta innovación se encuentra en los materiales compuestos, los cuales son una excelente alternativa a otros métodos constructivos tradicionales como es el caso del acero o el aluminio.

Su principal ventaja frente a otras formas de fabricación es la reducción de peso. En el caso particular del chasis monocasco, estos materiales presentan una rigidez torsional y resistencia a la fatiga excepcional. Sin embargo, su punto débil se encuentra cuando estos materiales hacen frente a esfuerzos puntuales. Para adaptar estas estructuras de la mejor forma posible se emplean insertos metálicos que transmitirán las diferentes fuerzas a la estructura. Es necesario por tanto un diseño exhaustivo de los insertos los cuales pueden ser de diferentes tipos:

- Insertos embebidos en caliente: introducidos durante el curado del material compuesto, empleando adhesivos estructurales. Ofrecen alta resistencia y reducen el tiempo de fabricación, aunque requieren especial atención para establecer la ubicación final del inserto teniendo en cuenta la expansión térmica.
- Insertos embebidos en frío: añadidos tras el curado del panel mediante la perforación del material compuesto y la aplicación del adhesivo. Ofrecen buena resistencia y flexibilidad en la fabricación, pero son menos resistentes que los insertos embebidos en caliente, además incrementan el tiempo de fabricación.
- Insertos superficiales: Se unen directamente a la superficie del panel con adhesivo. Son fáciles de ubicar, pero presentan baja resistencia debido a su dependencia única de las propiedades del adhesivo.
- Insertos remachados: Utilizan la deformación del inserto para asegurar la unión, similar al funcionamiento de un remache. Son económicos, ligeros y fáciles de ubicar, pero dañan fácilmente la superficie del panel y no ofrecen gran resistencia, dependiendo mucho de la calidad del material compuesto.

En este proyecto se ha decidido optar por los insertos embebidos en frio, ya que presentan unas buenas propiedades, son más económicos y dan una mayor flexibilidad en la fabricación.

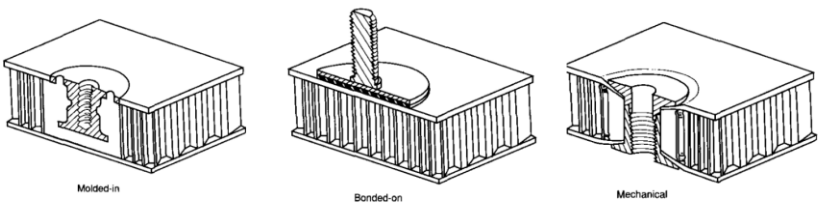

Ilustración 2: tipos de insertos [2]

2. Metodología:

El estudio se ha llevado a cabo siguiendo las consignas de diseño establecidas por la normativa de Formula Student Germany, la competición más exigente de todas en las que participa el ISC Racing Team. Se han seguido recomendaciones de la

ECSS (*European Cooperation for Space Standardization)*, la cual establece una serie de directrices en el diseño de insertos embebidos en frio. [3]

Las indicaciones de la ECSS han sido empleadas para establecer un diseño de partida para el diámetro de encapsulamiento del inserto y posteriormente se ha iterado este diseño preliminar. El diseño se ha modelado mediante el software de SolidWorks y las iteraciones han sido llevadas cabo con diferentes módulos de elementos finitos que incluye el software de ANSYS.

Para la etapa de diseño y modelado se ha empleado el SES (Structural Equivalency Spreadsheet) como forma de verificación, ya que esta es la guía que facilita la competición para el diseño de los elementos del chasis monocasco.

En cuanto a las simulaciones se ha prestado especial atención al mallado de los diferentes componentes ya que es fundamental para garantizar la fidelidad de los resultados. Para garantizar la calidad de la malla se ha buscado en el adhesivo un “element quality” de 0,95 y un “skewness” menor a 0,1. Por otro lado, se han ido realizando simulaciones variando la malla hasta que los resultados eran invariantes.

Para llevar a cabo las simulaciones se ha empleado el modulo “ACP” para modelar el material compuesto y posteriormente estudiarlo junto con los insertos y el adhesivo en el módulo de “Static Structural”.

3. Resultados:

Para llevar a cabo las simulaciones, se ha despreciado el laminado de fibra de carbono sobre el adhesivo, lo que concentra más la tensión sobre este. Al hacer esto se introduce un cierto factor de seguridad sobre los resultados. Por otro lado, es fundamental comprender el funcionamiento de las simulaciones con elementos finitos para interpretar los resultados. Estos realizan iteraciones comparando los resultados con los elementos que se encuentran en sus proximidades, por tanto, en zonas como las esquinas los resultados no son precisos al no poder comparar con un elemento cercano. Por ello, las máximas tensiones que se deben considerar son las que se encuentran en el elemento anterior a las esquinas. A continuación, se muestran los resultados obtenidos:

- PA_IT_001:

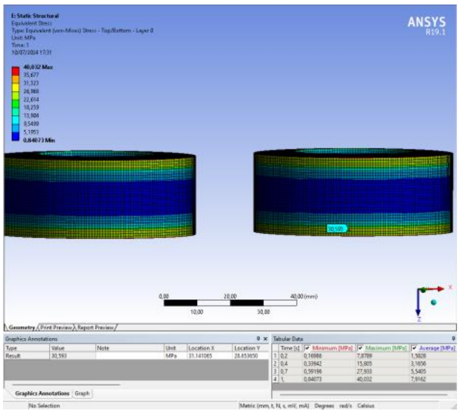

Ilustración 3: Resultado PA_IT_001

Este inserto presenta el diseño más sencillo y económico. Se puede observar que la máxima tensión que presenta el adhesivo tras el ensayo es de 30,593 MPa. Teniendo en cuenta que el adhesivo tiene un límite elástico frente a esfuerzos cortantes de 31,6MPa, se puede confirmar que este par de insertos soportarían una fuerza de 30Kn.

- PA_IT_002:

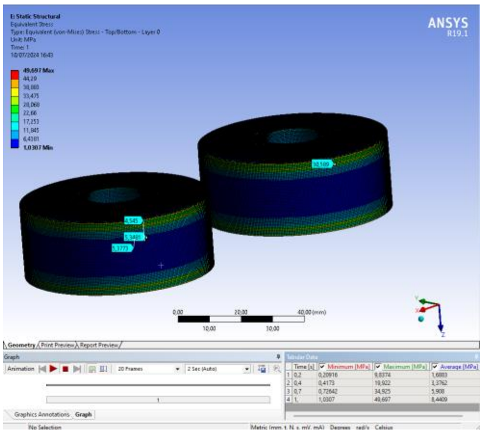

Ilustración 4: Resultado PA_IT_002

Este inserto presenta un diseño con forma cónica, de tal forma que su geometría ayuda a distribuir mejor las tensiones. En este caso se puede observar que la tensión máxima es de 30,589MPa, por tanto, de nuevo soportaría el esfuerzo exigido sobre este.

- PA_IT_003:

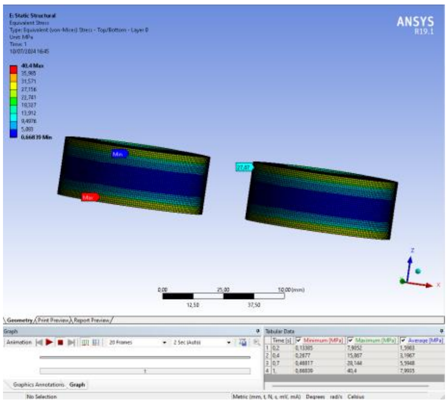

Ilustración 5: Resultados PA_IT_003

En este caso, el inserto es más complejo buscando aumentar al máximo la superficie de pegado para aumentar la resistencia. Sus resultados son excepcionales obteniendo una tensión máxima de 27,47MPa. Este es por tanto el mejor resultado de los tres tipos de inserto.

4. Conclusiones:

Los tres diseños serían válidos para ser empleados en las áreas donde la normativa exige soportar 30Kn de fuerza. En todos los casos las tensiones han sido inferiores, sin embargo, en el caso de los modelos PA_IT_001 y PA_IT_002 los resultados están muy cerca del límite del adhesivo. Por lo tanto, a partir de los resultados se deduce que lo ideal sería emplear el modelo PA_IT_001 para uniones de baja responsabilidad ya que es más económico. Por otro lado, las uniones de grandes exigencias deberían ser llevadas a cabo con el inserto PA_IT_003. En el caso del PA_IT_002 debería ser desechado ya que su resistencia es muy similar a la del PA_IT_001 y su coste es superior.

El coste de la fabricación completa (insertos, adhesivo…) requiere una inversión mínima de 5185,26€, lo cual es demasiado elevado para el estado actual del proyecto. Mientras que el coste de los insertos supone únicamente el 6,6% del presupuesto, el adhesivo representa el 93,4% restante.

Insert:	Insert cost [€]:	Adhesive cost [€]	Cost [€]:
PA_IT_001	340,56	4844,7	5185,26
PA_IT_002	412,72	4844,7	5257,42
PA_IT_003	555,28	4844,7	5399,98

Tabla 1: Tabla de costes

Teniendo todo esto en cuenta se concluye que no sería aplicable a corto plazo en el proyecto y que sería necesario continuar optimizando el modelo además de buscar nuevas formas de financiación.

5. **Referencias:**

[1] Formula Student Spain

Available: https://www.formulastudent.es/

[2] Manuel de Oña García-Matres. Universidad Politécnica de Madrid. Diseño y optimización de anclajes en paneles sandwich para estructuras monocasco.

[3] European Cooperation for Space Standardization (ECSS). "Space engineering. Design handbook"

COMPOSITE MONOCOQUE FS CHASSIS: DESIGN OF CO CURED OR BONDED-IN METALLIC INSERTS

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Collaborating entity: ICAI – Universidad Pontificia Comillas.

ABSTRACT

Key words: metallic inserts, monocoque, finite elements, simulation, structural adhesive, standards, manufacturing cost and composite materials.

1. **Introduction:**

This project aims to design and develop the metallic inserts needed for the first carbon fiber monocoque of the ISC Formula Student team. Formula Student is a competition where teams from universities around the world compete developing prototypes of combustion, hybrid and electric vehicles. The events are divided into dynamic and static, evaluating not only the performance of the car, but also the engineering behind its design. The aim of this project is to lay the design foundations that can be used during the manufacture of the team's first monocoque chassis.

Figure 1: ISC Racing Team [1]

The automotive industry is based on continuous improvement and the relentless pursuit of design limits. From the structural point of view, this innovation is found in composite materials, which are an excellent alternative to other traditional construction methods such as steel or aluminum.

Their main advantage over other manufacturing methods is weight reduction. In the case of the monocoque chassis, these materials have exceptional torsional stiffness and fatigue strength. However, their weak point is when these materials are subjected to punctual stresses. In order to adapt these structures in the best possible way, metallic inserts are used to

transmit the various forces to the structure. A thorough design of the inserts is therefore necessary, and they can be of different types:

- Hot bonded inserts: these inserts are introduced during curing of the composite material, using structural adhesives. They offer high strength and reduce manufacturing time, although they require special attention to establish the final location of the insert taking into account thermal expansion.
- Cold bonded inserts: they are added after curing of the panel by drilling the composite material and applying the adhesive. They offer good stiffness and flexibility in fabrication but have less strength than hot-embedded inserts and increase fabrication time.
- Surface-bonded inserts: These are bonded directly to the panel surface with adhesive. They are easy to locate but have low strength due to their unique dependence on the properties of the adhesive.
- Threaded inserts: they use the deformation of the insert to secure the bond, similar to the operation of a rivet. They are cheaper than the others, lightweight and easy to locate, but they easily damage the panel surface and do not offer high strength, depending heavily on the quality of the composite material.

In this project it has been decided to opt for cold bonded inserts, as they have good properties, are more economical and give greater flexibility in manufacturing.

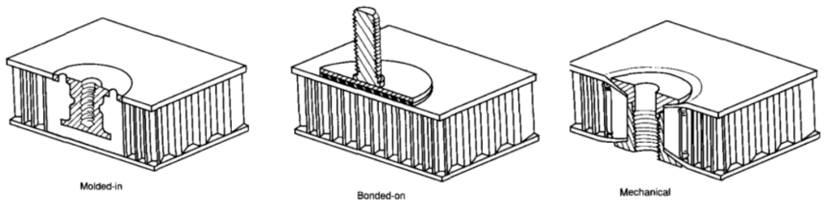

Figure 2: types of inserts [2]

2. Methodology:

The study has been carried out following the design guidelines established by the regulations of Formula Student Germany, the most demanding competition in which the ISC Racing Team participates. Recommendations of the ECSS (European Cooperation for Space Standardization) have been followed, which establishes a series of guidelines in the design of cold-embedded inserts. [3]

The ECSS guidelines have been used to establish a first design for the encapsulation diameter of the insert and subsequently this preliminary design has been iterated. The design has been modelled using SolidWorks

software and iterations have been carried out with different finite element modules included in ANSYS software.
For the design and modelling stage, the SES (Structural Equivalency Spreadsheet) has been used as a form of verification, since this is the guide that facilitates the competition for the design of the elements of the monocoque chassis.
As for the simulations, special attention has been paid to the meshing of the different components as it is fundamental to guarantee the accuracy of the results. In order to guarantee the quality of the mesh, an "element quality" of 0.95 and a "skewness" of less than 0.1 have been looked after in the adhesive. On the other hand, simulations have been carried out by modifying the mesh until the results were invariant.
To carry out the simulations, the "ACP" module was used to model the composite material and then study it together with the inserts and the adhesive in the "Static Structural" module.

3. Results:

In order to carry out the simulations, the carbon fiber laminate on the adhesive has been neglected, which concentrates more stress on the adhesive. Doing this introduces a certain safety factor on the results. On the other hand, it is essential to understand how finite element simulations work in order to interpret the results. They interpolate results through nodes of elements that are next to each other, therefore, in areas such as corners the results may not be accurate as they cannot be compared with a nearby element. Therefore, the maximum stresses to be considered are those found in the element upstream of the corners. The results obtained are shown below:

- PA_IT_001:

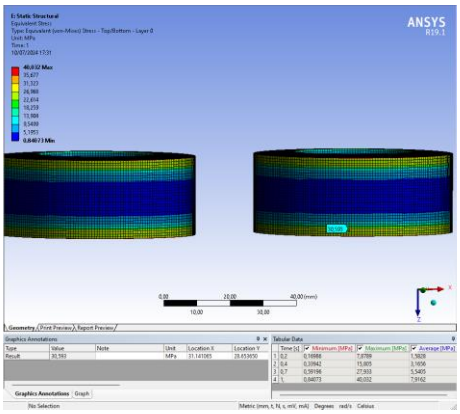

Figure 3: Results PA_IT_001

This insert has the simplest and most economical design. It can be observed that the maximum stress presented by the adhesive after the test is 30.593 MPa. Taking into account that the adhesive has an elastic limit against shear stresses of 31.6MPa, it can be confirmed that this pair of inserts would withstand a force of 30Kn.

- PA_IT_002:

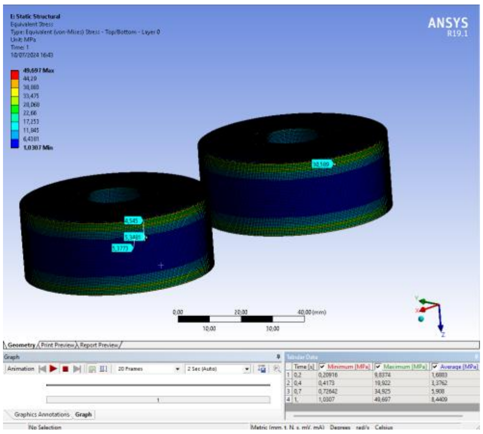

Figure 4: Results PA_IT_002

This insert has a conical design, so that its geometry helps to better distribute the stresses. In this case it can be observed that the maximum stress is 30.589MPa, therefore, it would again support the stress required on it.

- PA_IT_003:

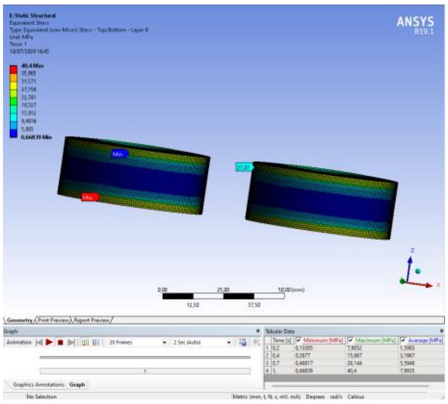

Figure 5: Results PA_IT_003

In this case, the insert is more complex, seeking to maximize the bonding surface to increase strength. Its results are exceptional, obtaining a maximum tension of 27.47MPa. This is therefore the best result of the three types of insert.

4. Conclusion:

All three designs would be valid for use in areas where the regulations require 30Kn of force to be withstood. In all cases the stresses have been lower, however, in the case of models PA_IT_001 and PA_IT_002 the results are very close to the limit of the adhesive. Therefore, from the results it can be deduced that the PA_IT_001 model should ideally be used for low responsibility joints as it is more economical. On the other hand, high responsibility joints should be carried out with the PA_IT_003 insert. In the case of PA_IT_002 it should be discarded as its strength is very similar to PA_IT_001 and its cost is higher.

The cost of the complete fabrication (inserts, adhesive...) requires a minimum investment of 5185,26€, which is too high for the current state of the project. While the cost of the inserts represents only 6.6% of the budget, the adhesive represents the remaining 93.4%.

Insert:	Insert cost [€]:	Adhesive cost [€]	Cost [€]:
PA_IT_001	340,56	4844,7	5185,26
PA_IT_002	412,72	4844,7	5257,42
PA_IT_003	555,28	4844,7	5399,98

Table 1: manufacturing cost table

Taking all this into account, it was concluded that it would not be applicable to the project in the short term and that it would be necessary to continue optimizing the model in addition to seeking new forms of financing.

5. Bibliography:

[1] Formula Student Spain

Available: https://www.formulastudent.es/

[2] Manuel de Oña García-Matres. Universidad Politécnica de Madrid. Diseño y optimización de anclajes en paneles sandwich para estructuras monocasco.

[3] European Cooperation for Space Standardization (ECSS). “Space engineering. Design handbook”

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Abbreviations:

SES	Structural Equivalency Spreadsheet
IMD	Insulation Monitoring Device
UD	Unidirectional
FS	Formula Student
AIP	Anti-Intrusion Plate
MH	Main Hoop
MHB	Main Hoop Bracing
FH	Front Hoop
FHB	Front Hoop Bracing

Introduction:

The goal of this project is to design and develop co cured or bonded-in metallic inserts for the first ISC Formula Student Racing Team carbon fiber monocoque. These inserts would seek to comply with Formula Student regulations. The project would take into account different analysis such as FEA simulation, CAD design and cost analysis.

Formula student:

Formula student is a competition where teams from different universities of the world challenge each other capacities. In this competition each university develops its own single-seater formula prototype (combustion, electric or hybrid) which will race in different events. These events are divided in two groups: dynamic and static events. The aim of these events is to evaluate not only the performance of the car but also the engineering behind its design.

In order to compete in formula student, the prototype must comply some strict regulations which have to do with different areas of the car. The single seater must pass all the inspections to be able to race.

These inspections aim to make the vehicle as safe as possible and cover all risk areas of the prototype:

- Pre-inspection: for this inspection it is necessary to present all the helmets and pilot's clothing that are going to be used. It is compulsory to present two fire extinguishers that comply with the electrical extinguishing standard, one set of dry and one set of wet wheels.
- Electrical inspection: The accumulator will be inspected in order to ensure that comply all the rules. If this inspection is approved, it will be sealed to prevent that any team modify it after the inspection. The accumulator handcart and the rest of the vehicle's electrical components will also be checked. All the documentation that has to do with the safety of this part of the car must be presented.

- Mechanical inspection: in this section all the mechanical elements of the vehicle will be checked in order to ensure rules compliance. All relevant measurements will be made with the tallest driver. As in the electrical inspection, the team is responsible of bringing the necessary documentation to prove any judge request.
- Tilt test: The purpose of this test is to analyze the vehicle respond in situations that could lead to a rollover. A test is realized by placing the prototype with the highest driver at an angle of 60 degrees with respect to the horizontal. To pass this inspection, there can be no fluid leaks and no wheels can be lifted off the platform.
- Vehicle weighing: the vehicle will be weighed with all liquids at their maximum level.
- Rain test: the vehicle will be sprayed with water for an interval of 120 seconds. Once this time has elapsed, the team will wait another 120 seconds and after this time period the insulation of the prototype is measured. If the IMD is activated, the inspection will be considered as failed.
- Brake test: in this test the team must demonstrate that the car is able to lock all four wheels in case of an emergency braking.

Figure 1: Tilt test

After each dynamic test, a post-inspection will be done to the vehicle to ensure that no deliberate attempt has been made to violate any rules in order to obtain performance.

Figure 2: Formula Student [4]

The team will also be evaluated through static tests in order to evaluate their ability as a company and to demonstrate the reasoning behind their decisions:

- Business plan: in this event, a real or fictitious business model must be created around the car in order to use the car not only as a competition vehicle. The team must try to convince the judges that they should invest in their project.
- Cost and manufacturing event: This event consists in showing the manufacturing processes and costs that the team has been done. With this guide the jury should be able to recreate the vehicle with the same budget.
- Design event: the judges will evaluate the engineering aspects of the vehicle. It will be judged that the technical decisions have been the right ones according to the economic context of the team.

The dynamic events include the following tests: acceleration, skidpad, autocross and endurance. Each of these disciplines try to evaluate different areas of the vehicle:

- Acceleration: This test evaluates the acceleration capacity of the prototype, for which a 75-meter straight line is available. The team that reaches first the end of the straight from a standstill start will receive the maximum score.
- Skidpad: This test evaluates the vehicle's ability in the corners. For this purpose, a figure-eight circuit is made and two complete circles will be timed.
- Autocross: This test tries to evaluate the maximum capacity of the vehicle in all areas. In order to do so a lap must be completed in the shortest time possible. The maximum score goes to the team that does this lap in the shortest time and it will also determine the starting order for the endurance test.
- Endurance: This is the toughest test for an electric single-seater. It evaluates not only its performance but also its autonomy. The score depends on the time it takes to complete the 22-kilometer circuit and the state of charge that the vehicle has when the race is finished.

The distribution of points in the competition is shown in figure 3:

	CV & EV	DC
Static Events:		
Business Plan Presentation	75 points	-
Cost and Manufacturing	100 points	-
Engineering Design	150 points	150 points
Dynamic Events:		
Skidpad	50 points	-
Driverless (DV) Skidpad	75 points	75 points
Acceleration	50 points	-
Driverless (DV) Acceleration	75 points	75 points
Autocross	100 points	-
Driverless (DV) Autocross	-	100 points
Endurance	250 points	-
Efficiency	75 points	-
Trackdrive	-	200 points
Overall	1000 points	600 points

Figure 3: points distribution

ISC FS Racing Team:

ISC FS Racing Team is the project that the students from the Pontifical university of ICAI develop. This team was founded in 2017 by a group of students with the goal of designing and manufacturing a racing car. During the following years the project has grown rapidly, which lead to continuous innovation.

In 2023 the IFS-05 was the first prototype to compete in all the dynamic events, finishing P7 in the overall classification of Formula Student Spain. The ISC has the goal of improving these result year by year, reaching the conclusion that an area of improvement is reducing car weight. In order to reduce mass some research about composite materials has been done.

One of the parts that suppose mass in the car is the chassis, because of that, we have been analyzing different alternatives. We are currently using a space frame chassis; however, we have made some research in hybrid and full monocoque chassis structures. These researches have focused on the structure and they didn't take into account how things should be integrated in the car.

The aim of this project is to design and simulate metallic inserts that complete previous information about monocoque and give the team the opportunity to manufacture its first monocoque. These inserts are used to attach all the components of the car to the monocoque chassis, and they must support all the loads transferred to the chassis.

Figure 4: ISC Formula Student Racing Team [4]

Motivation:

I have been working in the ISC FS Racing Team since I joined the Pontifical University of ICAI. During these years we have work very hard to manufacture the best prototype we can, and we are sure that if we want to keep improving, the next step should be a prototype with a monocoque chassis. This project represents the final stage of the design of a monocoque chassis. Taking the monocoque design by Miguel Torrens I will design the metallic inserts that will allow us to have a fully functional monocoque chassis design. [1]

Furthermore, this project will lead us into the use of composite materials that are essential in high-technology mobility projects due to their properties. This project will introduce us to the composite materials world which will be very useful for future generations.

Project objectives:

The idea of this project is to complete Miguel Torrens chassis in order to have a completely functional monocoque. The main objectives are:

- Design co-cured or bonded-in metallic inserts that are able to comply Formula Student rules.
- Develop a FEA model that is able to simulate the behavior of the inserts under certain forces. This simulation must comply with Formula Student rules.
- Reach a fully design Formula Student monocoque.

Manufacturing these inserts with a monocoque will be a long-term objective that during the following years will be reached.

State of art:

Facing the necessity of continuing to improve and looking after the limits of design we find composite materials. These materials represent a great alternative to other traditional constructive methods such as steel or aluminum due to its strength and lightness properties.

These composite materials allow us to substitute the traditional space frame chassis (steel) by a continuous structure, a monocoque. Carbon fiber monocoques are an excellent alternative due to their high torsional stiffness and their fatigue resistance. However, these chassis are vulnerable when they face punctual forces. Therefore, it is essential to carry out an exhaustive study to design the way we attach the different elements (suspension, engine…) to the chassis since it will determine how we transmit the specific loads into it. The way we transmit these loads is through inserts that can be of many types.

Types of inserts:

Embedded inserts

This kind of inserts are those that are introduced inside the sandwich panel and are bonded using adhesive and co-cured with the fiber. They can be divided into two sub-groups depending on the joining process:

- **Hot bonded inserts:**

  These inserts are introduced while the composite material is being cured. They can use foaming or epoxy adhesive in this process to join the panel. This type of insert is characterized for using a through the thickness encapsulation.

  When the inserts are co-cured with the sandwich panel their resistance is very high which make these inserts the most reliable ones. Furthermore, weight reduction can be increased by using foaming adhesives that have very low density. Another advantage of these inserts is that manufacturing time is reduced because they need fewer thermal cycles than other type of inserts. They do not introduce new thermal stages as they are integrated during sandwich panel curing process.

Nevertheless, these inserts have some disadvantages. They are not as flexible as other inserts in the manufacturing process because they need location methods, which can become complex as the insert needs to stay in place during curing process. Metal pins are used to guarantee that the final position of the insert is the desire one, in this case, thermal expansion needs to be accounted for.

- **Cold bonded inserts:**

These inserts are joined once the sandwich panel has cured and they are introduced by drilling a hole and subsequently applying an adhesive. These inserts can be fully encapsulated or partially encapsulated.

These inserts offer good stiffness, however, they are not as resistant as hot bonded ones. They provide flexibility in manufacturing techniques allowing a great range of curing temperatures depending on the adhesive that is used and adapting very well to different types of monocoque manufacturing methods. Furthermore, the location of the inserts depends on the precision of the operator. They are also an affordable adhesive option as the price depends mainly on the epoxy adhesive that is going to be used.

However, these inserts represent more manufacturing time due to the addition of extra stages in the manufacturing process (additional thermal cycle is require for curing the injected adhesive foam) and an increasing mass compared to the hot bonded inserts. Moreover, there are some possibilities of damaging the carbon fiber skins while drilling the panel. In order to introduce the cold bonded insert into the existing sandwich panel it is necessary to drill a hole into the skin and core that may crack the panel.

Surface-bonded inserts:

This type of inserts is characterized for being bonded directly to the surface of the sandwich panel using an adhesive. They base their resistance on the shear capacity of the adhesive.

Adhesive inserts have as their main advantage that their location is easy to carry out. However, the resistance is very low due to its huge dependency on the adhesive. Furthermore, they significantly increase the weight because they require bigger adhesive surface.

Threaded inserts:

This kind of inserts use the deformation of the insert to secure the joint, their behavior is very similar to a rivet. These inserts are problematic because they easily damage de skin of the sandwich panel. They do not acquire great resistance and depend strongly on the quality of the skins since they tend to separate when they are torn locally. Nevertheless, they are very cheap, light and easy to locate. [2]

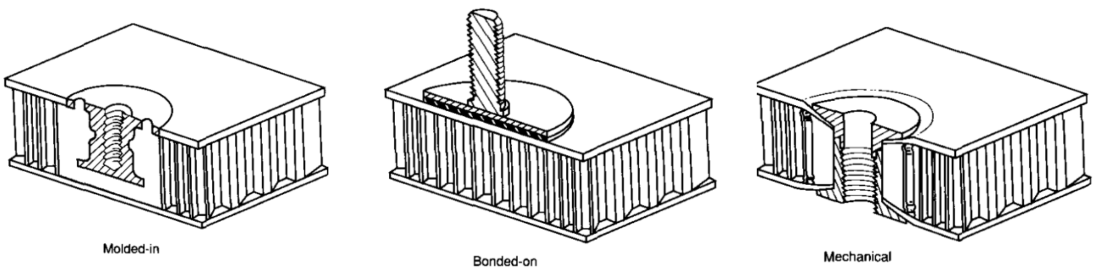


Figure 5: types of inserts [2]

Embedded inserts attend to other classification that affect their behavior. They can be manufactured in three different ways depending on the encapsulation of the insert:

- Fully potted inserts: the length of the insert is smaller than the encapsulation which is the same as the core. This configuration is commonly used in cold bonded inserts.
- Partially potted inserts: this is a particular case of the fully potted inserts. It is commonly used in cold bonded inserts. The application of the adhesive experienced some problems due to external factors (temperature, air…) and the curing time is accelerated, preventing the entire size of the core from being filled. In this case, the length of the insert is smaller than the encapsulation and smaller than the core.
- Through-the-thickness inserts: the length of the insert is the same as the encapsulation and the same as the core. The total length of the insert is the core plus the skins. This configuration is commonly used in hot bonded inserts.

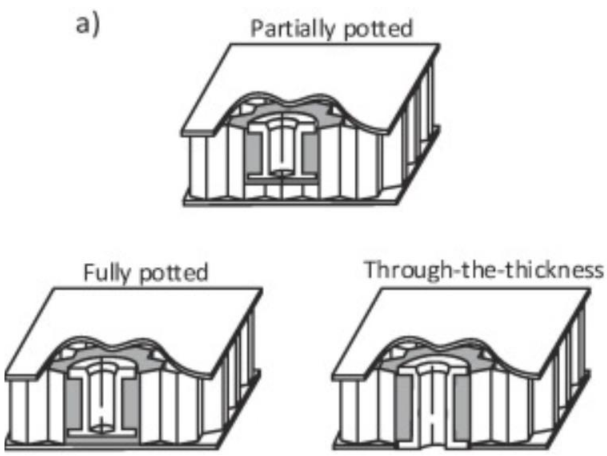


Figure 6: types of inserts depending on the encapsulation [5]

Sandwich panel:

The sandwich panel is the structure that conform the monocoque. It consists of two carbon fiber reinforced polymer (CFRP) skins joined by a core (aluminum, Nomex…). The principal advantage of this structure is that stiffness is easily obtained by increasing the thickness of the sandwich panel without increasing too much mass.

Each part of the sandwich panel faces different types of forces. The function of the core is to resist shear forces outside the plane of the panel without increasing excessively the mass of the assembly. When the panel face other types of loads, its characteristics are usually disregarded. There are many types of cores, although the most common ones can be: aluminum honeycomb, Nomex or foams.

The skins are responsible for facing the rest of stresses that appear in the panel, especially axial loads. The skins have a huge variety of configurations, from fiber unions such as carbon fiber or fiber glass to solid skins such as aluminum sheets. Nevertheless, all skins have in common that they have a higher yield strength than the core.[3]

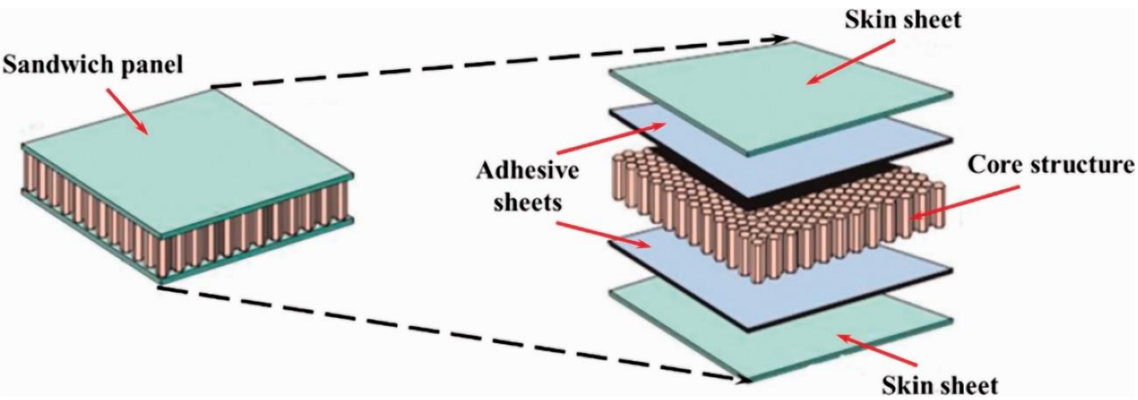


Figure 7: sandwich panel [12]

Theoretical analysis:

Formula Student rules:

In order to be suitable to race in the different competitions of Formula Student the inserts must comply FSG (Formula Student Germany) 2024 V1.1 rules. These rules are known for being more demanding than FSAE (Formula Society of Automotive Engineers) rules.

FSG 2024 V1.1 : [6]

T3.16 Bolted Primary Structure Attachments [6]

T3.16.1 If two parts of the primary structure are bolted together, each attachment point between the two parts must be able to carry a load of 30 kN in any direction.

T3.16.2 Data obtained from the laminate perimeter shear strength test must be used to prove that adequate shear area is provided.

T3.16.3 Each attachment point requires a minimum of two 8 mm metric grade 8.8 bolts and steel backing plates with a minimum thickness of 2 mm.

T3.16.4 For the attachment of front hoop bracing, main hoop bracing and main hoop bracing support to the primary structure the use of one 10 mm metric grade 8.8 bolt is sufficient, if the bolt is on the centerline of the tube, see figure 11.

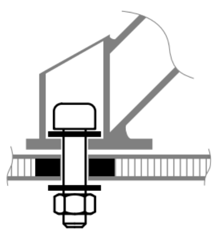


Figure 8: bolted roll hoop bracing support [6]

T3.16.5 When using bolted joints within the primary structure, no crushing of the laminate core material is permitted.

T3.16.6 For the AIP to front bulkhead attachment, and if two panels or plates of the primary structure are bolted together, for each 200 mm of reference perimeter a minimum of one 8 mm metric grade 8.8 bolt(s) must be used, rounded up to the next integer. Smaller, but more, bolts may be used, if equivalency is shown. The bolts must be evenly distributed over the circumference using good engineering practices. The reference perimeter is the outside perimeter of the attached part at the connection. The bolts are considered critical fasteners and must comply with T10.

T4.5 Driver's Harness Attachment [6]

T4.5.1 Any harness attachment to a monocoque must be using one 10 mm metric grade 8.8 bolt or two 8 mm metric grade 8.8 bolts (or bolts of an equivalent standard) and steel backing plates with a minimum thickness of 2 mm.

T4.5.2 Any harness that is fastened to the primary structure using brackets must use two 8 mm metric grade 8.8 or stronger fasteners.

T4.5.3 It must be proven that the attachments for shoulder and lap belts can support a load of 13 kN and the attachment points of the anti-submarine belts can support a load of 6.5 kN.

T4.5.4 If the lap belts and anti-submarine belts are attached less than 100 mm apart, these must support a total load of 19.5 kN.

T4.5.5 If the belts are attached to a laminated structure or the mounting brackets and tabs are not made from steel at least 1.6 mm or aluminium at least 4.0 mm thick, physical testing is required. The following requirements must be met:

- Load is applied to a test sample representing the tubular or laminated structure and must use the same brackets and tabs

• Edges of the test fixture supporting the sample must be a minimum of 125 mm from the load application point.

• The width of the shoulder harness test sample must not be any wider than the shoulder harness panel height used to show equivalency for the shoulder harness mounting bar.

• Designs with attachments near a free edge must not support the free edge during the test.

• Harness loads must be tested with the worst case for the range of the angles specified for the driver's harness.

EV5.5 Tractive System Energy Storage – Mechanical Configuration [6]

EV5.5.13 Any brackets used to mount the TSAC must be made of steel 1.6 mm thick or aluminium 4 mm thick and must have gussets to carry bending loads. Each attachment point including brackets, backing plates, and inserts, must be able to withstand 20 kN in any direction.

Insert design handbook:

The *European Cooperation for Space Standardization* give some advice in terms of inserts design. In the case of this project, we are interested in the ones that apply for cold bonded inserts. Some of the most important ones are collected in the following sections: Design aspects, design considerations and design flowchart. The main ideas are: [8]

- The encapsulation must have at least 1.5 times the radius of the insert in order to guarantee a correct join.
- To guarantee that the tension spikes between the core and the adhesive are distributed correctly the adhesive must be between 3 to 4 times more rigid. The adhesive is in charge of facing the tangential stress which helps with the total capacity.

- It is useful to reinforce locally the area of the insert with carbon fiber. This reinforcement helps the insert to transfer shearing forces to the skins.
- The surface of the insert must be completely parallel to the skins of the sandwich panel in order to avoid getting under them. Furthermore, it is important to keep in mind that threaded inserts will tend to come off once the operator tries to screw them in. In this case, it is common to leave a small space in order to correct these movement.
- Adhesives are very sensible to temperatures. Their ideal range of work is between -160 to 40 degrees. Once 40 degrees are reach, adhesive properties start to decrease until 100 degrees when it completely loses its resistance.
- According to figure 7, ECSS explains that the inserts need to be a minimum distance from the edges in order to avoid shear-out failing.

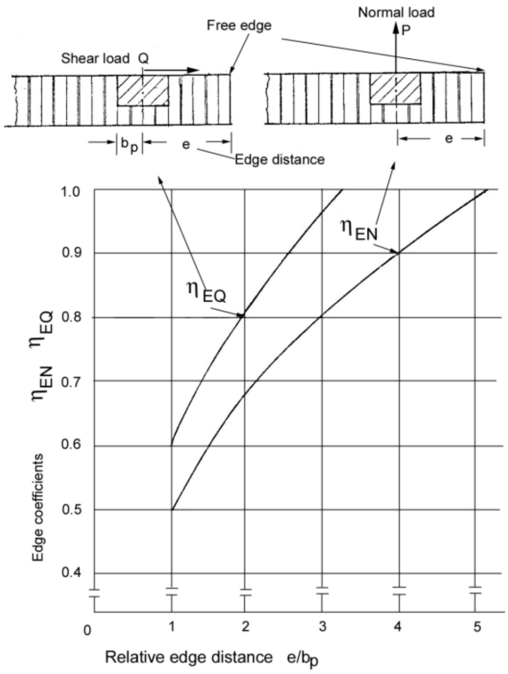


Figure 9: distance from edges [8]

- It is also important to take into account the distance between inserts. In this case, it depends on how the load is applied to the inserts:[8]
    - Two inserts loaded in same direction:

When two inserts are loaded in the same direction, and they are close enough their tension fields interact. Their strength capability is affected following equation 1:

$$P_{SS1}^{*} = \eta_{IS1} * P_{SS1}$$

Equation 1: reduce strength due to distance between inserts [8]

Where:

P_{SS1}^{*} is the capability of insert 1 after being affected by insert 2.

P_{SS1} is the initial capability of insert 1.

η_{IS1} is the interference coefficient between inserts.

The inserts are considered as close inserts if the distance between them is smaller than:

$$a \leq \ 5 * \left(b_{p1} + b_{p2}\right)$$

Equation 2: distance between inserts [8]

Where:

b_{p1} is potting for insert 1.

b_{p2} is potting for insert 2.

a is distance between centers.

In this case the interference coefficient is:

$$\eta_{IS1} = \frac{\frac{b_{p1}}{b_{p2}}}{1 + \frac{b_{p1}}{b_{p2}}} * \left(1 + \frac{a}{5 * b_{p1}} * \frac{1}{1 + \frac{b_{p1}}{b_{p2}}}\right)$$

Equation 3: interference coefficient between close inserts [8]

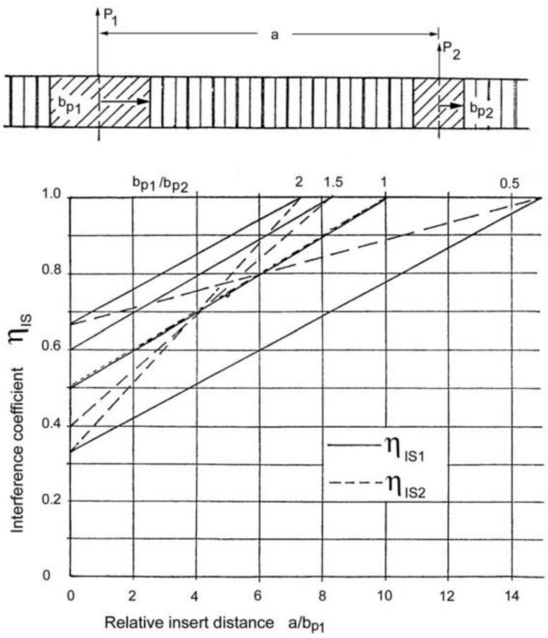


Figure 10: two inserts loaded in same direction [8]

- Two inserts loaded in opposite directions:

We can apply the same criteria to determine whether two inserts are close or not. If they are close their interference coefficient can be considered as:

$$\eta_{IS1} = 0.9$$

- Series of inserts loaded in same direction:

This distribution needs to be analyzed from two perspectives. The reduced capability is studied between first and last insert following the procedure of two inserts loaded in same direction.

Intermediate inserts have also need to be analyzed. Intermediate inserts are mainly affected by their adjacent ones. Their capability follows:

$$P_{SS1}^{*} = (\eta_{ISl} + \eta_{ISr} - 1) * P_{SS1}$$

Equation 4: capability reduction of series of inserts loaded in same direction [8]

Where:

η_{ISr} is the interference coefficient created by the right insert.

η_{ISl} is the interference coefficient created by the left insert.

- Series of inserts loaded in opposite directions:

These configuration follows a similar procedure to the ones in same direction. In this case, for first and last insert we use the following equation:

$$P_{SS1}^{*} = \eta_{IS1} * P_{SS1} * \eta_{IC}$$

Equation 5: capability reduction of series of inserts loaded in opposite direction [8]

Where:

η_{IC} is 0.9 for close inserts.

In the case of intermediate inserts, we use:

$$P_{SS1}^{*} = \eta_{IC} * (\eta_{ISl} + \eta_{ISr} - 1) * P_{SS1}$$

Equation 6: capability reduction of intermediate inserts [8]

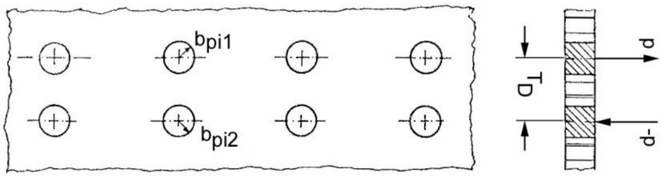


Figure 11: series of inserts loaded in opposite directions [8]

- Groups of inserts loaded in same direction:

This type of configuration is analyzed by the following equation that relates equal and equidistant inserts:

$$P_{SS}^{*} = \eta_G * P_{SS}$$

Equation 7: capability reduction of groups of inserts [8]

Where:

η_G is the interference coefficient for a group of equidistant inserts.

$$\eta_G = 2 * \left(\frac{n-1}{n} * \eta_{IS} + \frac{1}{n} - 0{,}5\right)$$

Equation 8: interference coefficient of a group of inserts [8]

Where:

n is the number of inserts.

η_{IS} is the interference coefficient for two inserts loaded in the same direction.

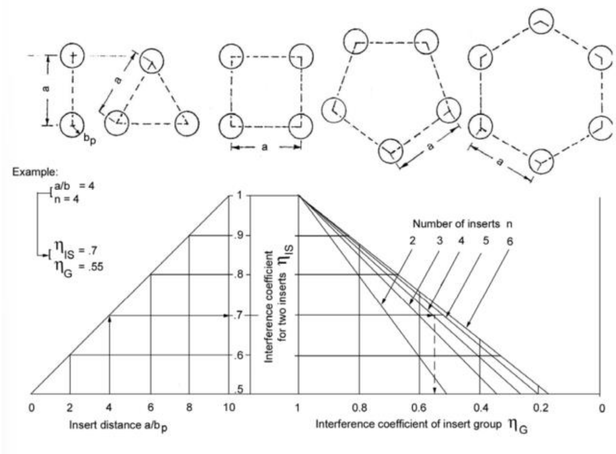


Figure 12: group of inserts loaded in same direction [8]

Input parameters:

Taking all these rules into account we can briefly summarize the rules about maximum loads in the following table:

Structure	Main hoop	Front Hoop	Main hoop bracing	Accumulator	Harness
Load (KN)	30	30	30	20	19,5

Table 1: maximum loads [6]

Throughout this project, only these force cases will be studied, as the rest of the vehicle components do not have higher structural demands. The suspension members are one of the most critical parts in terms of load transfer. However, the rules don't specify which load the inserts of the suspension member must support. According to the design of the suspension, the expected forces are described in the following tables 2 and 3:[7]

Highest operating force front suspension (N)						
Tie/Toe	Up-Fore	Up-Aft	Low-Fore	Low-Aft	Push/Pull	
Fatigue	-165	-1874	-11370	-4314	-515	-1510
Buckling	6701	3035	1748	5886	2541	1566
Comp	6701	3035	1748	5886	2541	1566
Tens	-165	-2503	-16754	-5733	-961	-2302

Table 2:Highest operating force front suspension [7]

Highest operating force rear suspension (N)						
Tie/Toe	Up-Fore	Up-Aft	Low-Fore	Low-Aft	Push/Pull	
Fatigue	-279	-1659	-9371	-7735	-492	-1032
Buckling	6701	2916	5878	2927	4632	4003
Comp	6701	2916	5878	2927	4632	4003
Tens	-165	-2343	-14377	-12776	-811	-1427

Table 3:Highest operating force rear suspension [7]

According to the results, the highest load is 16754N. The load expectance has been over dimensioned so we can ensure that the real force is lower than 16754N. In this project we will consider an additional safety factor for these forces of 1,2 which assume a maximum force of 20KN. Furthermore, these forces have been proved by real testing with the car so we can ensure that are trustworthy.

Basic theory of inserts:

When designing inserts for sandwich panels we can consider 5 different ways of transferring loads:

- Tensile: In this case, the load is normal to the plane, and it pulls away from the surface, see figure 13. This case is commonly known as pull-out.

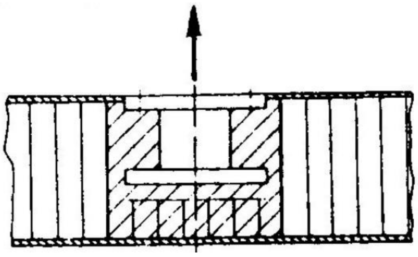


Figure 13: pull-out [8]

- Compressive: As in the tensile case the load goes perpendicular to the plane, however, in this case the force goes towards the surface, see figure 14.

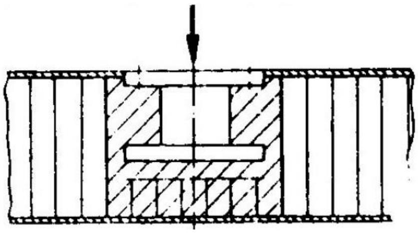


Figure 14: compressive [8]

- Shear: The load is in the plane of the surface, see figure 15.

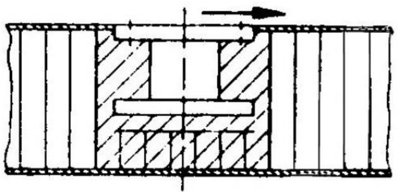


Figure 15: shear [8]

- Bending: The load is transferred as a torque in plane XZ, see figure 16. It is also known as rotation.

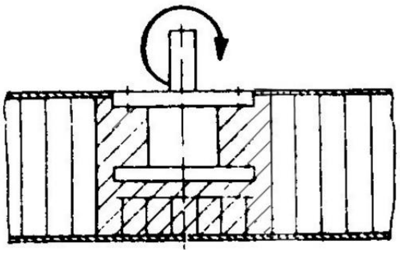


Figure 16: rotation [8]

- Torsion: The load is transferred as a torque in plane XY, see figure 17. It is also known as torque-out.

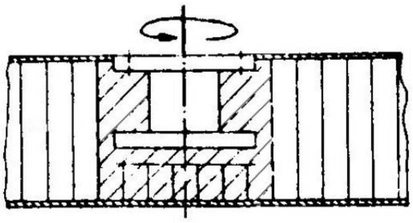


Figure 17: torque-out [8]

According to the design handbook, the most relevant loads that have to be considered in the analysis of inserts are out-plane loads (pull-out and compressive) and in-plane loads (shear). The failure mode of the panel depends mainly on the way the load is applied.

- Out-plane loads:

The failure mode of these kind of forces is directly related with the thickness of the core. Most of the times the failure is in the joint between the honeycomb and the potting. However, in some cases, the failure mode has its origin in the honeycomb or in the encapsulation.

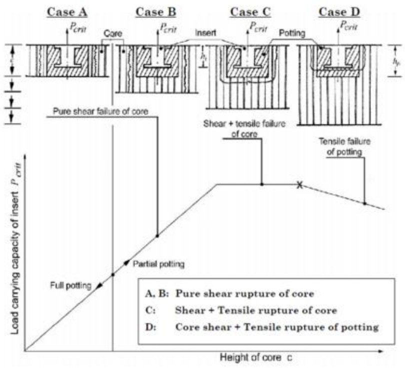


Figure 18: out-plane failure modes [8]

- In-plane loads:

These kinds of loads induce four types of failure modes:

- o <u>Tensile</u>: this failure mode appears in large panels without near edges. As it is shown in figure 19, the failure starts with a small crack and grows.
- o <u>Shear-out</u>: this failure mode appears in panels where the edges are near to the hole.
- o <u>Dimpling</u>: this failure mode is not critical unless it spreads through the hole panel (wrinkling). It appears in honeycombs with big cells. When the panel is submitted to compression forces the face sheet can buckle.
- o <u>Bearing</u>: this failure mode occurs when the diameter of the hole is small in comparison with the edge distance and the width of the panel.

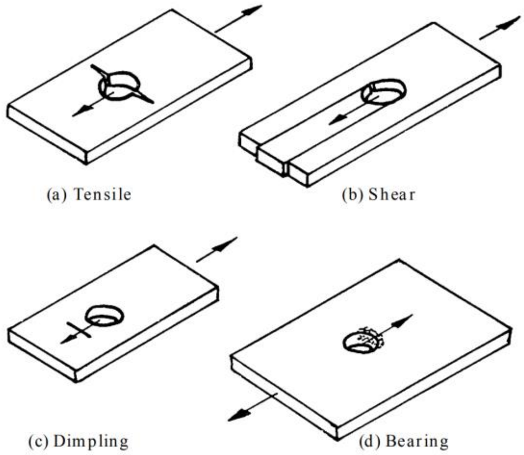


Figure 19: in-plane failure modes [8]

Analytical models:

The capability of inserts for sandwich structures can be analyzed by some theoretical calculations. This analysis started in 1953 when Ericksen studied deeply what happen with the introduction of loads in the sandwich panel. However, this model was proposed for rivet inserts, and it was not until 1981 when Hertel modified and adapted it to encapsulated inserts. [8]

This Ericksen-Hertel model is accepted by the ECSS, nevertheless, there are some differences with the experimental models. As it was mentioned in the previous part, the forces that are considered in the analysis are the out-plane and in-plane ones. In order to establish the capability of the insert, we study a force F that is divided in two components, P and Q, as It is shown in figure 20. Force P is representing the pull-out force while Q is representing the shear component of every force. F describes an ellipse that has its bigger axle in-plane forces. Because of that, the maximum capability of an insert is mostly determined by its shear component. The only forces that will faces are the out-plane ones, because of that, these are the ones to be studied.

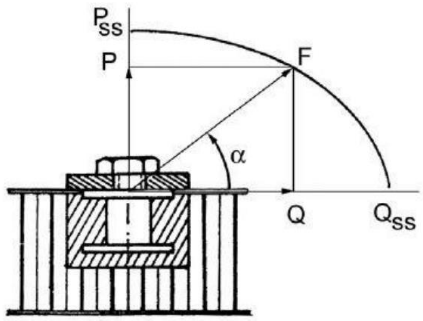


Figure 20: forces analysis [8]

We can define the used insert capability as:[8]

$$C_{ss} = \left[\left(\frac{P}{P_{ss}}\right)^2 + \left(\frac{Q}{Q_{SS}}\right)^2\right] * 100$$

Equation 9: used insert capability [8]

Where:

P_{ss} is the static capability in pull-out conditions.

Q_{SS} is the static capability in shear conditions.

Ericksen-Hertel analysis:

[9] There is a huge relation between the distance to the insert center and the core shear stress. Indeed, the core shear stress is inversely proportional to the center distance $\tau_{c,rz}(r) = f(\frac{1}{r})$. According to Hertel model, the maximum core shear stress appears in the middle of the sandwich thickness where the sandwich joins with the potting.

This relation can be used to determine the radius of the insert, including potting. The minimum radius is equal to the $\tau_{c,rz,critic}$.

$$\tau_{c,rz,critic} = \tau_{c,rz,max}\left(r = \frac{d_{p,min}}{2}\right)$$

Equation 10: critical core shear stress [8]

This $\tau_{c,rz}(r)$ can be modelled as: $\tau_{c,rz\ (r)=\frac{Q(r)}{A(r)}}$

Where:

Q(r) is the core shear force.

A(r) is the core shear area. $A(r) = \pi * d_{p,min} * h$

h is the core height.

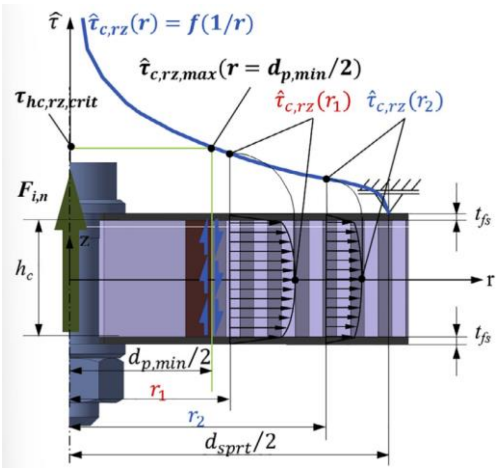


Figure 21: shear stress distribution [9]

Hertel took Ericksen model and established the core shear stress distribution as:

$$\tau_{c,rz}(r) = \frac{F*I_{fs}}{\pi*I_{ds}*(h+h_{fs})}*\left[\frac{1}{r}-\frac{I_1(\alpha*r)}{a*b}*\left(\frac{b*K_1(\alpha*b)-a*K_1(\alpha*a)}{I_1(\alpha*a)*K_1(\alpha*b)-I_1(\alpha*b)*K_1(\alpha*a)}\right)-\frac{K_1(\alpha*r)}{a*b}*\left(\frac{a*I_1(\alpha*b)-b*I_1(\alpha*a)}{I_1(\alpha*a)*K_1(\alpha*b)-I_1(\alpha*b)*K_1(\alpha*a)}\right)\right]$$

Equation 11: core shear stress distribution [8]

Where:

h_{fs} is the height of the skins.

a is the radius of the bearing support of the core.

b is the insert radius.

$I_1(\alpha * r)$ and $K_1(\alpha * r)$ are the Bessel functions.

I_{fs} is the moment of inertia of each face sheet.

I_{ds} is the moment of inertia of the face sheets of the sandwich.

F is the applied force.

α is a coefficient that represents the distribution of the shear stress between the skins and the core. If this coefficient is greater than 0,4 it can be neglected as there is no implication between the shear stress and the skins.

$$\alpha = \sqrt{\frac{G_{eff}*(t_1+t_2)}{\left(\frac{E_{eff}}{1-v_{eff}^2}\right)*h*t_1*t_2}*\frac{I_{ds}}{I_{fs}}}$$

Equation 12: coefficient of shear distribution between skins and core [8]

Where:

G_{eff} is the effective shear modulus. Which can be obtained as $G_{eff} = \frac{G}{3}$.

E_{eff} *is the effective young modulus.*

v_{eff} is the effective Poisson coefficient.

According to the ECSS the correct procedure for obtaining the E_{eff} and the v_{eff} is:

$$E_{eff} = \sqrt{E_{t1} * E_{t2}}$$

Equation 13: effective young modulus [8]

$$v_{eff} = \sqrt{v_{t1} * v_{t2}}$$

Equation 14: effective Poisson coefficient [8]

After replacing the Bessel functions for their values, the equation gets simpler:

$$\tau_{c,rz}(r) = \frac{F * I_{fs}}{\pi * I_{ds} * (h + h_{fs})} * K(r, d_i, d_p, \alpha)$$

Equation 15: core shear stress distribution replacing Bessel functions [8]

Where:

$$K = \frac{d_i}{2*r} * \left[1 - \sqrt{\frac{2*r}{d_p}} * e^{\alpha*\left(\frac{d_i}{2} - r\right)}\right]$$

Equation 16: potting diameter contribution [8]

The diameter (d_p) is represented by the potting. It is not possible to obtain a perfect diameter of the adhesive, because of that, it is necessary to calculate an effective diameter of the adhesive $d_{p,eff}$. Hertel created a formulation to determine this effective diameter. This formulation depends on d_i/s_c ratio with "a" coefficient according to table 4. These coefficients depend on the source as the ECSS doesn't use the same as Hertel or Wolf-Brysch.

$$d_p = d_i * a_1 + a_2 * S_c - a_3$$

Equation 17: potting diameter [8]

A-coefficients according to Hertel, ECSS and Wolff–Brysch for perforated honeycomb material.

Source		a-coefficients			
Hertel [25], valid for all cell sizes S_c		($a_{i,min,He}$ *are not specified*) $a_{1,avg,He} = 1$ ($a_{i,max,He}$ *is not specified*)	$a_{2,avg,He} = 1, 6$	$a_{3,avg,He} = 0$	
ECSS [23], valid for all cell sizes S_c		$a_{1,min,ECSS} = 0, 93192$ $a_{1,avg,ECSS} = 1, 002064$ ($a_{i,max,ECSS}$ *arenotspecified*)	$a_{2,min;ECSS} = 1, 748$ $a_{2,avg,ECSS} = 1, 8888$	$a_{3,min;ECSS} = 1, 32302$ mm $a_{3,avg,ECSS} = 1, 4226$ mm	
Wolff-Brysch [34]		Cell size S_c			
		3, 2 mm(≈1/8″)	4, 8 mm(≈3/16″)	6, 4 mm(≈1/4″)	9, 6 mm(≈3/8″)
	$a_{1,min,WB}$ $a_{2,min;WB}$ $a_{3,min;WB}$	1, 059 1, 732 0	1, 0684 1, 67 0	1, 0737 1, 67 0	1, 0876 1, 6022 0
	$a_{1,avg,WB}$ $a_{2,avg;WB}$ $a_{3,avg;WB}$	1, 0478 2, 0986 0	1, 052 2, 064 0	1, 0563 2, 050 0[*mm*]	1, 0625 2, 0229 0
	$a_{1,max,WB}$ $a_{2,max,WB}$ $a_{3,max,WB}$	1, 0375 2, 456 0	1, 0417 2, 397 0	1, 0472 2, 373 0	1, 0433 2, 377 0

Table 4: a-coefficients [8]

Attachment CAD design:

In this part of the project, the location, design, and feasibility of the inserts will be studied based on their purpose. The number of inserts required in each area is established and justified in the following table:

Location	Nº of Inserts per attachment	Nº of attachments	Establish by:
Main hoop & main hoop bracing	2	6	SES
Front hoop & front hoop bracing	2	8	SES
Harness	2	4	SES
Accumulator	2	4	SES
Suspension	2	22	Suspension & Dynamics department

Table 5: inserts distribution

The number of attachments in the MH, MHB, FH, FHB, harness and accumulator is determined by the SES. However, the number of inserts per attachment is selected taking into account design considerations. In the case of the suspension, the department choose the location and the number of attachments while the number of inserts is free to design.

The diameter of the inserts will initially be 25mm as starting point, however, it will be adjusted based on the simulation results.

Structural equivalency spreadsheet (SES):

The SES is a guide that Formula Student competitions give to their participants with the aim of simplifying the way of proving the structural equivalency of their models. The Excel document goes through different areas of the car such us harness bars, laminate test results of different parts… In each area, the document informs about the state of your design: pass or fail. However, passing through all the SES requirements does not guarantee that the car is legal. The car is not considered legal until it passes the technical inspection during the competition. This tool is useful to start the design process of the inserts. [10]

Main hoop and Main hoop bracing attachments:

In this stage of the SES the following are checked:

- Each side of the main hoop has more than 2 attachment points.
- There is not more than 50mm between the lower attachments and the lower part of the hoop.
- Backing plate thickness is bigger than 2mm.
- Fastener diameter must be bigger than 8mm.
- Needs at least 2 fasteners per attachment.
- Welded distance must be at least 80mm.
- Tearout strength (N):

$$T_{Strength} = E_d * 2 * S_{strength} * 2 * Sth$$

Equation 18: tearout strength of the MH & MHB inserts [10]

Where:

E_d is the edge distance.

Sth is the skin thickness.

$S_{strength}$ is skin shear strength.

- Perimeter shear strength of the bracket (N):

$$P_{Bracket} = (p_{bracket} * Sth + p_{insert} * Sth) * S_{strength}$$

Equation 19: perimeter shear strength of the MH & MHB bracket [10]

Where:

$p_{bracket}$ is the bracket perimeter.

Sth is the skin thickness.

p_{insert} is the insert perimeter.

$S_{strength}$ is skin shear strength.

- Perimeter shear strength of the backing plate (N):

$$P_{Bplate} = \left(p_{Bplate} * Sth + p_{insert} * Sth\right) * S_{strength}$$

Equation 20: perimeter shear strength of the MH & MHB backing plate [10]

Where:

p_{Bplate} is the bracket perimeter.

Sth is the skin thickness.

p_{insert} is the insert perimeter.

$S_{strength}$ is skin shear strength.

Front hoop and Front hoop bracing attachments:

In this stage of the SES the following are checked:

- Each side of the main hoop has more than 2 attachment points.
- There is not more than 50mm between the lower attachments and the lower part of the hoop.
- Backing plate thickness is bigger than 2mm.
- Fastener diameter must be bigger than 8mm.

- Needs at least 2 fasteners per attachment.
- Welded distance must be at least 80mm.
- Tearout strength (N):

$$T_{Strength} = E_d * 2 * S_{strength} * 2 * Sth$$

Equation 21: tearout strength of the FH & FHB inserts [10]

Where:

E_d is the edge distance.

Sth is the skin thickness.

$S_{strength}$ is skin shear strength.

- Perimeter shear strength of the bracket (N):

$$P_{Bracket} = (p_{bracket} * Sth + p_{insert} * Sth) * S_{strength}$$

Equation 22: perimeter shear strength of the FH & FHB brackets [10]

Where:

$p_{bracket}$ is the bracket perimeter.

Sth is the skin thickness.

p_{insert} is the insert perimeter.

$S_{strength}$ is skin shear strength.

- Perimeter shear strength of the backing plate(N):

$$P_{Bplate} = \left(p_{Bplate} * Sth + p_{insert} * Sth\right) * S_{strength}$$

Equation 23: perimeter shear strength of the FH & FHB backing plate [10]

Where:

p_{Bplate} is the bracket perimeter.

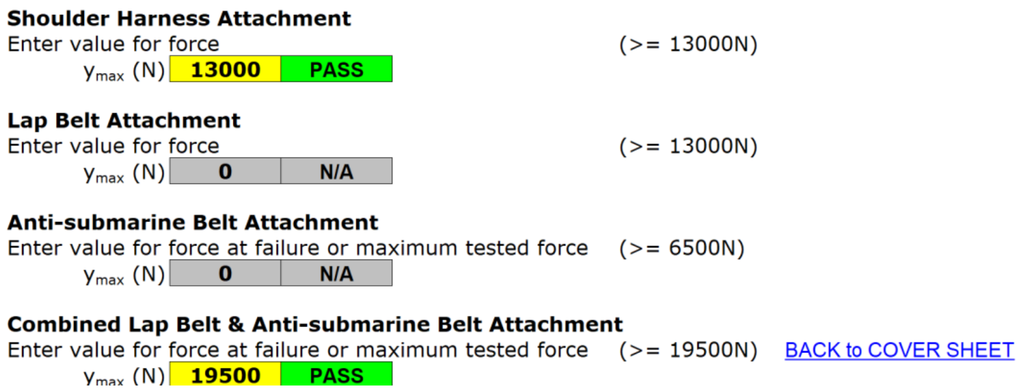
Sth is the skin thickness.

p_{insert} is the insert perimeter.

$S_{strength}$ is skin shear strength

Harness attachments:

The SES requires a physical testing of the harness attachments, the anti-submarine and the lap belt attachments. Deflection curves must show that the harness attachments supports more than 13KN and the lap belt and anti-submarine attachments support more than 19,5KN.



Shoulder Harness Attachment
Enter value for force (>= 13000N)
y_{max} (N) 13000 PASS

Lap Belt Attachment
Enter value for force (>= 13000N)
y_{max} (N) 0 N/A

Anti-submarine Belt Attachment
Enter value for force at failure or maximum tested force (>= 6500N)
y_{max} (N) 0 N/A

Combined Lap Belt & Anti-submarine Belt Attachment
Enter value for force at failure or maximum tested force (>= 19500N) BACK to COVER SHEET
y_{max} (N) 19500 PASS

Figure 22: harness attachments SES [10]

Accumulator attachments:

In this stage of the SES the following are checked:

- Fastener diameter must be bigger than 8mm.
- Backing plate thickness is bigger than 2mm.
- Tearout strength (N):

$$T_{Strength} = E_d * 2 * S_{strength} * 2 * Sth$$

Equation 24: tearout strength of the accumulator insert [10]

Where:

E_d is the edge distance.

Sth is the skin thickness.

$S_{strength}$ is skin shear strength.

- Perimeter shear strength (N):

$$P_{st} = (p_{bracket} * Sth + p_{insert} * Sth) * S_{strength}$$

Equation 25: perimeter shear strength of the accumulator bracket [10]

Where:

$p_{bracket}$ is the bracket perimeter.

Sth is the skin thickness.

p_{insert} is the insert perimeter.

$S_{strength}$ is skin shear strength.

Attachment design:

In this section, the aim is to carry out an initial design of the various attachments to the monocoque. These are determined by the SES, the arrangement of inserts, and the specifications of each area's departments. These designs will not be taking into account in simulations.

Main hoop, main hoop bracing, front hoop & front hoop bracing:

Main Hoop and Main Hoop Bracing Attachments

No. of attachment points per side	2
Main Hoop Brace to Monocoque?	YES

	Upper Attachment		Lower Attachment		Main Hoop Bracing Attachment	
Attachment Status	PASS		PASS		PASS	
Fastener dia., mm	8	PASS	8	PASS	8,0	PASS
No. of fasteners	2	PASS	2	PASS	2	PASS
Proof for T3.7.4			40	PASS		
Bracket to hoop weld length, mm	160	PASS	160	PASS	160	PASS
Bracket thickness, mm	2	PASS	2	PASS	2	PASS
Bracket perimeter, mm	314		314		314	
Insert Perimeter, mm	314		314		314	
Backing plate thickness, mm	2	PASS	2	PASS	2	PASS
Backing plate perimeter, mm	203		203		203	
Edge distance, mm	65		65		65	
Skin / Material type	Composite 1		Composite 1		Composite 1	
Skin / Material name	T3.5_Laminate		T3.5_Laminate		T3.5_Laminate	
Skin shear strength, MPa	65		65		65	
Skin thickness, mm	1,8		1,8		1,8	
Skin thickness, mm	1,8		1,8		1,8	
Perimeter shear strength, kN	73	PASS	73	PASS	73	PASS
Perimeter shear strength, kN	60	PASS	60	PASS	60	PASS
Tearout strength, kN	30	PASS	30	PASS	30	PASS

Figure 23: MH & MHB SES pass

Front Hoop and Front Hoop Bracing Attachments

No. of attachment points per side	3
Front hoop material	Steel

	Upper Attachment		Lower Attachment		Front Hoop Bracing Attachment	
Attachment Status	PASS		PASS		PASS	
Fastener dia., mm	8	PASS	8	PASS	8	PASS
No. of fasteners	2	PASS	2	PASS	2	PASS
Proof for T3.7.4			40	PASS		
Bracket to hoop weld length, mm	160	PASS	160	PASS	160	PASS
Bracket thickness, mm	2	PASS	2	PASS	2	PASS
Bracket perimeter, mm	314		314		314	
Insert Perimeter, mm	314		314		314	
Backing plate thickness, mm	2	PASS	2	PASS	2	PASS
Backing plate perimeter, mm	203		203		203	
Edge distance, mm	65		65		65	
Skin / Material type	Composite 1		Composite 1		Composite 1	
Skin / Material name	T3.5_Laminate		T3.5_Laminate		T3.5_Laminate	
Skin shear strength, MPa	65		65		65	
Skin thickness, mm	1,8		1,8		1,8	
Skin thickness, mm	1,8		1,8		1,8	
Perimeter shear strength, kN	73	PASS	73	PASS	73	PASS
Perimeter shear strength, kN	60	PASS	60	PASS	60	PASS
Tearout strength, kN	30	PASS	30	PASS	30	PASS

Figure 24: FH & FHB SES pass

Both structures will use the same inserts as they need to face same forces.

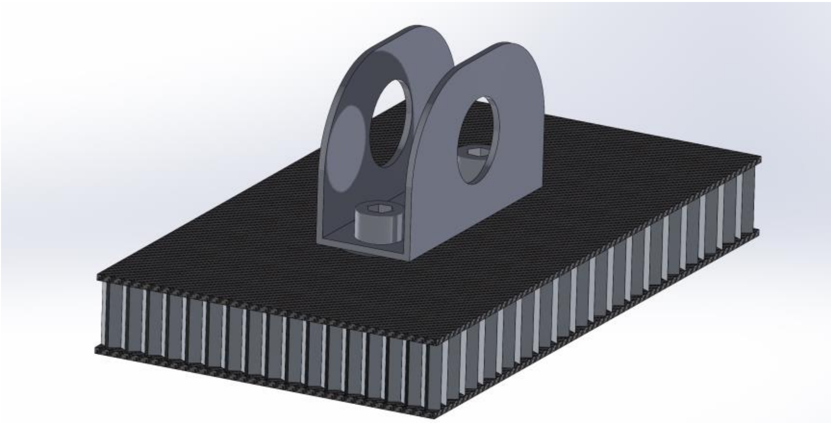


Figure 25: isometric view of PA_hoop_001

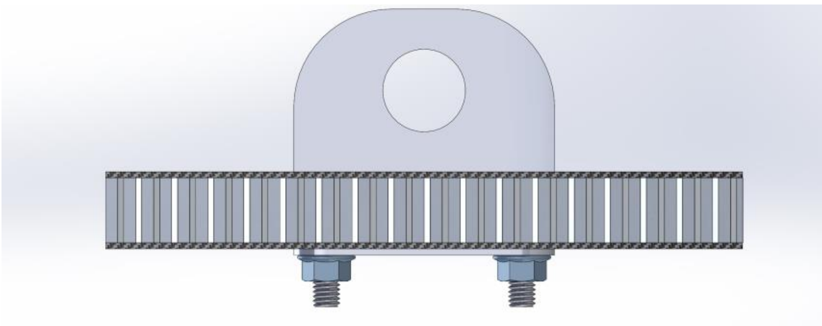


Figure 26: front view of PA_hoop_001

Harness:

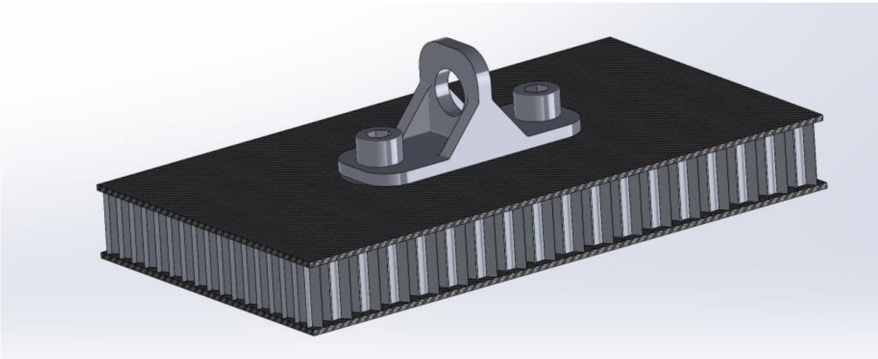


Figure 27: isometric view of PA_HA_001

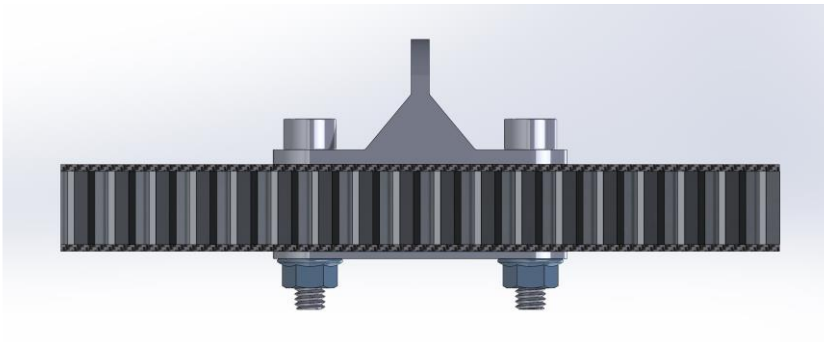


Figure 28: front view of PA_HA_001

Accumulator:

Accumulator Container Attachment to laminated chassis structures	**PASS**	
Fastener dia., mm	8,0	PASS
Washer/bolt perimeter, mm	25	
Skin thickness, mm	1,8	
Insert Perimeter, mm	314	
Skin thickness, mm	1,8	
Backing plate thickness, mm	2	PASS
Backing plate perimeter, mm	203	
Edge distance, mm	50	
Skin shear strength, MPa	65	
Perimeter shear strength, kN	60	PASS
Tearout strength, kN	23	PASS

Figure 29: accumulator SES pass

The method to anchor the accumulator to the chassis will be through the hooks integrated into the accumulator itself and a backing plate as it is shown in figure 30.

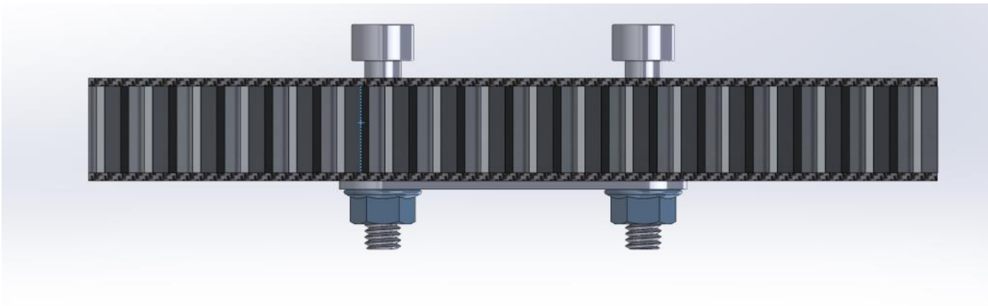


Figure 30: side view of PA_ACU_001

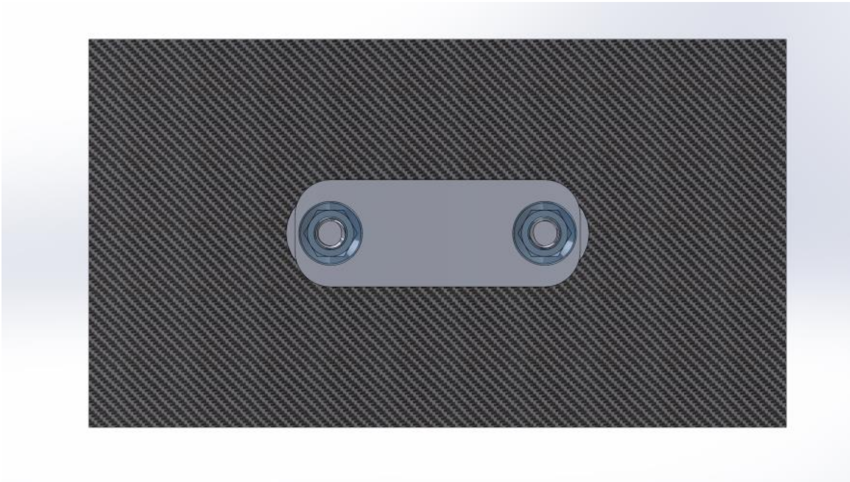


Figure 31: front view of PA_ACU_001

Suspension: PA_SP_001

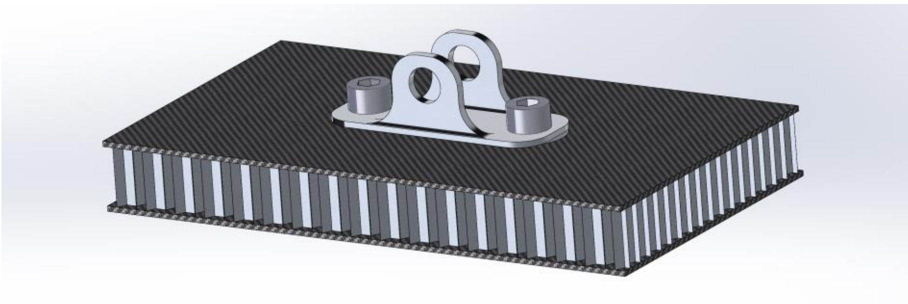


Figure 32: isometric view of PA_SP_001

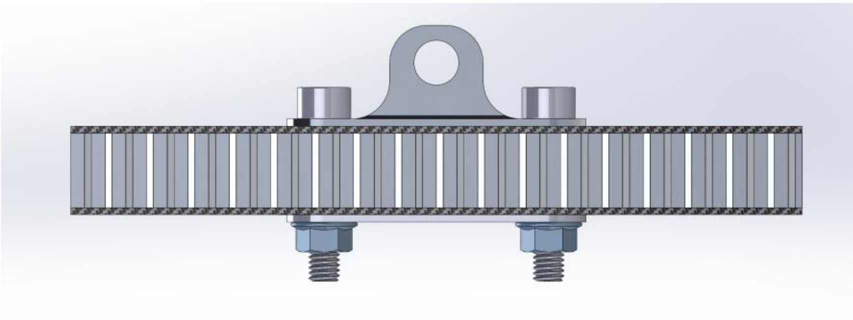


Figure 33: front view of PA_SP_001

Insert design:

This section will involve designing three different types of inserts. Each of these three inserts will be simulated with all the models designed for every specific part of the car.

Insert 1: PA_IT_001

The first iteration consists of the simplest model, seeking a through-the-thickness insert with a good bonding area. It is expected to have high stiffness, but being a simple design, it may not be sufficient to support the 30KN that the rules specify for the critical areas.

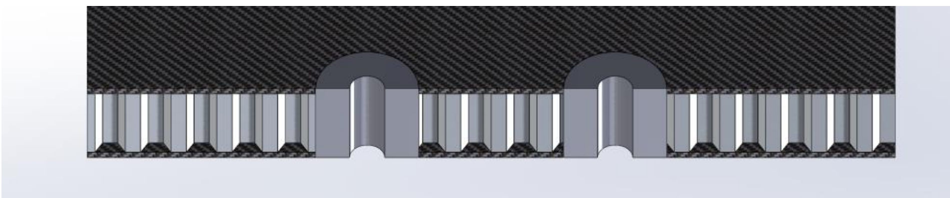


Figure 34: Sandwich panel and PA_IT_001

Insert 2: PA_IT_002

The second iteration aims to maintain a simple design while utilizing the insert's own shape to increase its resistance to point forces.

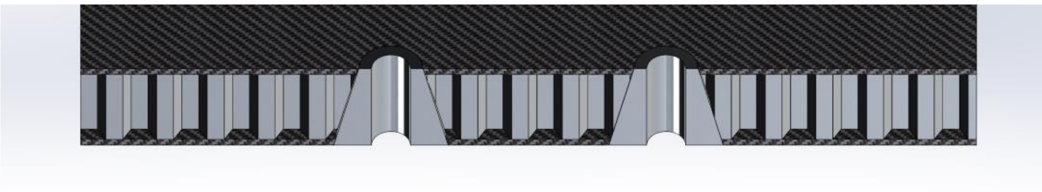


Figure 35: Sandwich panel and PA_IT_002

Insert 3: PA_IT_003

The third iteration appears after analyzing insert theory. It is observed that an increase in the bonding area greatly increases stiffness. Therefore, the goal is to maximize the area by incorporating the central fin. In this case, holes are added on each face to allow adhesive filling and ensure uniform distribution.

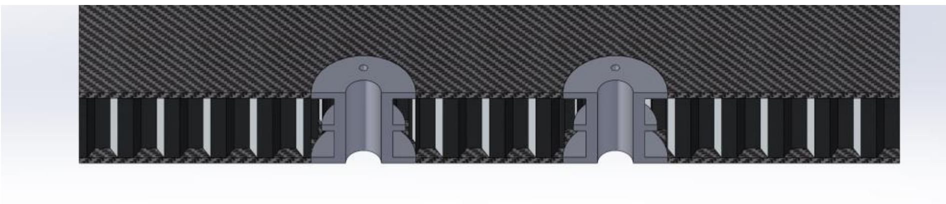


Figure 36: Sandwich panel and PA_IT_003

FEA simulation:

Material properties for simulation:

Epoxy potting compound:

The selected potting compound is the *3M Scotch-Weld DP490.* This two-part adhesive is designed for structural application which makes it suitable for cold bonded inserts. It is commonly used in the aerospace industry due to its properties:

- Shear strength: 31,6Mpa
- Operating temperature: -55 to 150 degrees

Figure 37: Epoxy adhesive [11]

With the aim of establishing a base potting diameter, the A-coefficient average criteria proposed by ECSS will be employed as it is shown in table 4. This result will be subject to modifications based on the outcomes of the simulations. In order to determine the potting diameter, it is used equation 17 and 18:

$$d_p = d_i * a_1 + a_2 * S_c - a_3 = 25 * 1{,}002064 + 1{,}8888 * 6{,}35 - 1{,}4226 = 35{,}62mm$$

Therefore, the initial models will be studied with an insert diameter of 25 mm and an encapsulation diameter of 36 mm.

The properties of the composite materials have been obtained from the Ansys library. In the case of the skins, they are pre-impregnated fiber.

Carbon fiber skins:

Outline of Schematic D2, F2: Engineering Data

	A	B	C	D
1	Contents of Engineering Data			Source
2	Material			
3	Epoxy Carbon UD (230 GPa) Prepreg			Composite_Materials.xml
4	Epoxy Carbon Woven (395 GPa) Prepreg			Composite_Materials.xml
5	Honeycomb			Composite_Materials.xml
*	Click here to add a new material			

Properties of Outline Row 4: Epoxy Carbon Woven (395 GPa) Prepreg

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1,48E-09	mm^-3 t		
3	Orthotropic Secant Coefficient of Thermal Expansion				
8	Orthotropic Elasticity				
9	Young's Modulus X direction	91820	MPa		
10	Young's Modulus Y direction	91820	MPa		
11	Young's Modulus Z direction	9000	MPa		
12	Poisson's Ratio XY	0,05			
13	Poisson's Ratio YZ	0,3			
14	Poisson's Ratio XZ	0,3			
15	Shear Modulus XY	19500	MPa		
16	Shear Modulus YZ	3000	MPa		
17	Shear Modulus XZ	3000	MPa		
18	Orthotropic Stress Limits				
19	Tensile X direction	829	MPa		
20	Tensile Y direction	829	MPa		
21	Tensile Z direction	50	MPa		
22	Compressive X direction	-439	MPa		
23	Compressive Y direction	-439	MPa		
24	Compressive Z direction	-140	MPa		
25	Shear XY	120	MPa		
26	Shear YZ	50	MPa		

Table 6: Carbon fiber skins properties for simulation

Honeycomb core:

Outline of Schematic D2, F2: Engineering Data

	A	B	C	D
1	Contents of Engineering Data			Source
2	Material			
3	Epoxy Carbon UD (230 GPa) Prepreg			Composite_Materials.xml
4	Epoxy Carbon Woven (395 GPa) Prepreg			Composite_Materials.xml
5	Honeycomb			Composite_Materials.xml
*	Click here to add a new material			

Properties of Outline Row 5: Honeycomb

	A	B	C
1	Property	Value	Unit
2	Density	8E-11	mm^-3 t
3	Orthotropic Elasticity		
4	Young's Modulus X direction	1	MPa
5	Young's Modulus Y direction	1	MPa
6	Young's Modulus Z direction	255	MPa
7	Poisson's Ratio XY	0,49	
8	Poisson's Ratio YZ	0,001	
9	Poisson's Ratio XZ	0,001	
10	Shear Modulus XY	1E-06	MPa
11	Shear Modulus YZ	37	MPa
12	Shear Modulus XZ	70	MPa
13	Orthotropic Stress Limits		
14	Tensile X direction	0	MPa
15	Tensile Y direction	0	MPa
16	Tensile Z direction	5,31	MPa
17	Compressive X direction	0	MPa
18	Compressive Y direction	0	MPa
19	Compressive Z direction	-5,31	MPa
20	Shear XY	0	MPa
21	Shear YZ	1,21	MPa
22	Shear XZ	2,24	MPa

Table 7: honeycomb core properties for simulation

Aluminium 7075-T6:

ρ	$2800\,\frac{Kg}{cm^3}$
σ_z	450 MPa
σ_R	530 MPa
E_z	72 GPa

Table 8: aluminum 7075-T6 properties for simulation [13]

Simulation procedure:

Ansys is a software that works through modules that the user makes interact with each other. In the case of simulations with different bodies, it is recommended to upload each body in separate modules to define a specific mesh to each one.

In the case of the simulation of inserts, the modules have been divided as much as possible following the distribution: Geometry-Material-Model-Result. In this case, having bodies of different natures (composite materials, adhesives and aluminum), the simulation has been carried out using a specific module to represent the composite materials and a different one for the adhesive and aluminum.

In the case of composite materials, the ACP PRE and ACP POST module have been used, which is specific for this type of materials. The rest of the materials have been incorporated using the usual geometry and model modules. All of them are contained in a single simulation module, Static Structural. Figure 38 shows the simulation structure:

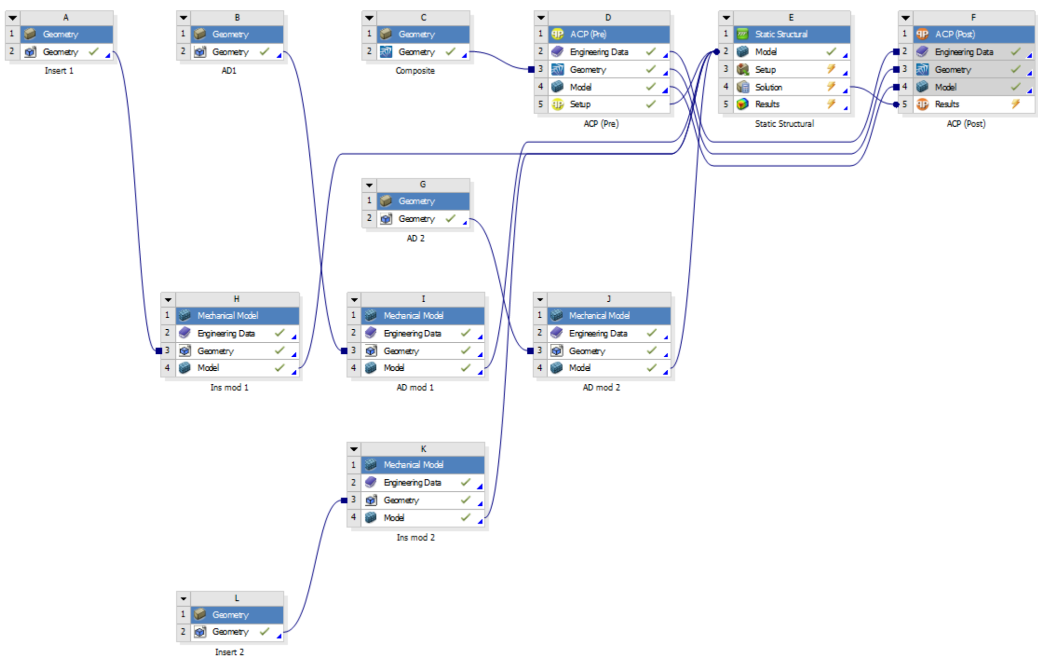


Figure 38: Ansys modules configuration

- Geometry: in this section is where the structure of each solid is uploaded. This work module allows importing parts from other programs such as SolidWorks in .STEP format or designing them through its own tool, Space Claim. In this case, solids have been designed using SolidWorks software.
- External Model: in this module the first step is to load the materials that are going to be used through the "Engineering Data" section. In this tab all the data about the material will be loaded such as yields modulus, Young's modulus, poison's coefficient... Once this step is completed and the module is connected to the previous one, "Geometry", the meshing of the body will be done through the "Model" tab.

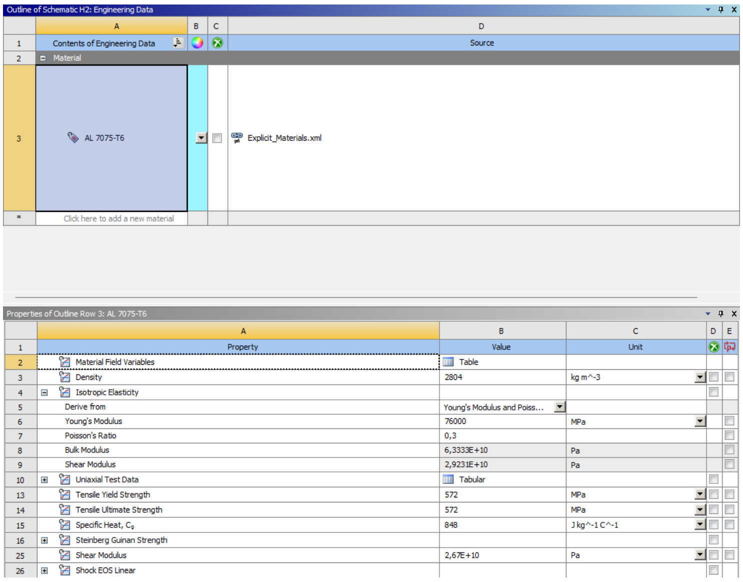


Figure 39: AL-7075 Engineering Data

In order to proceed with meshing, special attention must be paid to the results we want to obtain. In this case, as the main objective is to analyze the bonding, we will carefully mesh the adhesive.

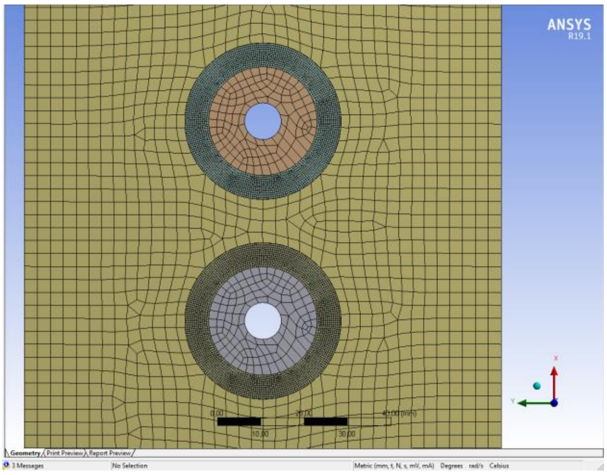


Figure 40: Meshing

- ACP PRE: in this module is where composite materials are studied. This module does not accept a solid as an input, instead it uses a surface that later through the different definitions will obtain thickness. The most relevant section of this module is "Setup", here is where the materials, number of layers, coordinate system... will be specified.

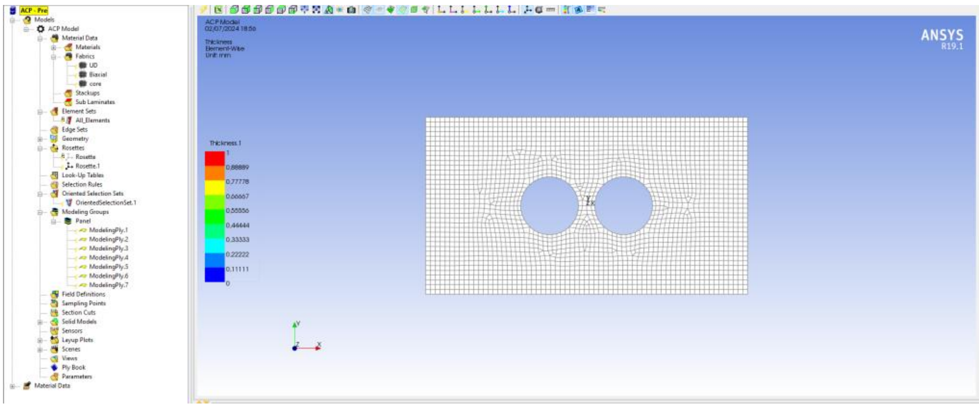


Figure 41: ACP setup

In ACP it is essential to enter all the information since the panel will be built from them. In the "Stackups" and "Sub Laminates sections", the software allows you to create sets of skins that are incorporated together. This tool is very useful when there are several groups of the same skins. Here you can also specify the orientation of the skins and composition details.

On the other hand, it is essential to set the rosettes correctly since they will determine the direction in which the material properties are applied, likewise it is important to set the "Oriented Selection Sets". In the "Modeling Groups" option is where the program allows you to stack the skins with the desired orientation and order. Finally, the type of structure to be represented by the different skins is determined in the "Solid Model" section as shown in figure 42.

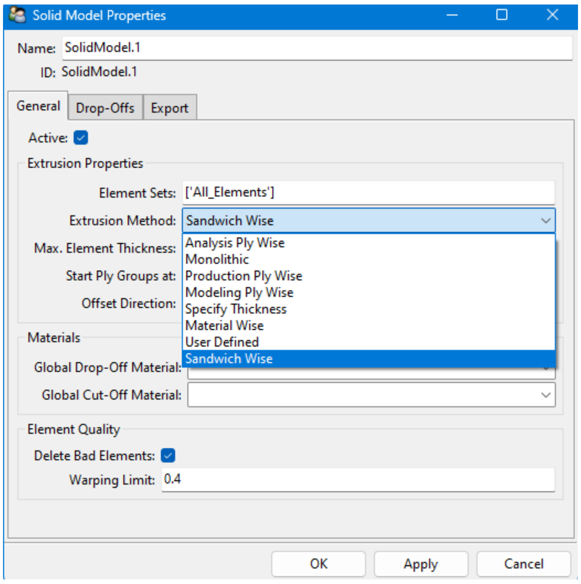


Figure 42: Solid Model

- Static Structural: This module is where the actual simulation is carried out. Firstly, it is essential to specify the position of each body so that the desire assembly is achieved. In order to do this, select the “model” section in Static Structural and set the desired coordinates in the properties tab on the right as shown in figure 43.

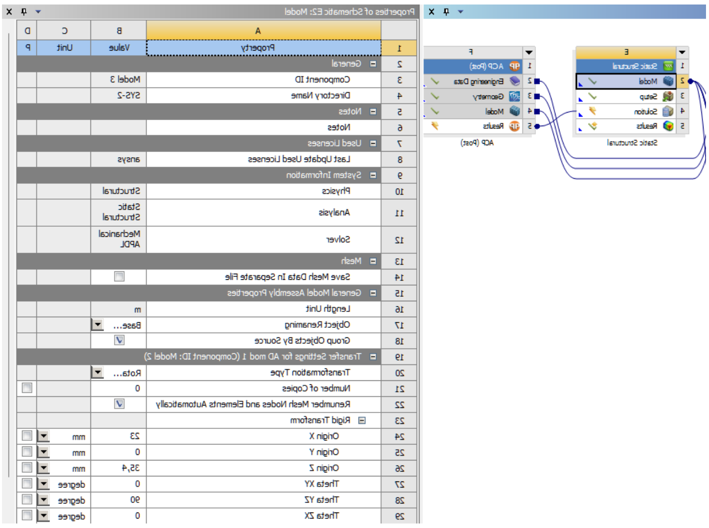


Figure 43: Properties of Schematic

Once it is verified that the assembly is correct, the connections between bodies are established. In this case, the relationship between solids is "bonded" as shown in the figure 44. Subsequently, it is necessary to incorporate the supports of the solids, in this test the surfaces of the composite material have been fixed in order to concentrate all the tension on the adhesive. On the other hand, the forces have been applied on the surface of the insert, 15Kn in each one, corresponding to the highest load case.

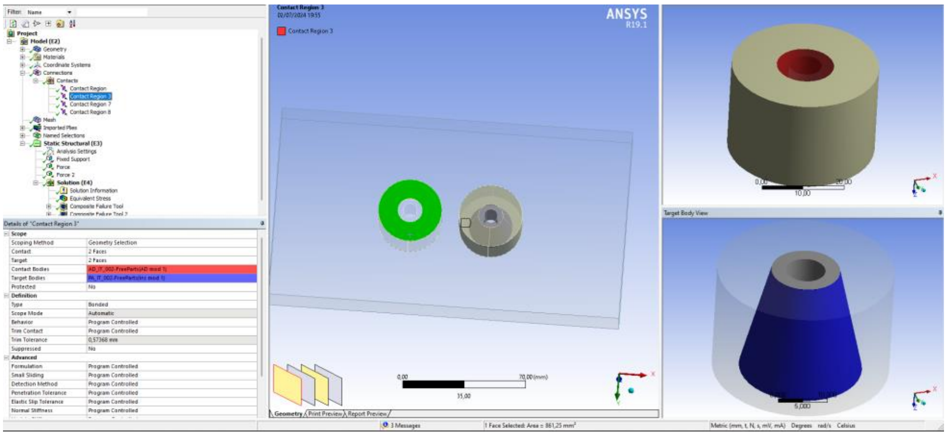


Figure 44: bonded connections

In this section it is necessary to specify the desire results that want to be studied by the software. In the case of this project, the goal is to observe whether the shear stress of the adhesive is exceeded at any point, so the desire result is "Equivalent stress". Once all the data has been entered, the system will proceed to analyze the information, this step can take about 30 to 40 minutes on a desktop computer.

- ACP POST: in this section the stresses on the composite material are studied in detail. Different information such as delamination or stress on the skins can be obtained. However, this is not the subject of study in this project.

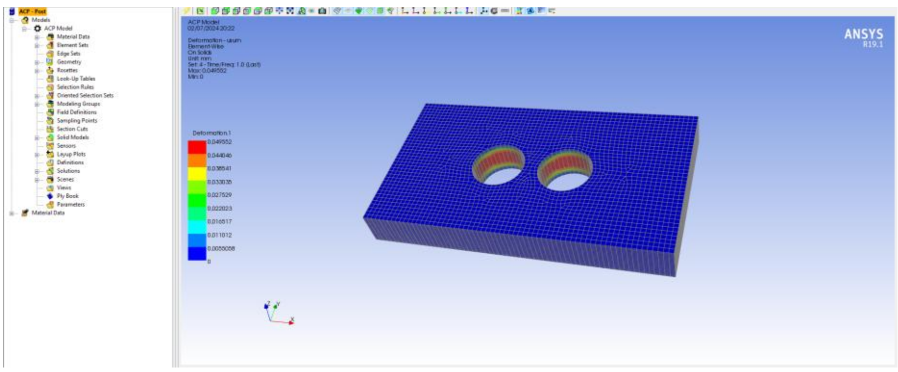


Figure 45: ACP POST

Simulation Results:

Following the above process, the 3 types of inserts have been simulated. Special attention has been paid to the meshing as the accuracy of the results depends on the meshing quality. Initially, according to equations 17 and 18, the simulations were carried out with an encapsulation diameter of 36mm, however, as the expected results were not obtained, the diameter was increased to 60mm. As a consequence of this increase in encapsulation, the diameter of the insert was also increased from 25mm to 36mm.

In all the models, the aim has been to obtain a mesh that represents reality as much as possible. In order to do this, two criteria have been followed, the first of which is that the "Element quality" must have an average greater than 0.95 and the second is that the average "Skewness" must be less than 0.1 and its maximum less than 0.8. On the other hand, it has been observed in which mesh quality environment the results remain invariant so that we use the simplest possible computational models.

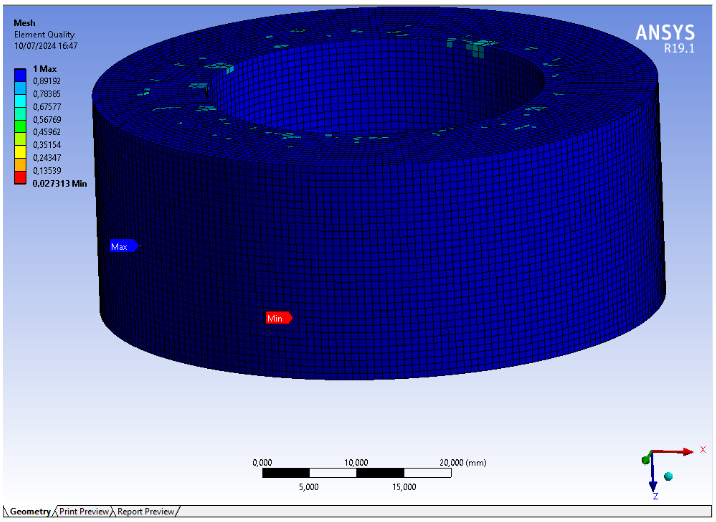


Figure 46: mesh

These simulations neglect the carbon fiber laminate on the adhesive and therefore represent a more restrictive model than reality. This means that the results are over dimensioned with respect to reality. On the other hand, before presenting the results, it is necessary to understand how to interpret the results. Finite elements perform calculations through an iterative process, which means that they interpolate results through nodes of elements that are next to each other. Therefore, when they reach a corner, the results they overturn might be inaccurate due to geometry and sometimes can be disregarded. Therefore, the maximum stress will be considered in the nearest element to the corner itself.

Results PA_IT_001:

In this case, the design of the insert is as simple as possible, thus seeking a more affordable insert.

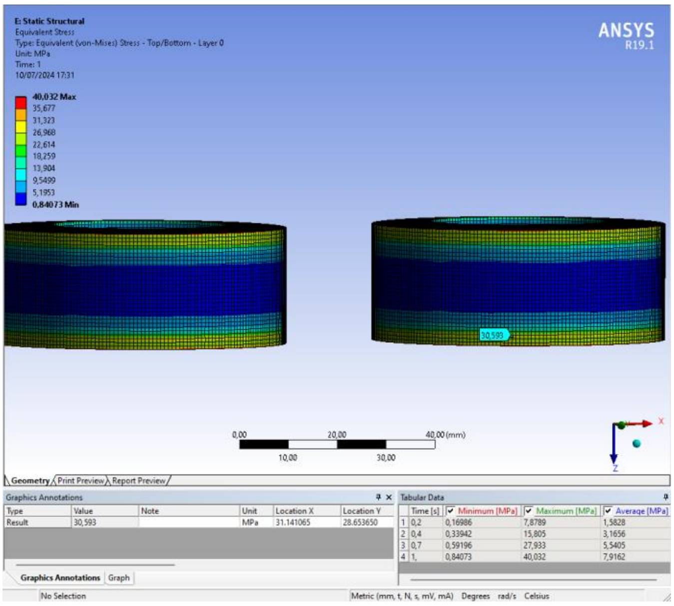


Figure 47: adhesive for PA_IT_001

In this case the next element to the corner has a stress of 30.593MPa and therefore would be able to withstand a force of 15kn at each insert.

Results PA_IT_002:

This type of insert uses its conical shape to reduce the stress transmitted to the adhesive. As with the rest of the inserts, the simulation has been carried out by subjecting each insert to 15KN, obtaining the results shown below.

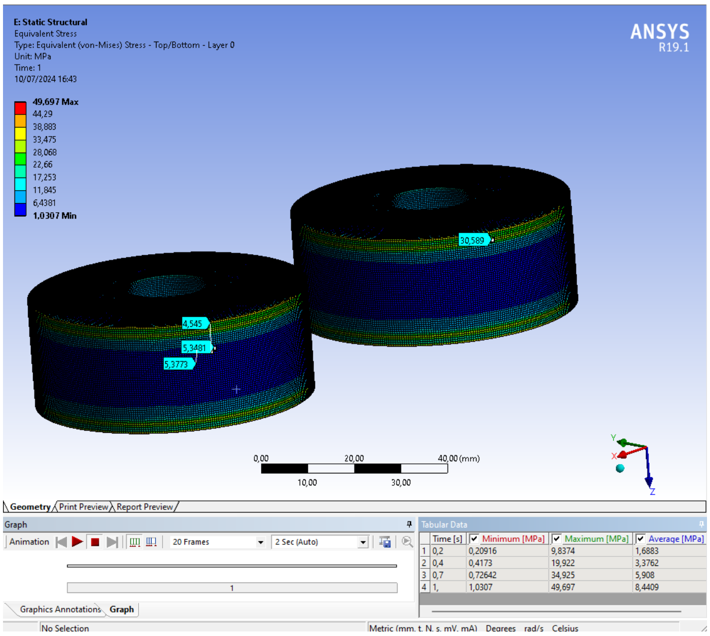


Figure 48: Adhesive for PA_IT_002

In this case the result must be interpreted taking into account the finite element performance. Despite having a peak stress of 49MPa at the corner, the next element presents a stress of 30.589MPa. This means that it is very close to the limit of the adhesive but would be able to resist the load.

Results PA_IT_003:

This type of insert is the most elaborate design and the results have proven its effectiveness. Its design is intended to be used in joints of great responsibility. As with the rest of the inserts, the simulation has been carried out by subjecting each insert to 15KN, obtaining the results shown below.

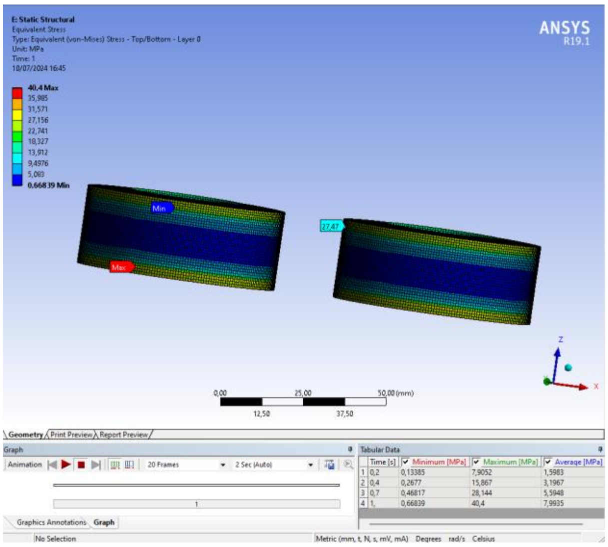


Figure 49: Adhesive for PA_IT_003

Once the results have been interpreted, it can be deduced that the peak of 40MPa is not significant, but that the reality is reflected in the areas close to the edges, with a value of 27,47MPa. This result can be considered acceptable as it does not exceed the shear stress that the adhesive can withstand.

Manufacture procedure:

The manufacturing process is critical in order to ensure that the simulations represent reality as closely as possible. If this process is not performed correctly, it can be guaranteed that the properties will not be optimal, resulting in a defective model that has little in common with the simulated one. To achieve the desired properties, it is recommended to follow the procedure described below.

Tools and material:

- Unidirectional carbon fibre fabric.
- Woven carbon fibre fabric
- Honeycomb core
- 3M Scotch-Weld DP490
- Milling insert
- Adhesive injection kit
- Bench drill
- Grit-blasting machine
- Ethanol

Process:

The first stage of manufacturing consists of laminating the first skin (with the desired layer configuration) together with the core. For this purpose, there are several methods such as infusion, vacuum... Therefore, this part of the manufacturing process will be determined by the design of the monocoque.

Once the first skin is cured together with the core, the next step is the injection of the adhesive. For this stage it will be useful to use templates that represent the diameter of the potting to be filled. The filling process will be done with adhesive injection kit, which will ensure that the cells are filled in their entirety. This process must be carried out until the adhesive overflows.

During this gluing stage, it is essential to control the temperature, keeping it at around 25°, so that the adhesive flows smoothly. According to the data sheet, the manufacturer recommends purging the first 30 ml in order to obtain the best properties of the product. The mixture will not start to cure until 10 minutes are reached, therefore, this is the time available to mix and perform the entire encapsulation. The curing time of the adhesive depends largely on the temperature at which it is made. The manufacturer recommends curing at room temperature of 25° for 12 to 24 hours. There are other alternatives such as curing for 2 hours at 65° or 1 hour at 100°, however, these are less recommended as they may compromise the properties of the skin and core. Once It has been cured, it is recommended to sand the adhesive so that a completely flat surface is achieved. This is made in order to avoid the second skin will not seat properly on the core.

Once this step is completed, the lamination of the second skin should continue following the chosen procedure. Once this second skin has cured, the template will be used to mark the location of the insert.

This is the point where the hole for the insert is drilled using the bench drill. It is recommended to use a drill bit slightly larger than the size of the insert (0,1-0,2mm), so that this difference in size is filled with adhesive. The use of special lubricants and drills for carbon fiber is recommended for this stage, in order to reduce the stress on the panel to a minimum.

In parallel to these processes, it is necessary to proceed with the preparation of the insert surface. To do this, the surface of the insert will be cleaned with ethanol to remove any residue from the milling operation that may remain on the surface of the insert. The next step is to increase the roughness of the insert in order to rise the bonding surface. To increase the roughness, the insert is sandblasted using the grit-blasting machine. Once the desired roughness is achieved, the insert is cleaned again with ethanol to remove the sand residues and to obtain a clean bonding surface.

Finally, adhesive will be added in the hole and in the insert itself to guarantee the correct encapsulation. Once the insert is introduced, the excess of adhesive will be cleaned and the curing procedure described in the encapsulation stage will be followed.

Once the adhesive has cured, it is recommended to carry out a visual inspection for defects such as lack of bonding or delamination of skins. If the necessary means are available, a radiographic analysis would allow to check if the glue has been entirely distributed and has covered all the volume.

Theoretical pull-out resistance study:

This type of test is carried out by applying a perpendicular force on the insert that is adhered to the panel. To carry it out, it is necessary to design the tooling that will couple the screw of the insert to the tensile machine as shown in Figure 44. This type of test cannot be predicted by linear equations and therefore requires real tests.

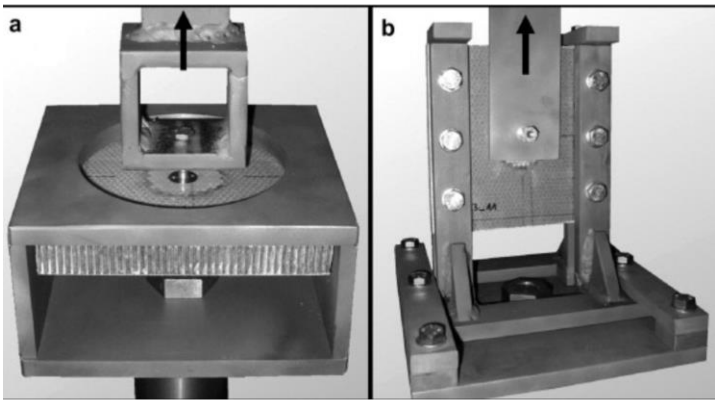


Figure 50: pull-out study [16]

These tests can result into two different types of curves. Figure 51 shows the two types of failure that can occur in these joints. The first one represents a curve with two crests corresponding to two maximum stresses. The first one represents the force at which the elastic limit of the adhesive is exceeded causing irreversible damage. The second crest refers to the maximum load that the bond admits before it fails completely. In the case of the second curve both forces converge at the same time.

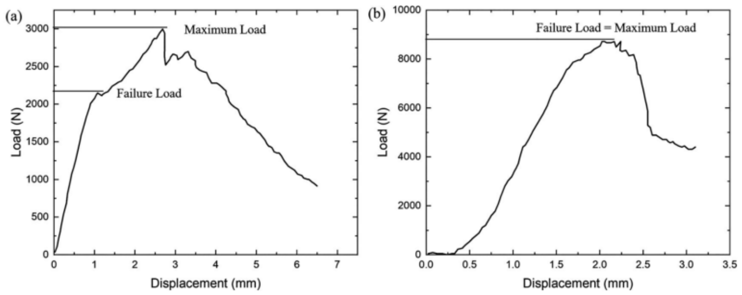


Figure 51: failure curves [17]

The failures that can occur in the assembly are very diverse and have different reasons. The most common are shown in figure 52:

- Core buckling: this is the failure that tends to appear in the first instance and is characterized by plastic deformation of the core.
- Shear cracking: This type of failure occurs when the perpendicular force ceases to be perpendicular and causes shear stresses that cause the panel to fail in its principal direction.
- Tensile rupture: The next type of failure occurs when the insert detaches from the bottom skin. It is not common in fully encapsulated inserts.
- Delamination: This next failure mode appears hand in hand with shear cracking. In this case it occurs when shear stresses are incorporated into the skins.
- Out of plane shear: This appears due to the displacement of parts of the assembly that have broken.

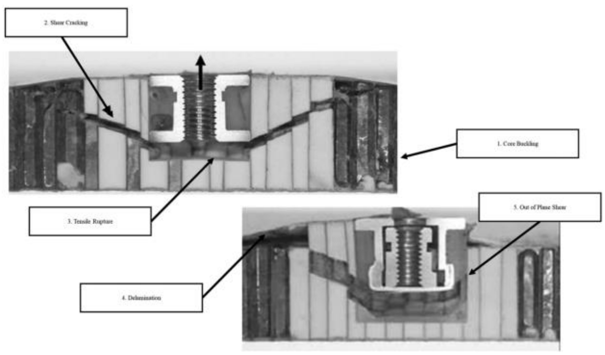


Figure 52: failure modes [17]

The following steps are necessary to carry out the test:

- Step 1: Design and manufacture of the necessary tooling to hold the panel. In the same way, it will be necessary to design and manufacture the brackets for the connection between the insert and the traction arm.
- Step 2: Manufacture the inserts and the panel following the procedure described in the "Manufacture procedure" section.
- Step 3: Enter the necessary settings in the machine configuration software. At this stage, the panel shall be anchored to the machine and checked for correct fastening.
- Step 4: Start the calibration process indicated by the manufacturer. It is usually recommended to perform a force-zero calibration.
- Step 5: Once the correct connection between machine and model has been checked, gradually apply tension. At all times be present to supervise correct operation. The test shall end when there is a sustained drop in load as shown in Figure 51.
- Step 6: Once the test is completed, the data must be exported to a .csv file for further analysis.
- Step 7: Examine the model after the failure for defects and try to identify the type of failure that has occurred according to Figure 52.
- Step 8: Write a report with the procedure followed, with special emphasis on steps 6 and 7. It will also be necessary to highlight the relationship between the failure and the manufacturing process if it exists.

Budget:

This study will take into account the budget required to carry out the complete fabrication of all the inserts necessary to have a functional monocoque. For this purpose, the cost will be studied according to each type of insert. However, the cost of composite materials will not be evaluated, since it depends on the design of the chassis itself.

In order to carry out the cost estimation, quotes will be requested from companies in the sector that could perform this task. In this case, quotations from Xometry [18] will be used. According to Table 5, 88 inserts will be necessary to attach all the necessary elements. Therefore, we can estimate the following costs:

Insert:	Material:	Tolerance:	Quantity:	Cost [€]:
PA_IT_001	AL-7075	ISO-2768mk	88	340,56
PA_IT_002	Al-7075	ISO-2768mk	88	412,72
PA_IT_003	Al-7075	ISo-2768mk	88	555,28

Table 9: Inserts cost

The amount of adhesive required can be easily calculated from the volume and number of inserts:

$$V_{adhesive} = Nº Ins * \pi * h * r^2 = 88 * \pi * 23{,}6 * (60^2 - 36^2) = 15032354{,}97\ mm^3$$

Equation 26: Adhesive volume

Therefore, approximately 15 L are needed to encapsulate all the inserts. In this case, the price amounts to 322,98 €/L and therefore the total cost is 4844,7 €.

After analyzing the three options, three possible budgets are obtained:

Insert:	Insert cost [€]:	Adhesive cost [€]	Cost [€]:
PA_IT_001	340,56	4844,7	5185,26
PA_IT_002	412,72	4844,7	5257,42
PA_IT_003	555,28	4844,7	5399,98

Table 10: Total cost per iteration

Conclusions and future work:

Conclusions:

- The three inserts would be functional to withstand the 30KN required by the standards in the most compromised areas. In all cases the maximum stress was below the adhesive limit, although in the case of PA_IT_001 and PA_IT_002 it was very close to failure.
  Therefore, with respect to these results, it would be ideal to use the PA_IT_001 insert for joints of lower responsibility. On the other hand, for high responsibility joints such as the primary structure, PA_IT_003 inserts should be used because of their exceptional strength. In the case of the PA_IT_002 insert, it should be discarded as it is more expensive than PA_IT_001 and has the same strength.

- The cost of manufacturing these inserts would require a minimum investment of 5185,26€. This sum is too high for the current state of the ISC FS Racing Team project.
  The main problem lies in the cost of the adhesive, which represents 93.4% of the total budget. The manufacturing cost of the inserts themselves is relatively low with a minimum investment of 340,56€. This suggests that in order to implement these elements in the project it would be necessary to have a sponsor supplier for the adhesive.

These results suggest that they would not be implementable in the model in a short time because of their cost. Therefore, they should serve as a starting point for future designs.

Future work:

- Optimize the design and encapsulation diameter of the inserts in order to reduce costs. This will require simulations based on the Ansys model created for this project.
- Increase the accuracy of the simulations by improving the meshing and modeling of the carbon fiber. To improve the modeling of the carbon fiber it will be necessary to perform real tests to obtain the exact properties of the sandwich panel.
- Carry out the fabrication of the inserts and composite material. The panel + insert assembly will be assembled in such a way as to perfect the bonding procedure. The influence of curing times and other external factors should be studied.
- Study the location of the inserts according to the chassis design.
- Carry out real tests with the models in order to contrast the simulations with reality. This is the most important point as it will not only guarantee the performance of the inserts but will also serve as an reliable test to be included in the SES for competitions.

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[19] United Nations. “Sustainable development goals”

Available: https://sdgs.un.org/goals

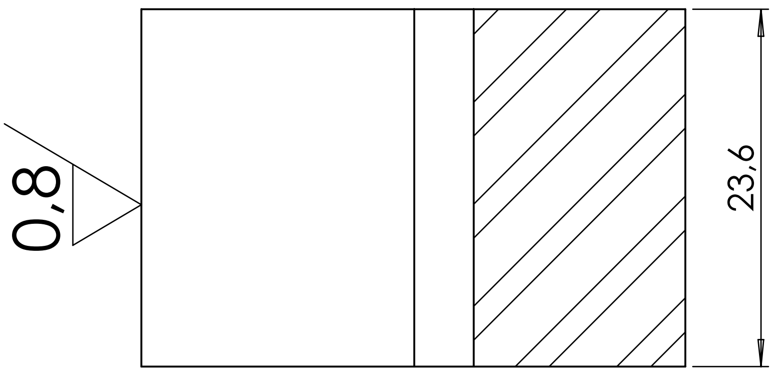
Annex 1: Sustainable Development Goals

Figure 53: Sustainable development goals [19]

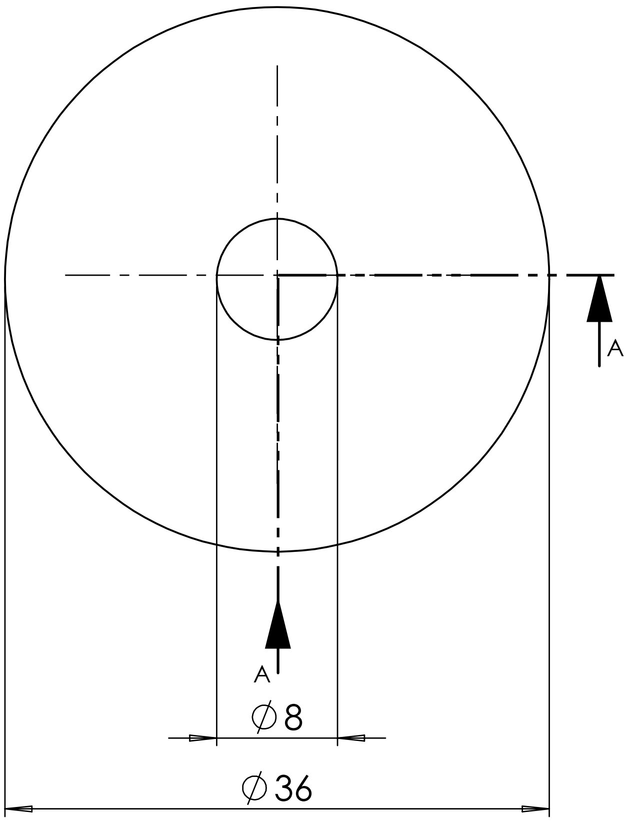
Sustainable Development Goals is a plan that focuses on creating a better world by 2030. We all can contribute to achieve these objectives and this final project has lot to do with them:

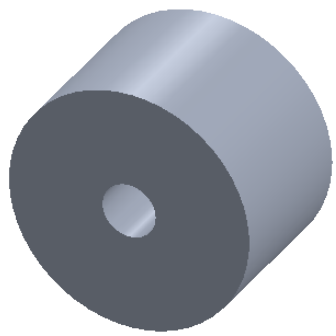
- Objective 4: This Project will allow future students and engineers to develop this area deeper.
- Objective 7: This project is completely engaged with the exclusive use of clean energy. The project is design for an electric prototype which aim is to promote electric and sustainable mobility with zero emissions.
- Objective 8: In this project the idea is to fulfil a reasonable budget that encourages a sustainable economic growth.
- Objective 9: The project is concerned with the future automotive industry which will be fully electric. The idea is to contribute to the development of a strong electric mobility industry by the innovation and training of professionals.
- Objective 11: The electric car is the perfect option to reduce emissions in the mobility through big urban centres. It will be also extrapolated to other ways of transport such as motorbikes or buses.
- Objective 17: The ISC is financed by different companies that have one thing in common, they all look for a sustainable mobility industry.

Annex 2: Drawings



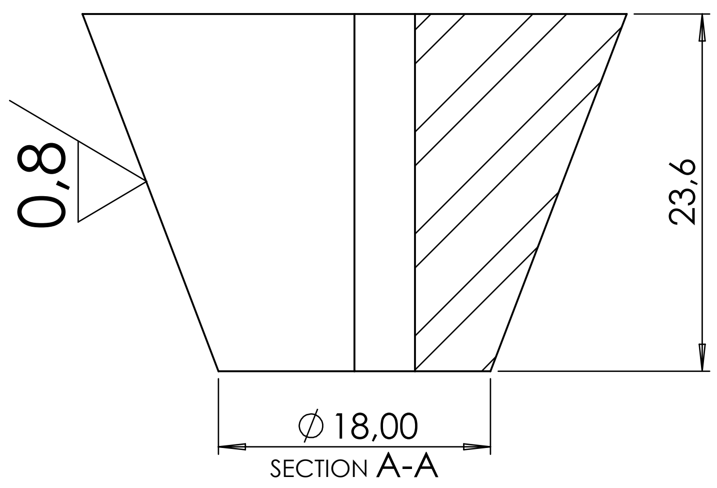
SECTION A-A

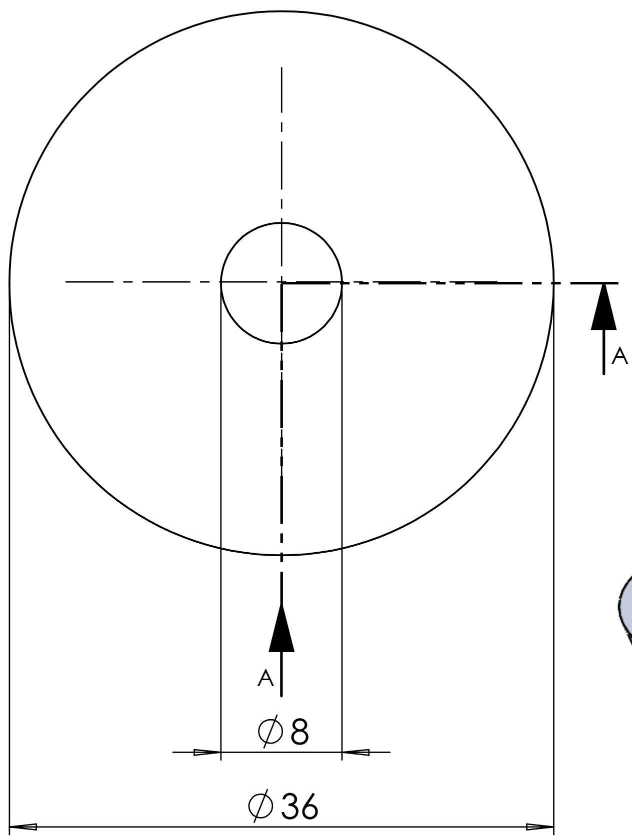


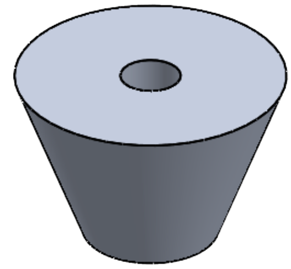


CONFIDENCIAL

SI NO SE ESPECIFICA LO CONTRARIO LAS COTAS SE EXPRESAN EN MM	NORMA DE TOLERANCIA: UNE-EN 22768 m-K		CÓDIGO DEPARTAMENTO:	CH
	NOMBRE	FIRMA	FECHA	TÍTULO: Insert IT1
DIBUJADO	J.L.M		20/06/24	
VERIFICADO	-		-	
APROBADO	-		-	CÓDIGO INTERNO: PA_CH_INS_IT1
ISC FORMULA STUDENT RACING TEAM				MATERIAL - MASA (kg): AL 7075-T6 - 64 gr
				ESCALA: 2:1 · CÓDIGO IFS PLANO: D_CH_INS_IT1 · A4

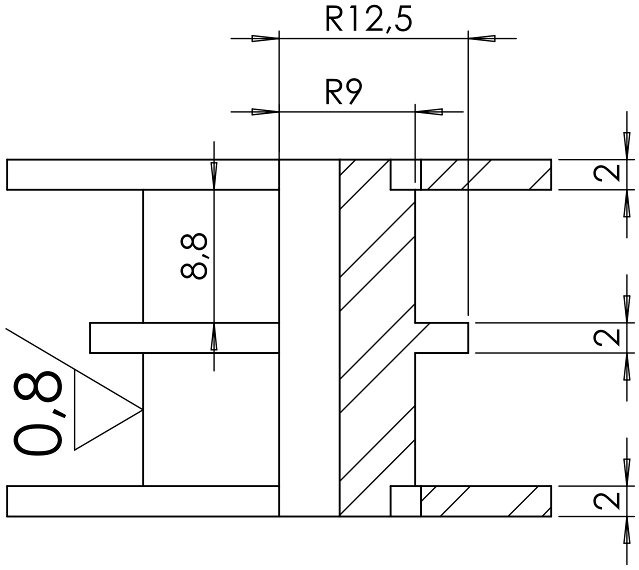




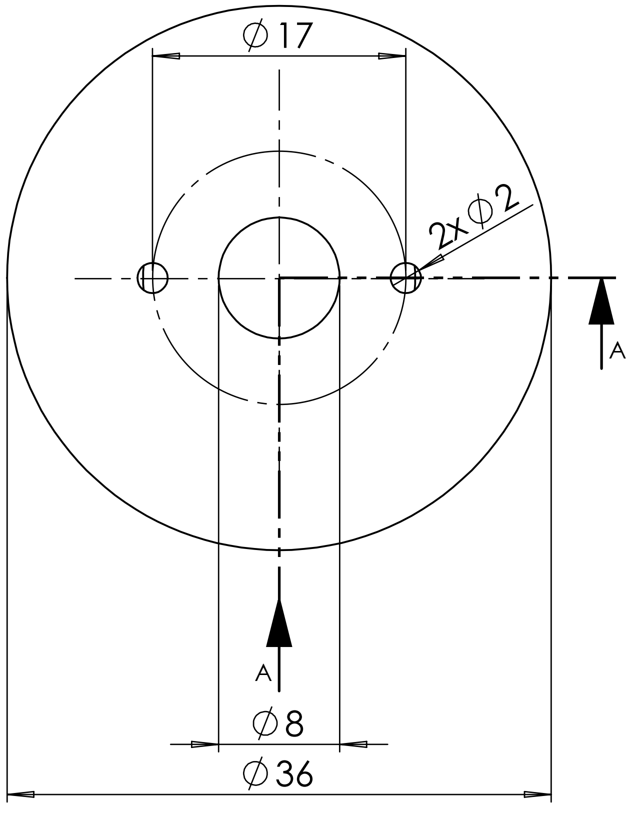


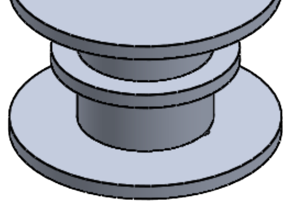
CONFIDENCIAL

SI NO SE ESPECIFICA LO CONTRARIO LAS COTAS SE EXPRESAN EN MM		NORMA DE TOLERANCIA: UNE-EN 22768 m-K		CÓDIGO DEPARTAMENTO:	CH
	NOMBRE	FIRMA	FECHA	TÍTULO:	Insert IT2
DIBUJADO	J.L.M		20/06/24		
VERIFICADO	-		-		
APROBADO	-		-	CÓDIGO INTERNO:	PA_CH_INS_IT2
ISC FORMULA STUDENT RACING TEAM				MATERIAL - MASA (kg):	AL 7075-T6 - 36gr
				ESCALA: 2:1	CÓDIGO IFS PLANO: D_CH_INS_IT2 — A4



SECTION A-A





CONFIDENCIAL

SI NO SE ESPECIFICA LO CONTRARIO LAS COTAS SE EXPRESAN EN MM		NORMA DE TOLERANCIA: UNE-EN 22768 m-K		CÓDIGO DEPARTAMENTO: CH
	NOMBRE	FIRMA	FECHA	TÍTULO: Insert IT3
DIBUJADO	J.L.M		20/06/24	
VERIFICADO	-		-	
APROBADO	-		-	CÓDIGO INTERNO: PA_CH_INS_IT3
ISC FORMULA STUDENT RACING TEAM				MATERIAL - MASA (kg): AL 7075-T6 - 23,49gr
				ESCALA: 2:1 — CÓDIGO IFS PLANO: D_CH_INS_IT3 — A4

Annex 3: Datasheets and Quotation

Xometry Europe GmbH
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85521, Ottobrunn
T: +49 893 803 4818
F: +49 89 93 960 142
E: info@xometry.eu
www.xometry.de

UST-id.Nr.: DE318027176
Steuer-Nr.: 143/194/00231
Handelsregister: Amtsgericht München / HRB 256172
Bank: J.P. Morgan AG
IBAN: DE38 5011 0800 6161 5322 02
BIC: CHASDEFX

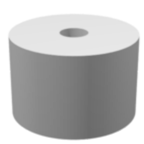
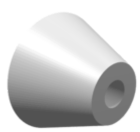
Director / Geschäftsführer: Dmitry Kafidov

PRESUPUESTO E-1064252-1028010

Para:	**ISC**
A/A:	Jesús
Dirección de facturación:	Calle Alberto Aguilera 23 28015, Madrid Spain
ID IVA:	ESG87957841

Número de presupuesto:	**E-1064252-1028010**
Fecha del presupuesto:	**08.07.2024**
Fecha de envio estimada:	14 business days

*(calculado a partir de la fecha de pedido del cliente)

Pos.	Descripción	Cantidad	Precio unitario	Total
10. 	**Nombre de la pieza:** PA_IT_001_13.SLDPRT **Caja contenedora:** 36.0mm × 36.0mm × 23.6mm **Proceso:** CNC Machining **Material:** Aluminium EN AW-7075 / 3.4365 / Al-Zn6MgCu **Acabado:** Standard **Insertos:** - **Roscas y agujeros roscados:** - **Tolerancia:** ISO 2768 - media (Estándar), entire part **Rugosidad superficial:** Standard (3.2 um Ra), entire part	88	€3.87	€340.56
20. 	**Nombre de la pieza:** PA_IT_002_14.SLDPRT **Caja contenedora:** 36.0mm × 36.0mm × 23.6mm **Proceso:** CNC Machining **Material:** Aluminium EN AW-7075 / 3.4365 / Al-Zn6MgCu **Acabado:** Standard **Insertos:** - **Roscas y agujeros roscados:** - **Tolerancia:** ISO 2768 - media (Estándar), entire part **Rugosidad superficial:** Standard (3.2 um Ra), entire part	88	€4.69	€412.72
30. 	**Nombre de la pieza:** PA_IT_003_12.SLDPRT **Caja contenedora:** 36.0mm × 36.0mm × 23.6mm **Proceso:** CNC Machining **Material:** Aluminium EN AW-7075 / 3.4365 / Al-Zn6MgCu **Acabado:** Standard **Insertos:** - **Roscas y agujeros roscados:** - **Tolerancia:** ISO 2768 - media (Estándar), entire part **Rugosidad superficial:** Standard (3.2 um Ra), entire part	88	€6.31	€555.28
	Gastos de envío a: ISC, Calle Alberto Aguilera 23 28015 Madrid, Spain. (Delivery terms: DAP)			€53.60
			Valor total del pedido, neto:	**€1,362.16**
			Valor total del pedido, bruto:	**€1,362.16**

Estado del presupuesto: **Auto presupuestado**

Abrir el presupuesto

Web: **get.xometry.eu**
Servicio de atención al cliente: **enquiry@xometry.eu**
Teléfono: **+49 893 803 4818**

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Handelsregister: Amtsgericht München / HRB 256172
Bank: J.P. Morgan AG
IBAN: DE38 5011 0800 6161 5322 02
BIC: CHASDEFX

Director / Geschäftsführer: Dmitry Kafidov

Queremos trabajar con usted. Si obtiene un presupuesto más bajo, envíenoslo e intentaremos superarlo.

Por favor, revise este presupuesto para comprobar su exactitud antes de realizar el pedido

- Hemos presupuestado y estimado un plazo de entrega para su pedido basándonos en la geometría del modelo 3D que nos ha proporcionado, junto con las tolerancias, características y operaciones secundarias que ha seleccionado durante el proceso de envío y que son confirmadas específicamente por nosotros en este Presupuesto. No extraemos automáticamente características, tolerancias u otra información no geométrica del modelo 3D que nos ha enviado, aunque esté representada en él (por ejemplo, roscas, agujeros roscados, etc.). Aunque nuestros precios se generan dinámicamente en tiempo real, respetaremos el precio de este presupuesto durante siete (7) días a partir de su generación (aunque el plazo de entrega estimado se volverá a calcular en el momento de realizar el pedido).

- Aunque podemos proporcionarle asistencia en el diseño para la fabricación, usted es el responsable último de la idoneidad de su diseño y de la selección de los materiales asociados, para cualquier fin previsto. Puede enviarnos uno o más dibujos de ingeniería y/o hojas de especificaciones. Aunque haremos todo lo posible para identificar cualquier incoherencia o conflicto en sus materiales antes de fabricar su pieza, usted es el único responsable de cualquier incoherencia entre los materiales que nos proporciona y lo que se refleja en este presupuesto.

Las filos vivos internos se mecanizarán con un radio de 2 mm, a menos que se solicite explícitamente lo contrario.

- A menos que se especifique lo contrario, se aplican los Términos y condiciones de Xometry Europe GmbH

- Las piezas fabricadas con materiales propensos a la oxidación pueden ser recubiertas con un agente anticorrosivo a base de aceite a nuestra discreción. Por favor, infórmenos si acepta el riesgo de una posible corrosión durante el transporte y desea recibir sus piezas sin aceite

3M

Scotch-Weld™

EPX™ Adhesive DP490

Product Data Sheet

Updated : March 1996
Supersedes : November 1993

Product Description

DP490 is a black, thixotropic, gap filling two component epoxy adhesive with particularly good application characteristics.

It is designed for use where toughness and high strength are required and shows special benefits in the construction of composite assemblies.

The product has excellent heat and environmental resistance.

Physical Properties
Not for specification purposes

	BASE	**ACCELERATOR**
Specific Gravity	1.00	1.00
Consistency	Non-sag paste	Non-sag paste
Mix Ratio By Weight By Volume	100 100	50 50
Colour	Black	Off-White
Work Life	1.5 hours minimum at 23°C	
Time to Handling Strength	4 to 6 hours at 23°C	
Time to Full Strength	7 days (test to full performance at one week)	
Shelf Life	15 months from date of despatch by 3M when stored in the original carton at 21°C (70°F) & 50 % Relative Humidity	

Performance Characteristics
Not for specification purposes

Performance Characteristics of the Cured Adhesive.

Two cure cycles were evaluated as follows:

Cure Cycle 1	7 days at 23°C
Cure Cycle 2	24 hours at 23°C, 1 hour at 80°C

Performance Characteristics (Cont...)
Not for specification purposes

Temperature Performance in Shear and Peel.

(Etched Aluminium) Shear Strength to BS 5350 C5, Peel Strength was floating roller peel to BS5350 C9.

Tests were performed at 23°C unless otherwise stated.

Temperature (°C)	Shear Strength (1) (N/mm^2)	Shear Strength (2) (N/mm^2)	Peel Strength DaN/cm
-55	23.7	31.6	N/A
23	30.2	28.7	9.24
80	11.9	12.7	7.32
120	2.8	3.2	N/A
150	1.9	1.7	N/A

Adhesion to Etched Aluminium after Environmental Ageing

Ageing Condition	Shear Strength (N/mm^2)
RT Control	26.2
Water at 23°C, 750 hours	25.6
50°C, 96% RH, 750 hours	22.0
120°C, 750 hours	25.3
175°C, dry heat, 120 hours	29.6
Skydroll 500B at 23°C, 750 hours	27.6
JP4 at 23°C, 750 hours	28.7
Hydraulic Oil at 23°C, 750 hours	29.5

DP490 shows good adhesion to many plastic surfaces even by simply solvent wiping.

This can be improved still further by the use of 3M Scotchbrite abrasion and/or use of the primer Scotch-Weld 3901.

Plastics	Shear Strength (N/mm^2)
Carbon Fibre Reinforced Epoxy	36.1 (cohesive)
Polyester Sheet Moulding Compound	4.3 (substrate)
Glass Fibre Reinforced Phenolic	30.3 (cohesive)
ABS (filled)	3.2 (substrate)
PVC (filled)	2.9 (substrate)
Azloy (glass filled polycarbonate)	3.0 (adhesion)
Valox (glass filled PET)	1.4 (substrate)
PMMA	3.7 (adhesion)
Noryl (tm XTRA) (glass filled PPO)	4.9 (adhesion)

Storage Conditions

Store product at 15°C to 25°C for maximum storage life.

Directions for Use /Clean Up

Place the cartridge into the 3M EPX Applicator and clip into position.

Remove the resealable cap.

Expel a small quantity of adhesive and ensure both components flow freely.

Attach correct mixer nozzle (this should have 20 or more elements).

Dispense the adhesive as required.

When finished either leave the nozzle in place and store, or remove the nozzle, wipe clean the tip, and replace cap.

To re-start after storage remove the old nozzle with cured adhesive and re-fit a new nozzle, or remove the cap and fit a new nozzle.

Surface Preparation:
The degree of surface preparation depends on the bond strength required and the environment likely to be encountered by the bonded structure. For most plastics solvent wiping with 3M VHB surface cleaner, followed by abrasion with 3M Scotchbrite 7447, followed by a further solvent wipe until clean, will give good performance (except for acetal, polyethylene and polypropylene and some other low surface energy materials). This also applies to powder coat paints and other stoved paint systems.

The same surface preparation will also give good adhesion to metal surfaces. The objective is to remove loosely attached surface films such as oils, waxes, dusts, mill-scale, loose paints and all other surface contaminants in addition to enhancing mechanical adhesion. Grit-blasting using a clean, fine grit also offers excellent adhesion on many metallic substrates.

Where humid environments are likely to be encountered by metallic substrates we recommend additional priming with 3M Scotch-Weld 3901. Alternatively, chemical conversion coating techniques combined with priming can offer the best durability.

Clean-Up:
Excess uncured adhesive can be removed with the following solvents:

3M VHB Surface Cleaner (mild alcohol based cleaner)
3M Scotch-Grip Solvent No2. (Ketone blend)
3M Industrial Cleaner (Aerosol).

Additional Product Information

Please contact your 3M Salesperson for additional information on the preparation of difficult surfaces, or likely exposure to aggressive environments.

Date : March 1996
EPX Adhesive DP490

Health & Safety Information

Precautions:
Causes severe eye irritation, may cause permanent eye damage. Irritating to skin. May cause sensitisation by skin contact. Avoid contact with the skin and eyes. Wear suitable gloves and eye/face protection.

Launder contaminated clothing before re-use. Avoid prolonged breathing of vapours. Avoid inhalation of dust when grinding or cutting cured material.

First Aid:

Eye Contact: Immediately flush eyes with copious amounts of water for at least 15 minutes, holding eyes open. Call a physician.

Skin Contact: Wash immediately with plenty of soap and water.

For further information please contact the Toxicology Department at the Bracknell Head Office on (0344) 858000.

Values presented have been determined by standard test methods and are average values not to be used for specification purposes.
Our recommendations on the use of our products are based on tests believed to be reliable but we would ask that you conduct your own tests to determine their suitability for your applications.
This is because 3M cannot accept any responsibility or liability direct or consequential for loss or damage caused as a result of our recommendations.

Specialty Tapes & Adhesives

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M15 4PA

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Fax 0161 237 1105

3M Ireland
3M House, Adelphi Centre,
Upper Georges Street,
Dun Laoghaire,Co. Dublin,
Ireland

Customer Service :

Tel (01) 280 3555
Fax (01) 280 3509

aluNID®
Nido de Abeja de Aluminio

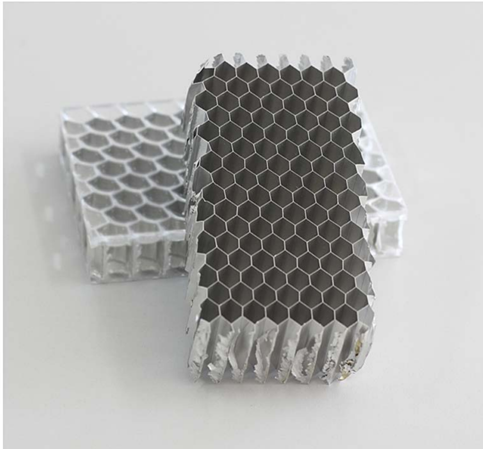
Ficha Técnica

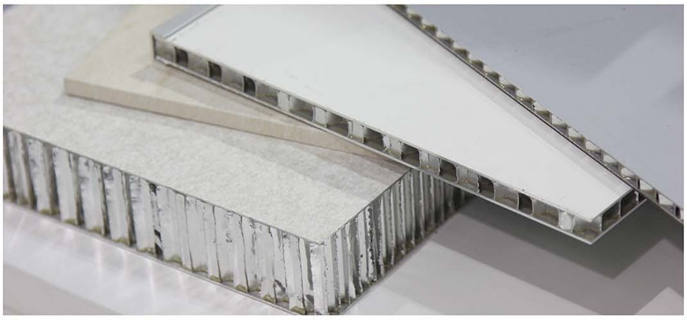
Alucoat®
Grupo Alibérico

ALUCOAT es una compañía española que produce núcleo de nido de abeja de aluminio de alta calidad, **aluNID®**, que tiene una amplia variedad de aplicaciones.

Nuestro núcleo de nido de abeja de aluminio se adapta a los requerimientos del cliente y puede ser suministrado en diferentes condiciones. **aluNID®** ofrece soluciones en colaboración con los clientes y trabaja junto a pequeñas y grandes empresas tanto a nivel nacional como internacional.

aluNID® se utiliza por tanto en sectores tan diversos como en el de la construcción y arquitectura, transportes (ferroviario, naval…), en la industria y diferentes aplicaciones comerciales gracias a su composición y propiedades únicas en el sector.





Propiedades

- •Ligero
- •Resistente y rígido en compresión y cizallamiento
- •Incombustible
- •Reciclable
- •Conductor eléctrico y térmico
- •Buena planicidad
- •Resistente a la corrosión

Edificación | Naval | Automóvil | Ferroviario | Diseño de interiores

Camino de San Luis s/n - Apartado de correos 27, CP. 23700 Linares (Jaén) - SPAIN
Telf.: + 34 953.60.71.90 - info@alunid.com
www.alucoat-conversion.com - www.alunid.com

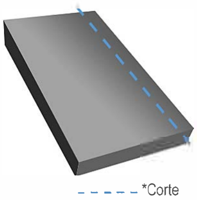
Propiedades Mecánicas

Ejemplo de referencia para su pedido:

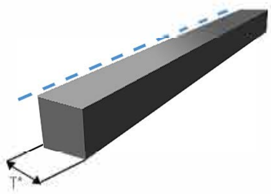
aluNID® 3000	-	O 1/4”	-	56	-	L1500-W3000	-	P	-	T10	-	B	-	EX
Aleación		Tamaño de Celda		Densidad		Dimensiones Expandidas		Perforado		Espesor		Tolerancia de corte		Expandido

Se suministra de 3 maneras:

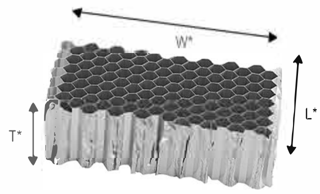
Bloques no expandido(BLQ)



No expandido en loncha (NEX)



Expandido en plancha (EXP)



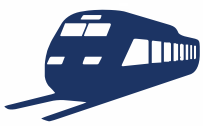
* T = Espesor, L = Longitud, W = Ancho

ALUCOAT diesgnation	ø inch	ø mm	Foil µm	Density kg/m3	Compressive Strength Plain Strength Mpa	Compressive Strength Stabilised Strength Mpa	Crush Strength Mpa	Plate Shear In L direction Strength Mpa	Plate Shear In L direction Strength Mpa	Plate Shear In W direction Strength Mpa	Plate Shear In W direction Strength Mpa
aluNID® 3000	1/4	6,35	50	56	2,2	3,50	0,90	1,65	327	0,97	172
aluNID® 3000	3/8	9,52	50	40	1,2	1,95	0,50	1,10	214	0,64	107
aluNID® 3000	1/2	12,7	50	29	0,70	0,95	0,30	0,70	143	0,43	68
aluNID® 3000	3/4	19,1	50	20	0,35	0,60	0,15	0,40	90	0,28	40
aluNID® 3000	1/4	6,35	70	80	4,15	4,30	1,65	2,70	511	1,50	284
aluNID® 3000	3/8	9,52	70	54	2,00	2,60	0,85	1,60	312	0,95	163
aluNID® 3000	1/2	12,7	70	40	1,20	1,50	0,50	1,10	214	0,65	107
aluNID® 3000	3/4	19,1	70	27	0,60	0,85	0,25	0,65	131	0,40	61

Edificación

Naval

Automóvil



Ferroviario

Diseño de interiores

Aluminio AW7075

Composición química

ELEMENTOS	Mg	Mn	Fe	Si	Si +Fe	Cu	Zn	Cr	Mn +Cr	Ti	Bi	Ni	Pb	Sn	Zr
Máximo	2,1-2,9	≤0,30	≤0,50	≤0,40	-	1,2-2,0	5,1-6,1	0,18-0,28	-	≤0,20	-	-	-	-	-

Propiedades técnicas

NORMA E.N.		AW7075
Norma U.N.E.		L-3710 / 38.371
Densidad	g/cm3	2,80
Estado del tratamiento		T-6
PROPIEDADES GENERALES		
Carga de rotura	N/mm2	480-530
Límite elástico	N/mm2	390-450
Módulo elástico	N/mm2	72000
Alargamiento a 5,65%		2-8
Dureza	Brinell	130-140
PROPIEDADES FÍSICAS		
Punto de fusión	ºC	475-635
Conductividad térmica	W/(K*m)	134
Coefic. dilatación terminal lineal	m/(m*K)	23,5
Conductividad eléctrica	%IACS	33
CAPACIDAD TECNOLÓGICA		
Ambiente industrial		R
Ambiente Rural		R
Ambiente marino		M
En agua de mar		M
MECANIZACIÓN		
Fragmentación viruta		B
Brillo superficial		B
SOLDADURA		
A la llama		B
Al arco bajo gas argón		M
Por resistencia eléctrica		B
Braseado		R
ANODIZADO		
De protección		B
Decorativo		R
Duro		MB

Características principales

Aleación de alta resistencia. Alto límite elástico, adecuado para piezas sometidas a grandes fatigas.

Uso habitual

Moldes soplado, troqueles, maquinaria, armamento, blindajes, industria automóvil, piezas estampadas, etc.

Leyenda:

- **MB** Muy Bueno
- **B** Bueno
- **C** Correcto
- **R** Regular
- **M** Malo
- **(1)** Valores típicos

CODIFICACION INTERNACIONAL DE LAS ALEACIONES DE ALUMINIO

1xxx Aluminios cuya riqueza es > 99%
2xxx Aleaciones al cobre.
3xxx Aleaciones al manganeso.
4xxx Aleaciones al silicio.
5xxx Aleaciones al magnesio.
6xxx Aleaciones al magnesio-silicio.
7xxx Aleaciones al zinc.
8xxx Otras aleaciones.

La primera cifra indica el componente principal de adición y el grupo al que pertenece la aleación.

Nota: Aunque nos hemos esforzado por asegurar la exactitud de los datos provistos, ACP Materials S.L., no garantiza ni acepta ninguna responsabilidad por la exactitud de los mismos.

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