DESING PROPOSAL OF A PLASTIC PANEL FOR SLABS FORMWORK DURING CONCRETE CASTING AND HARDENING

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POLITECNICO
MILANO 1863

Desing School
Milan, Italy
A.Y. 2017 – 2018

“Design is Everything”
Paul Rand

A Dios, guía y protector.

A mis Padres por cada esfuerzo y todo su apoyo.

A mis hermanos Jorge y Mauricio por ser ejemplo que seguir.

A ti Yeimmy, por tu apoyo desinteresado.

A mis amigos del “International Students Office” del Politecnico di Milano,
por ser mi segunda familia en Italia.

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Glossary

Formwork: It is temporary or permanent moulds into which concrete or similar materials are poured. In the context of concrete construction, the falsework supports the shuttering moulds.

Concrete: A very hard building material made by mixing together cement, sand, small stones and water.

Slab: A thick, flat piece of a solid substance, such as concrete, stone, wood, metal that is usually square or rectangular.

Column: It is a structural member designed to carry compressive loads, composed of concrete with an embedded steel frame to provide reinforcement.

Beam: It is a structural element that primarily resists loads applied laterally to the beam's axis.

Extrusion: Isis a process used to create objects of a fixed cross-sectional profile. A material is pushed through a die of the desired cross-section.

Polymer: Is a large molecule, or macromolecule composed of many repeated subunits. Most manufactured polymers are thermoplastic. This property allows for easy processing and facilitates recycling.

Yield Strength: is the maximum stress that can be applied along its axis before it begins to change shape.

RESUME

Inside the building field, specifically in the Colombian Social Housing (SH), structural designs are realized to edification of family houses which are composed by two levels and on the construction process, it is necessary to use formwork for concrete.

Formwork is used elements to mould reinforced concrete either cylinder or prismatic or cylindrical shapes regarding planned designs. Those elements are designed to support applied pressures by concrete on casting and later hardening. Division slabs are moulded by panels which commonly are made of leftover wood such pine or metallic materials such as steel or aluminium. Also, nowadays those panels are producing polymers like Polypropylene (PP), Acrylonitrile-Butadiene-Styrene (ABS) and composites material of Polyethylene (PE) plus Glass fibre. However, rustic material panels could present inconvenient at certain times since the concrete sticks on if formwork is not coated with petrol. Also, panels can present damages in their components at disassembling, so, in consequence, it is necessary to do maintenance.

The project's objective is to do a design proposal of a polymeric panel which is on the capacity to support applied pressures by fresh concrete at the pouring of division slabs for SH of two levels, avoiding components' damages because of dismemberment and necessary maintenance after each use.

At the end of the process, it is hoping to arrive at a projected panel to be produced by plastic extrusion method that is being selected following established parameters to piece design, which is parametrized in CAD/CAF and to do the applied pressure simulation by concrete and following analysis of possible polymeric materials according to results.

Keywords: slab mould, plastic panel, formwork, polymer, extrusion

RIASSUNTO

All'interno del campo edilizio, in particolare nel Social Housing (SH) colombiano, sono realizzati progetti strutturali per l'edificazione di case familiari che sono composte da due livelli e nel processo di costruzione, è necessario utilizzare casseforme per calcestruzzo.

Le casseforme sono elementi utilizzati per modellareil cemento armato sia cilindriche che forme prismatiche rispetto ai progetti pianificati. Questi elementi sono progettati per supportare le pressioni applicate dal calcestruzzo alla fusione e successivamente all'indurimento. Le lastre divisorie sono modellate da pannelli che sono comunemente fatti di legno rimasto e materiali metallici come acciaio o alluminio. Inoltre, al giorno d'oggi quei pannelli sono prodotti di polimeri come polipropilene (PP), acrilonitrile-butadiene-stirene (ABS) e materiali compositi di polietilene (PE) più fibra di vetro. Comunque, i pannelli di materiali rustici potrebbero presentare inconvenienti in determinati momenti poiché il calcestruzzo si incolla se la cassaforma non è rivestita di benzina. Inoltre, pannelli sofrono danni nei loro componenti allo smontaggio, quindi, di conseguenza è necessario fare manutenzione.

L'obiettivo del progetto è quello di progettare una proposta per un pannello polimerico che sia in grado di supportare pressioni applicate da calcestruzzo fresco a colata di lastre divisorie per SH di due livelli, evitando i danni dei componenti a causa dello smembramento e della manutenzione necessaria dopo ogni utilizzo.

Alla fine del processo, si spera di arrivare a un pannello progettato per essere prodotto da un metodo di estrusione di plastica che viene selezionato in base ai parametri per la progettazione, parametrizzata in CAD / CAF e alla simulazione di pressione applicata da calcestruzzo e dopo l'analisi di possibili materiali polimerici in base ai risultati.

Parole chiave: stampo per lastre, pannello in plastica, cassaforma, polimero, estrusione

INTRODUCTION

Inside the housing construction, it is realized the structural manufacture where moulds are used to contains and give self to columns, beams and slabs. Those elements are considered the main components of the building. Structure manufacturing is realized following steps: reinforcement assembling, formwork installation, concrete pouring, concrete hardening and finally formwork disassembling. At the moulds installation stage, supports, beams, joists, anchors and sheathing components are placed to contain concrete.

At slab formwork placement, a series of components are assembled to support fresh concrete to mould and create the division of house levels. Sheathing is an industrialized metallic or wooden panel. It is the closest component to concrete, so, these is on direct contact with poured material, generating the slab self. In addition, it is transferring pressure which is produced by cement to support components of the formwork. Nevertheless, there are handmade panels at Colombian far away regions from main cities. Those moulds are assembled of discard battens which can present inconvenient when plyboards are in contact whit concrete such as stuck, dismemberment and total disassembling. So, it is necessary to do maintenance on panels or throw away damaged goods.

Currently, the are products for formwork according to presented needs in work out. It is possible to find plyboards with different measures and materials composition. Meva (MEVA, 2017) company is presenting a hybrid panel which is composed by Aluminium frame and Polypropylene board, it is a light sheathing part and avoid concrete stuck in its face. Topec® is formwork line from Hunnebeck (Hunnebeck, 2017) company. This module is combined Aluminium framing whit wood as sheath part. Regarding to current solutions, those are improving the formwork performance, but goods are offered in main cities of the country.

Concerning to the previous expressed matters, it is proposed a design of a plastic panel for slab formwork for concrete casting and hardening. It is given a solution to avoid different inconvenient at work out and improving panel characteristics regarding to concrete finishing, modularity and material for production.

Project methodology is following the proposed process by Karl T. Ulrich and Steven D. Eppinger called “Product Design and Development” in which first step is to realize an analysis of current problem through literature revision in scientific papers and books regarding formwork design and structures construction, also interviews are made with workers and experts to collect opinions and direct needs coming out from the daily users of those products. Then, design requirements are established from the got information which is the starting point for the design proposal for the plastic panel.

Second step is driven to product ideation. Current moulds are analysed in a benchmarking to produce initial concepts to find possible solutions referring to previous established problems and needs. Conceptions are evaluated in a matrix when weakness are noticed. These contains design parameters, each one has a quantitative score. After qualification it is selected the best concept. It is carry out to next step where is done the detailed design.

Detailed design is executed considering the product that is being proposed. Following production processing and materials literature, the product design improvement is realised. Also, panel’s profile and fabrication process are set up. After that, final design proposal is showed and defined for the plastic panel for slab formwork.

The final step of the project is to validate and compare the design proposal through CAD/CAM tools. To effectuate qualitative and quantitative validations product 3D model is tested in a simulation at Solidworks® software. Also, at the end of the process it is carry out a costing analysis of the piece for a future production. It is done in CES Edupack software.

1. JUSTIFICATION

Into the construction field, it is done housing structural manufacturing by formwork to produce columns, beams and slabs. In Colombia and specifically in faraway regions from main cities handmade formwork is used to construct those important components of a house. Commonly, panels are made of leftover wood which can generate inconvenient such as concrete stuck or dismemberment at the removal step.

In those regions Social Housing has got popularity and projects to build residential zones have increased by the time (DANE, 2016), those projects can reach at least 100 houses, so, it is necessary to provide elements for construction to the workout such formwork for concrete to build structural components. In the market there are moulding systems which can assist in the forming of columns, beams and slabs construction, but in general, it is not possible to rent those because of geographical position of building plan. Then, the implemented solution by workers has been to used wood planks to mould columns and beams and assembled panels to produce slabs. This panel is in direct contact with fresh concrete and support it from the casting to the hardening. Nevertheless, those plyboards present problems regarding to the disassembling step as it was told before. In addition, as panels must be used several times to cast slabs, it is necessary to do maintenance anytime it is dismounted from the slab to remove concrete stuck and to fix or change damaged lumbers of the panel. Furthermore, environmental factors are affecting the material; those can rut panel's components and damages on itself if these are not coated with oil or a chemical substance to protect against those factors.

So, after the problem analysis, it is the opportunity to take advantage of the technologies which can give a support in the implementation of a plastic panel to offer a solution for those inconvenient at workout in those regions. It is used the knowledge about plastic processing and production to generate an alternative which can be manufactured and transported to those far zones and implemented to avoid common difficulties with keeping handmade plyboards.

2. OBJECTIVES

2.1 PRIMARY OBJECTIVE

Realize the design proposal of a plastic panel for slab concrete casting and hardening through literature and workout problems analysis as well as product conception methodology to make it more efficient the social housing construction at faraway regions in Colombia.

2.2 SECONDARY OBJECTIVES

- Analyse concrete slab construction variables for Social Housing through bibliography research and interviews with workers and experts to stablish product's design parameters.

- Design proposal of a plastic panel for slab formwork for concrete.

- Evaluate the design proposal with CAD/CAM to determine product requirements accomplishment.

- Do a qualitative comparison between the proposal and current handmade and industrial products for formwork to determine design pros and improvements.

3. PROJECT METHODOLOGY

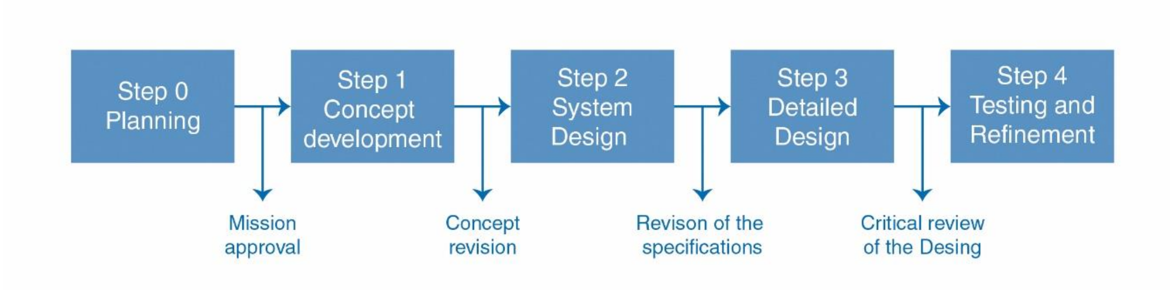


Fig. 1 Product development process(Ulrich & Eppinger, 2009)

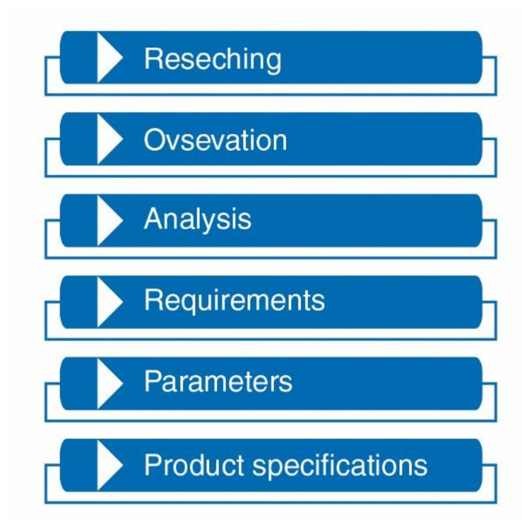


Fig. 2 Planning step(Ulrich & Eppinger, 2009)

The American Psychological Association (APA) norm for documents.

The following document which is refereeing a project for a proposal of a panel for slab formwork is written under the APA norm for academic documents in 2017 – 2018, which has as main objectives to identify people's ideas in any work and to indicate sources from those contributions or text material in a list of refences at the end on the writing. (MRU, 2018)

3.1 Problem Analysis

3.1.1 Formwork for concrete

Formwork is defined as a temporary structure whose purpose is to provide support and containment for fresh concrete until it can support itself. It moulds concrete according to design sizes and shape, controlling position and alignment. (Hanna, 1999)

On this study of concrete form, it is given the detailed component's description such us sheathing, structural supports also accessories like form ties, form anchors, form hangers and else. Figure 3 shows placing of components of a mould for concrete.

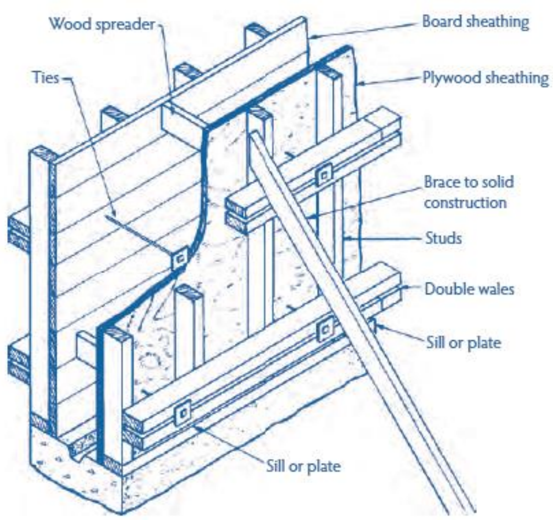


Fig. 3 Formwork system(Johnston, 2010)

Sheathing: It is the supporting layer of formwork closest to the fresh concrete. Generally, it is made of wood, plywood, steel or any material capable to transfer loads to supporting members. It gives finishing after the drying process to the concrete.

Structural Supports: This is a system, it is composed by temporary beams and columns whose carry transferred dead and live loads through the sheathing.

Accessories:

Form ties: It is a tensile unit used to hold concrete forms against the active pressure of freshly placed plastic concrete.

Form anchors: Those are devices used to secure formwork previously placed concrete during pouring. They give to system the adequate strength.

Form hangers: Devices used to suspend formwork loads from structural steel, precast concrete or other system members.

Side form spaces: Devices that keep the desire distances between a vertical form and reinforcing bars.

The building requires formwork to support the slabs and footings or foundations which are considered as horizontal forms, also columns, beams and walls whose are considered vertical moulding. On the building field, there are different two different techniques used to construct those forming systems: hand-set and crane set.(Hanna, 1999)

Hand-set system: It is called conventional system too. This is still the most common and popular formwork systems because it is fabricated for the specific need of the slab, it means that is assembled with wood beams and ribbons. However, this system sometimes becomes in a high and expensive labour.

Crane-set: It is also called nonconventional method consist in modular panels which are faster assembled and disassembled for forming. That system has increased by the time because facilities in construction cycle, low cost and less time labour.

3.1.2 Horizontal forms:

Footing form: Footing or foundation are those structural elements which works on walls, columns and beams loads and their characteristic is to be low in height. Forming is defined by tiny height and grand wider components depend on design requirements as it is illustrated in the figure number 4. (Figure 4a)

Wall form: This kind of forming is divided in three categories: Built in place, Prefabricated and patented panels. The first is commonly fabricated of plywood for sheathing and lumber for studs and wales. Prefabricated ones use plywood for sheathing as well and those are attached to a semi permanently frame made of lumber of different sizes. And the third kind of wall form uses also plywood for sheathing and frame is fabricated of steel or wood or a combination of both. (Figure 4b)

Column form: Concrete columns are usually square or rectangular, L-shaped, octagonal or round. To create those shapes, it is commonly used Ply-form for sheathing and vertical wood battens. For clamping the are different methods such us wood ribbons or steel clamps whose surround form components and keep them together reacting to fresh concrete pressure. (Figure 4c)

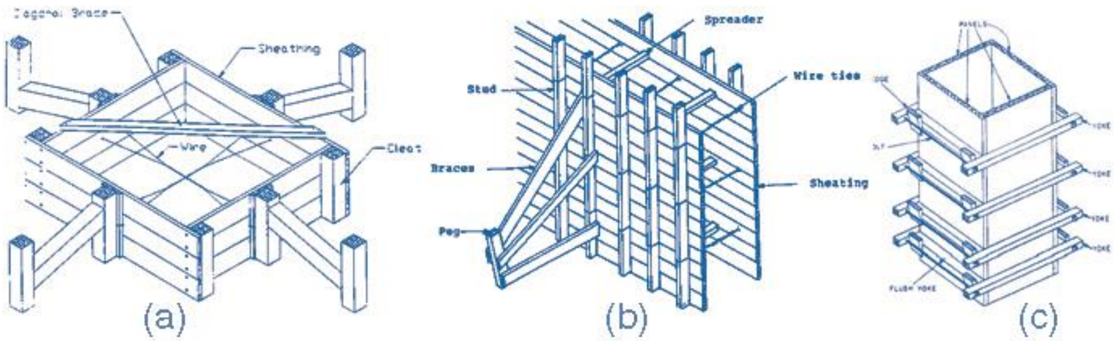


Fig. 4 Types of formwork: (a) Foundations; (b) Walls; (c) Columns (Johnston, 2010)

Formwork for slabs: This type of forming is used to support different kind of slab compositions and concrete type that is employed on. Those concretes floor slabs but not just them according to needs can be:

- Concrete slabs supported by concrete beams
- Concrete slabs of uniform thickness whit no beams, designed as flat slabs
- Fiberglass dome forms for two-way concrete joist system
- Metal-pan and concrete-joist-type slabs
- Cellular-steel floor system
- Corrugated-steel forms and reinforcement floor systems
- Concrete slabs on steel lath

Formwork to be proposed on this case of study are for slabs supported by beams, uniform thickness slabs and fiberglass domes to lighten up slabs.

Concrete Slab: It is a wider and flat reinforced concrete element. Generally, this is horizontal where its upper and lower faces are totally o partially parallel between them. Slabs are supported by structural beams, masonry or structural walls, also by columns or directly on the ground. (Subsidiarios & Mexicanos, 2006)

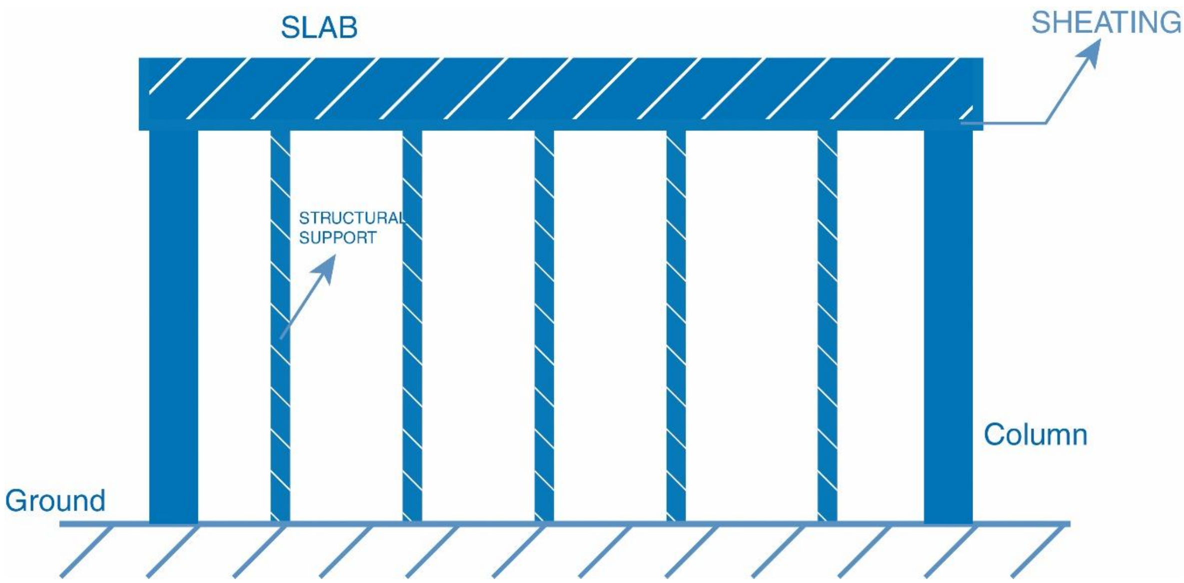


Fig. 5 Concrete Slab formwork system (Author)

Solid Slab: It is built of concrete and steel. The main use of them is on family buildings and industrial application.

Lightened and Reticulated Slab: It is made of concrete, steel and lightener elements such us coffers, hollow bricks or polyurethane. Those slabs are used on skyscrapers and elevated structures.

3.1.3 Design criteria for formwork

In the chapter number 4 of Formwork for Concrete there are some suggestions about formwork design such us sheathing component which is the very first contact support of fresh concrete and so it is important to mention it due to the focus of the design proposal. Sheathing materials consist of wood, plywood or metal materials capable to transfer the load of the concrete supporting (ACI commititee 347 (American Concrete Asociation), 2004). At the same time, it says that plastics and composites can be considering to be applied on this component of the slab-form. Following is shown the list of requirements to select materials:

- Strength
- Stiffness
- Release
- Reuse and cost per use
- Ability to drain water excess

- Resistance to mechanical damage
- Workability
- Adaptability to environmental factors

Materials specification

Following instruction from ACI-347 manual (ACI 347, 2004), those are materials with their specifications to be used in the formwork making off:

- **Sawn lumber:** For components such as framing, sheathing and shoring.
- **Plywood:** For sheathing and shoring.
- **Steel:** Panel framing and bracing: Heavy forms and falseworks; Columns and joist forms: Stay in place deck forms shoring.
- **Aluminum:** Form panels and form framing members.
- **Reconstructed wood panel:** Form liners and sheathing.
- **Wood fiber or Glass fiber:** Stay in place form liners and sheathing.
- **Laminated paper or fiber:** Colum and beams forms. Forms for slabs beams and pre-cast piles.
- **Corrugated cardboard:** Internal forms in beams and girders (Generally this is used internal shape call “egg-crate” stiffeners.)

3.2 Case of study: Social Interest Housing projects.

In Colombia, according to National Department of Statistics DANE by its acronym in Spanish, in the last years, family buildings has increased in a 13,3% (DANE, 2017). Construction field has put its interest on Social Housing (SH), that is a government system to give economy assistance to buy a house by a family or workers and which has getting popularity because same given benefits for. By the third quarter of 2017, according to DANE there were 3.994 SH on construction process and 3.900 not SH too(DANE, 2017), so, it is interesting to have a look of how those kind of hoses are built and which tools are implemented into the construction area to fabricate slabs and others structural components of it.

In those projects commonly, there are implemented 2 floor houses where at list a slab is casted to generate levels. Buildings are replied “n” times as in the figure 6 is shown and it depends on the project’s objectives but, in general 100 houses as minimum rate are built.

Fig. 6 Social Interest Housing project (Chachareros, 2015)

3.2.1 House type: Two levels House

A typical SIH is composed in the ground floor by kitchen, laundry, dining and living room. In the second floor are placed dormitories and the bathroom. Following parametric drawings are shown house distribution.

Fig. 7 Typical SIH distribution (Gelvez, 2017)

3.2.2 Structural composition

As Colombia is a country placed on a high seismic zone because their position on “Pacific Fire Belt” and mountain geography, there are specifications on the Earthquake-Resistance Norm NSR-10 title A Chapter 2 (SCI, 1997a) emitted by Colombian Engineering Association to structures design and where it is specified different structural elements sizes such as columns, beams and slabs.

Helbert Giraldo is mentioning in it work “How is a structure pre-measured” the NSR-10 Title C, where there are specified dimensions about slabs thickness according to other parameters like distance between supports where it is placed (Giraldo, 2000). In the following table expressions to calculate are shown.

Table. 1 Slabs measuring for different structures

Minimum thickness "h" to avoid beams and slabs deflection calculus of, whose are working in one direction and supporting division walls.				
Elements	**Minimum thickness, h**			
	Simple supporting	Continue Supporting	Both continue supporting	Cantilever
Solid slabs	L/14	L/16	L/19	L/7
Beams, slabs or ribbed slabs built in one direction.	L/11	L/12	L/14	L/5

(Segura, 1999)

Columns' size section is calculated by specific equation regarding to total load to be supported by. Professor Segura of "Universidad Nacional de Colombia" is giving expressions to calculate it

Equation 1 Calculation of column section (SCI, 1997b)

$$A = 18 * P$$

Where,

A: Column section (cm2)

P: Axial load (Ton)

P is calculated since total load generated by all structure, where live and dead loads are added to get it.

Consequently, to measure columns it is also adding a seismic factor depending on the zone where the structure is placed; commonly lateral dimensions of elements are 20 cm for low seismic, 25 cm for medium and 30 cm for high vulnerability zone. (Segura, 1999)

3.3 Plastic processing methods.

Into plastics processing there are different options to fabricate pieces according to design specifications and product's need. Depending on the project, it is used one of the following methods for moulding a plastic article as in the "DESIGN FOR MANUFACTURABILITY HANDOBOOK" of James G. Bralla is specified:

- **Injection moulding for thermoplastics:** *"It consist in get a specific shape by injecting material into a mould from this is getting the form after cooling and solidification"* (Bralla, 2004a)

- **Blow moulding:** *"Blow moulding is a means of forming hollow thermoplastic objects. Air pressure applied inside a small hollow and heated plastic piece expands it like a balloon and forces it against the walls of a mould cavity, whose shape it assumes. There it cools and hardens. The mould opens, and the part is ejected."* (Hodska, 2004)

- **Plastic profile extrusion:** *"Extrusion is a process for moulding thermoplastic materials into sheets, tubes, or shapes that have a constant and often complex cross section. Dry plastic material, normally in the form of pellets or powder, is placed in a hopper that feeds into a long, carefully heated chamber. In the chamber, a rotating screw mixes the plastic to produce a uniform melt and forces it through a die orifice. As the extrudate leaves the die, it is passed through a cooling medium (air or water) by a conveyor or other take-off mechanism. It solidifies to the cross-sectional shape of the die opening. The extrudate is pulled away from the die faster than it is extruded, thus causing it to draw down to a smaller cross section."* (Bralla, 2004b)

- **Thermoforming plastic: "**The plastic sheet or film is heated to the softening point, clamped over the mould or between mould halves, and drawn or forced into the mould by one or a combination of methods including vacuum, air pressure, gravity, and mechanical force. It cools in the mould, taking the mould's shape. It is then removed from the mould and trimmed as *necessary."* (Bralla, 2004a)

3.4 Background

Since concrete structures have been developed by the time, there was the formwork developing too. In the beginning used material was wood and high quantities of it where implementing to raise moulds for concrete element. (Hanna, 1999)

In the 1970's researching and developing products about plastic formworks had been proposed to start avoiding high weight in, and high-density plastic materials which according to critical design specifications can reach supporting of fresh concrete pressures applied by. The inconvenient of those formworks were poor strength on load and it was a needing to increased dimension of to reach supporting of. However, this product implementation was focused on vertical element of structures with steel components which kept geometrical composition to avoid undesirable shapes as in the patent number 4,516,372 in United Stated of America. (Application et al., 1985)

According to a research made by Mi Jiaping in the 90's, in China it has become a trend which is proposing and applying formwork made of plastic composites plus natural fibre of bamboo. Since building field in some parts of that country is working as handmade techniques, implemented moulding cited before is growing by the time thanks to the low cost and production. (Jiaping, 1994)

An approach of a re-useable plastic panel produced by injection moulding has been presented by Geoplast S.p A from Italy to get a patent in EEUU in 2008, which was put on redesign process where reinforcing ribs were implemented to raise supporting on load applying.(Kong, Application, & Data, 2011)

In Italy, companies such Farina Formworks® is currently working with frames and complete elements fabricated of steel and aluminium. There are different options according to design needs and structural elements to cast.

Since 1987, Modali® construction system has worked on developing for solutions of low cost housing in Africa. Nowadays, it is a reusable system to cast houses in one day, it consists in a complex of plastic panels which generates house's walls where concrete is poured by the mortar method, it consists in put in the cement manually layer by layer. Those moulds are used at least fifty times, then material is recycled for new products.

In Colombia, there are not plastic formworks implement in the building field. Since tiny projects for SIH have been carried into effect, rustic systems are used, commonly those are made of wood and/or steel and aluminium in great projects for skyscrapers. In contrast, there are companies such as PlastiPol S. A (Plastipolsa, 2012) in Medellin, that works in the making of products for construction field where they recycle industrial waste of PP, PVC, PE and PS and after the recycling process this company produces “plastic wood” which is extruded in different profiles to get ties and lumbers for panels, stowage and fences. This production is replied by other little companies on a smaller scale in Santander region.

3.5 Problem establishment.

Nowadays in Colombia there are companies where their focus is on the formwork systems for concrete, however those work for a great building projects in main. Since offered products cannot be carried to specifically zones and towns, by the time there has been developed handmade moulds commonly made of waste of local raw material such as wood. Sheathing components are built panels of lumber and ribbons according to pouring of structural elements specifications. In interviews whit workers of some projects which currently are on construction, they told that each time those panels are used and released, there are problems related to dismemberment of components, so, it is necessary to do maintenance like replacing ribbons or cleaning the panel surface because the concrete is stuck. In addition, professionals whose oversee construction express that to rent certificated panels is generating an extra cost in the project. In consequence, they prefer to make a control on the handmade components maintenance and reused as much as possible times.

Also, when panels are destroyed, waste wood is burned. It means, finalize its cycle as combustible in ovens or simply, those are blistered to eliminate that useless material.

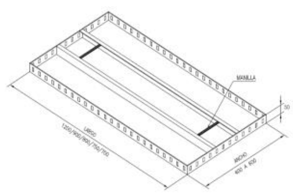
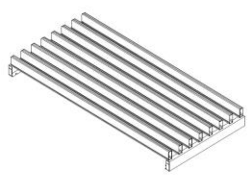
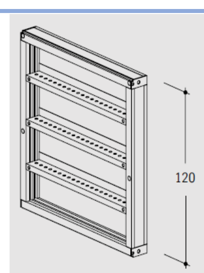
So, related problems whit formwork in those zones are panels to mould without correct certification and avoid for instance maintenance. Other inconvenient is when module’s face is not covered with a non-stick additive, concrete can stick on the surface so to release the plyboard, workers must to destroy it.

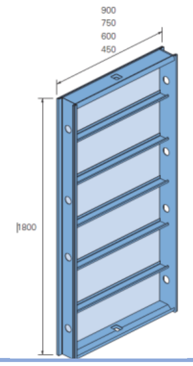
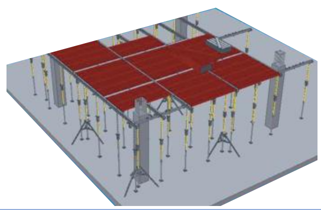
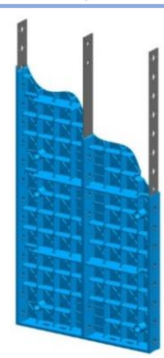
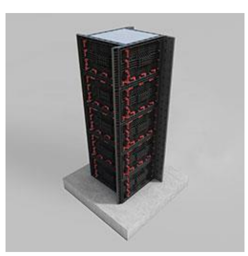
Environmental factors are acting too against sheathing components. As those are made of wood without any water and anti UV protection, modules came rotten by the time because long exposition to those agents.

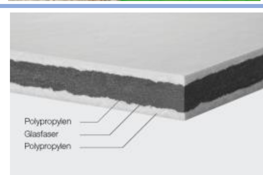
3.6 Bench Marking.

To understand what current formwork systems are most implemented and innovative on buildings, it has been analysed a group of them which have different disposals to be assembled and performing into construction. In addition, materials and plastic products are checked to get a reference of supporting in load. Following it is shown a table in which parameters such as general dimensions, used materials and else are compared to stablish useful information to later proposal of alternatives for the panel and implementation of a material that performs supporting applied loads on.

Table. 2 Benchmarking

Den.	Sub-group	Image	Material	Dim. (mm)	N° comp.	Comments
MEVA DEK			Aluminium frame Plastic face-sheathing	1600x1600 1600x800 400x600	7	It is carried by a worker, GM Alkus face sheathing is a composite PP + Glass fibre + PP
UNISPAN	All steel		10% Steel made	1200x600	4	
	Light-form		100% Aluminium made	2000x1000	10	Sheathing is a plywood of 18 mm thick
MANTO			Steel famed Plywood sheathing	1200x1200	7	18mm thick plywood. 140 mm height panel guarantees 80KN/m2

TOPEC			Aluminium framed 10 mm plywood thickness	1800x900 1800x600 1800x450	5	141.5 depth panel. Panels carried by a worker
ESTEEN basic			Steel	Beam: 4000 Crossbeam: 1970	2	Complex of beams, crossbeams and plywood sheathing.
STEN girder			Wood Beams	1600, 1950, 3300, 4800	2	Polly-facing geometry. Machinable. Complex generates supporting structure.
SBS DSCAFF			PP	1200x600x70	4	Plastic -steel reinforce modular slab formwork.
GEOPLAST			ABS	1200X600X80	4	100 + reuse cycle. Concrete doesn't stick on

REFERENCE PRODUCTS FOR SHEATHING						
METSA plywood			Conifer Nordic wood bonded with phenolic resin	2400x1200x18	1	Building app. Ideal for formwork concrete casting.
Plastform 333 MDO			Hardwood and Arclin 333 MDO	2240x1220x17.5		Manufactured with mixed of wood spices
Corgrid sheet Forming			Steel wares + PE	2400x1800x4	1	Used to poured founding
Alkus Panel			PP + Glass fibre	1200x800x15	1	PP Glass-fibre core reinforced
Plastic Stowage	ER-100		HDEP	1200x1200x150	1	100%HDEP lower pressure injection (Structural foam) Can support 5000 kg in static load
	ER-100 HD		HDEP + Anti UV + Anti impact additives	1200x1200x150	1	Copolymer HDPE. Can support 6000Kg in static load

(Author)

In conclusion of the benchmark, it is selected possibilities which can be implemented at concept generation step. Also, since the object is to arrive at a plastic panel that works well for the slab moulding, materials, dimensions and productions process are analysed to stablish design parameter in later step like detailed design.

Materials.

The most common material presented into benchmark is metallic one. Thanks to the high performance because mechanical properties, it is fulfilling resistance and deformation at loading. Plywood is the second material in the list, it is combined with metallic frames to generate panels, it also has good resistance to deformation. However, since those materials are susceptible to environmental agents, it is obligatory to add anticorrosion agents to care them.

Polymers are appearing in three of the options, in the materials reference there is a fibre produce of polymer that is used in casting for foundations. Products such as Geoplast panel are 100% polymer production, in contrast SBS panel is needing an embed steel reinforcement. It is present in the MEVA DEK panel a composite which is working as sheathing component of the same. Reference products for stowage are also 100% polymer and are supporting high loads during long times because are used for storing.

So, a material's resume to evaluate later to the product proposal is: High Density Polyethylene (HDPE), Polyethylene (PE), Polypropylene (PP), Glass fibre and composites as in the Alkus Panel is disposed PP plus Glass fibre. As those materials are currently implemented on formwork products, it is done the material selection process once creation step has been done.

Dimensions

It is being analysed common dimensions presented on actual products to measure the proposed product. It is important to notice that as buildings in Colombia are denotated in square meters, constructors prefer to make panels which fulfil generic sizes where modules reach almost 1 m2. So, according with it and expressed suggestions by workers, a synthesis is doing to arrive to desire dimensions.

Larger panels oscillate between 1.8 * 1.8 m2 and 1.2 * 0.6 m2, as in the table 1 it is noticed. There are elements like lumber which are measured in m, generally are form 3 to 6m.

Production process

Knowing that the project's goal is to propose a plastic panel, it is deduced from the benchmarking and background that injection and extrusion process have been used to produce panels. However, it is well noticed that in Colombia it is used extrusion of plastic material to fabricate different products made of. So, in consequence, it would be the best option to extrude a plastic for this aim.

3.7 Design Parameters

Before to proceed with concepts generation and design alternatives for the product proposal, design parameters are stablished to arrive at well approximation of panel ideas. Following, it is described and shown product's requirements.

3.7.1 Dimensions establishment.

As in benchmarking conclusions were described, dimensions are also referring to covered area in which is going to be cast concrete. It means, building managers are in change to quantify the number of square meters the need to use on the slab forming. So, to in that case, the panel should be measured whit an area closer to 1 m2 that is facilitating the work out quantification.

Regarding to the handmade wood board, its measures are 1400 * 700 * 100 mm as in figure is shown. And its components are described in the following table:

Table. 3 Handmade panel measures

	Length (mm)	Height (mm)	Base (mm)
Lumber	1400	85	40
Ribbon	700	15	100

(Author)

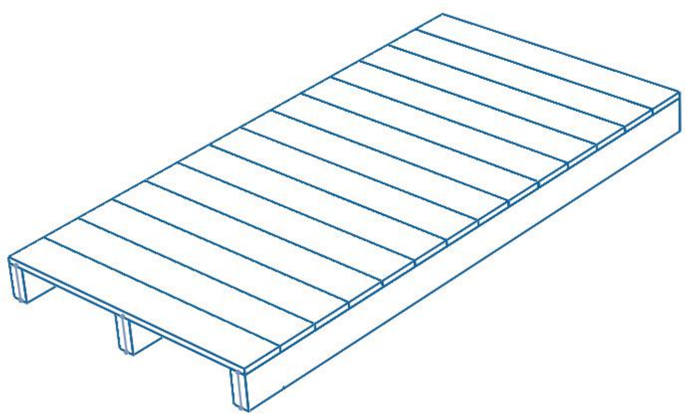


Fig. 8 Handmade wood board (Author)

Resuming most common measures at benchmarking and current wood panel, it is presented the next table covered areas of formwork possibilities.

Table. 4 Covered areas by formwork possibilities at benchmark

Option	Length (m)	Height (m)	Area (m2)
A	1,6	0,8	1,28
B	1,8	0,6	1,08
C	2	1	2
D	1,4	0,7	0,98

(Author)

In conclusion, the most convenient measure to propose the plastic panel is option D because it is the closest area to 1 m2, so, it is giving facilities for work out quantification and sizes are acceptable to be carried by a worker. In contrast, option C is the useless because larger sizes. Although it is covering a great area, problems like high weigh are decreasing its usability.

3.7.2 Number of components

On the production projection, number of components define how many steps to reach complete product are executed for. Two defined options are: to be monolithic, or to be composed by two or more pieces. In addition, that parameter will be applied in the later concept selection where regarding to alternatives' profiles, it is getting a weighing on each one of them.

Both options are working well for production process methods: Injection or extrusion processing. To stablished which of the alternatives is used, it is made a pros and cons table.

Table. 5 Monolithic pros and cons

MONOLITHIC PRODUCT	
Pros	**Cons**
■ One mould for production ■ Not needing to be assembled. ■ Finishing is included at production process. ■ Lower production price because production complex.	■ General maintenance required; Cleaning of complete piece after using. ■ If the peace suffers any fail, it is necessary to get it out of the working field.

(Author)

Table. 6 Assembled product pros and cons

ASSEMBLED PRODUCT	
Pros	**Cons**
■ Maintenance by components replacing in case of damages or dismemberment. ■ Panel is not discarded because any imperfection. ■ Low cost maintenance.	■ It is necessary to use more than one mould for production process. ■ Production time is increased by assembling step. ■ Possible dirty on assembling remain spaces between components

(Author)

So, for concepts proposal, two cases about system composition are used. It will be one of the comparative criteria to select an alternative to be developed in detail for production. It is important to notice that both monolithic and more than one component are useful for product ideas, then as a conclusion those are adaptable for panel conception.

3.7.3 Concrete reaction un the pouring processes.

It is necessary to get important values from the casting process of fresh concrete. During the pouring on it and depending on the structure (horizontal or vertical), there are loads and pressures which acts on the formwork: lateral pressures or vertical pressures.(Johnston, 2010)

Loads: Those forces are commonly applied by dead loads, it means structure components and placed formwork weight. Also live loads such as workers, tools and different stuff different form structural things. On slabs, fresh concrete pressure is understood as its proper weight depending on slab type (solid or lightened). (Figure 7a)

Lateral pressures: Those are applied pressures on the formwork of slender elements by fresh concrete. On horizontal elements like slabs, lateral pressure is not affecting to be considered. (Figure 7b)

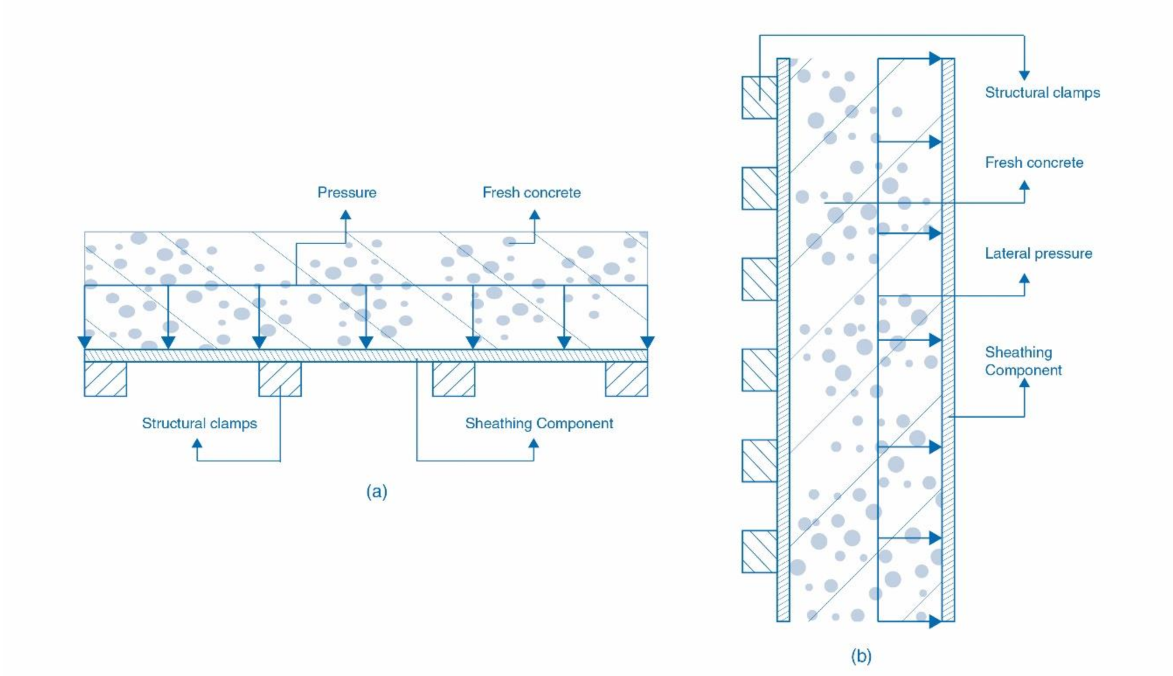


Fig. 9 Pressures on formwork: (a) Concrete pressure on slab; (b) Lateral pressure on svelte elements (Author)

3.7.4 Calculation of slab load

As it was explained before, there are loads acting in the slab composition. According to the chapter C of NSR-10 , to calculate total slab load, it is mandatory to consider following specific weights described in the table depending on the type of slab.(SCI, 1997b)

Table. 7 Dead loads for slabs

Dead Loads	kgf/m2	kN/m2
Concrete proper weight for lightened slab (w)	205	2,09
Concrete weight for solid slab (w)	240	2,45
Floor finishing (f)	154	1,57
Lightener (lg)	25	0,25
Division walls (d)	300	3,06
Settings and else (s)	16	0,17

(Gelvez, 2017)

Table. 8 Live loads for slabs

Live loads	kgf/m2	kN/m2
Furniture (fr)	205	2,09

(Gelvez, 2017)

Detailed quantities explained before are putting on calculation showed later to get a proper pressure applied on formwork which is being proposed. For this calculation following variables are considered:

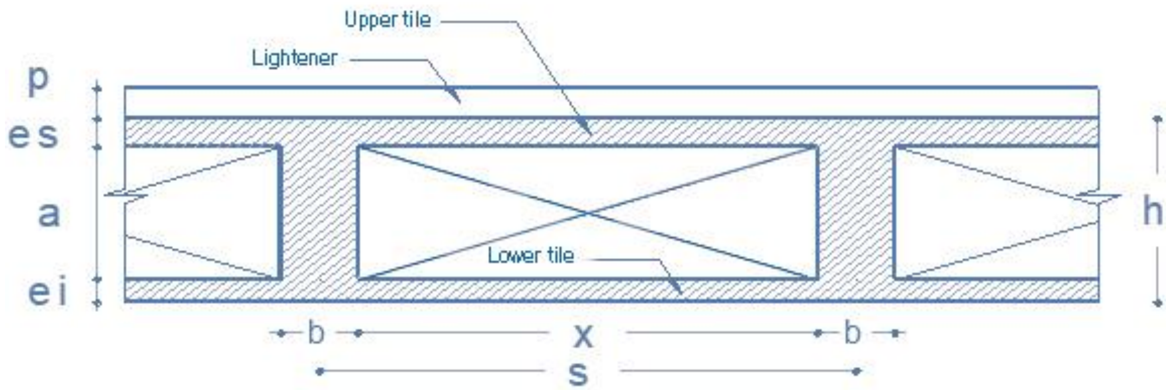


Fig. 10 Lighten slab scheme (Gelvez, 2017)

Where:

p: Floor finishing

es: Upper tile

ei: Lower tile

a: Lightener height

b: Joist width

x: Lightener width

S: Joist separation

h: Slab thickness

Following NSR-10 norm to stablish slab thickness, it is expressed previously in tables number 7 and 8, the critical design for a SH slab is 0,35 m. So, for this calculation are getting pre-set structural element parameters obtained from a project in Colombia which is on working nowadays and given by its structural designer: Eng. Jorge F. Gelvez who has supported this panel proposal with specific information to figure out total pressure applied by this case.

After calculations of this house path structure, applied pressure by critical designed slab is given by:

Dead loads (kgf/m2)

w: 205

f: 154

lg: 25

d: 300

s: 16

Live loads (kgf/m2)

fr: 180

So, adding dead and live loads:

Equation 2 Addition of parameters

$$[(w + f + lg + d + s) + (\mathrm{fr})] \;=\; \mathrm{T}\ [\mathrm{kgf/m2}]$$

$$[(205 + 154 + 25 + 300 + 16) + (180)] = 610\ [\mathrm{kgf/m2}]$$

Then, the total applied pressure after calculations is: **610 kgf/m2**

3.7.5 Calculation of critical deformation

According to the norm, it is defined a parameter that allows the maximum replacement in structural elements at pouring and hardening process of. NSR-10 has stablished the formula to get the critical deformation on elements depending on the distance between supporting:

Equation 3 Maximum deflexion on slab (SCI, 1997b)

$$\boldsymbol{\delta} = \frac{l}{360}$$

Where:

δ: Maximum deflexion

L: Length between supporting

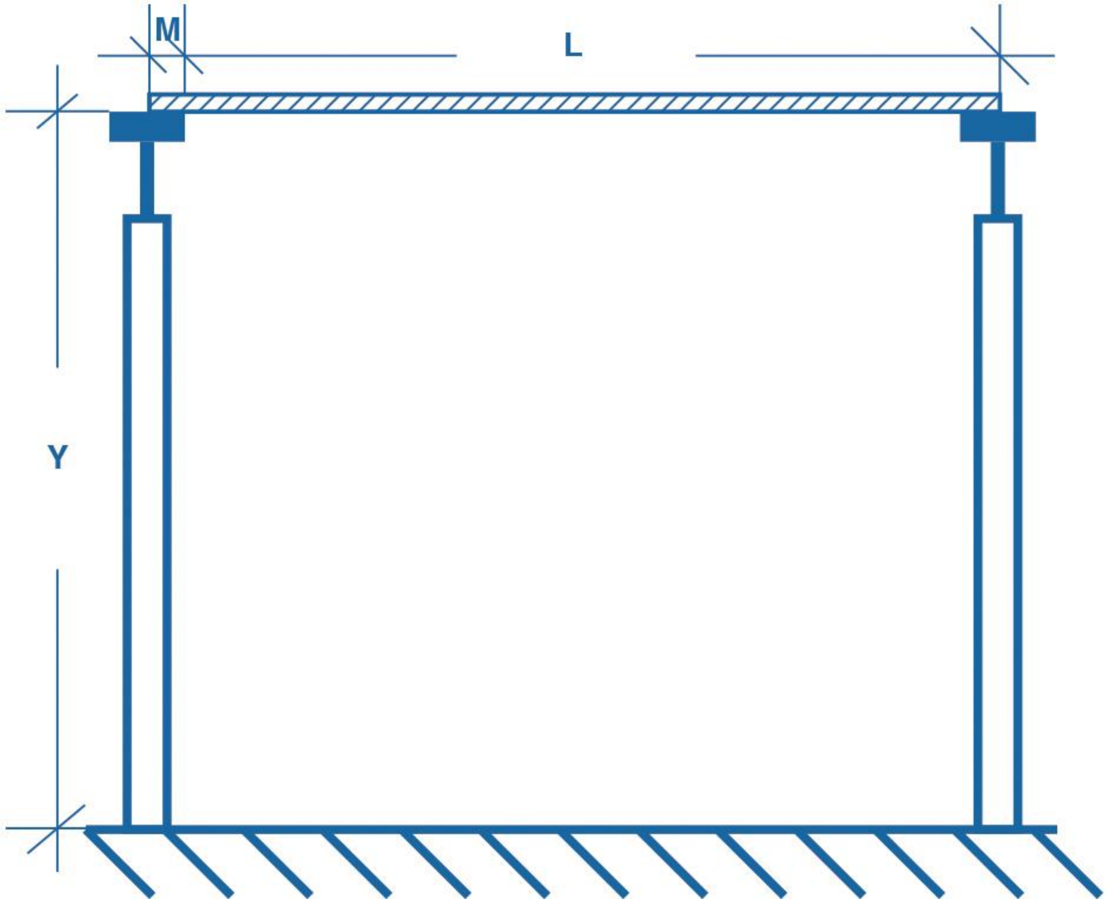


Fig. 11 Sheathing setting for maximum allowed deformation on load diagram (Author)

As panel measure was defined before at dimensions section, the L is considered as 1,40m, so, replacing L on the equation number 3 is getting:

$$\boldsymbol{\delta} = \frac{1{,}40}{360}\ [m]$$

$$\boldsymbol{\delta} = 3{,}8 * 10^{-3}\ [m] \cong 3{,}8\ [mm]$$

Finally, maximum allowed deformation is **3,8 mm** when total pressure 610 kgf/m2 is applied on the board which has an area of 1m2.

Resuming, define needs and parameters are enounced in the table behind:

Table. 9 Needing to Design parameters

Need	Parameter
Module can be covered a closer area about 1 m2	Panel facing dimensions are: 1,40 * 0.7 m
Module must be as rigid as possible	Panel's maximum deflexion on load is less than 3,8 mm
Module must support concrete slab load	Panel is supporting at least 610 kgf/m2 without suffering damages.
Module is made of plastic material	Panel is produced with polymers
Module is massive producible	Panel is processed by plastic injection or extrusion method, it fulfils method's recommendations
Modules is easy to clean	Panel is avoiding concrete stuck
Module should resist heavy duty	Panel is resistant to crashes, and hard treatment in work out
Module should resist water, fresh concrete, sun, petrol, and else agents use on work out.	Panel is resistant to environmental agents, also it does not suffer damage because contact with oils or chemical agents
Module is storable and easy to transport	Panel's geometry is allowing to save space in storing and transport by trucks

(Author)

4. CONCEPT

4.1 Ideation process

Ideation step is applying to arrive at first concept possibilities for the panel. In the process, existing articles for civil work out are analysed to extract profiles, shapes and supporting structures which are constantly working on load.

Following, these are showed and explained current products and structures for buildings, in addition actual wood and plastic panels profiles are analysed to generate primary ideas.

4.1.1 Plastic sheet semblable panels:

It is an extruded plastic module which is generating a dam. It is used to isolate specific zones to work out on bridge's foundations or to make water ponds in rivers. Its shape can distribute the water applied pressure on its self. It does not need any glue or mechanical element to be assembled with other modules.

Fig. 12 Plastic sheet semblable panel (Plasticpiling.co, 2016)

4.1.2 Plastic panel for columns and walls formwork:

It is a produced panel by injection method. It is assembled with other modules by an instrument call “fixation pin” which passes through lateral perforations, and those are fastened by a rotation of 45°. It self is a reticular composition to give support on applied load and to avoid fractures on duty.

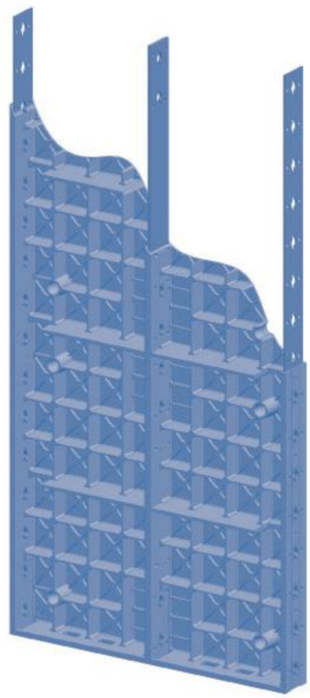


Fig. 13 Plastic panel SBS (DSCAFF, 2017)

4.1.3 Prefabricated concrete beams:

Those are commonly used in great buildings to save production time on working out. Profiles are designed be ductile and dissipate produced energy by the vibration on load and seism. Beams are casted on metallic moulds then, elements are transported to the final place for duty. Commonly, these are used on bridges or highways construction.

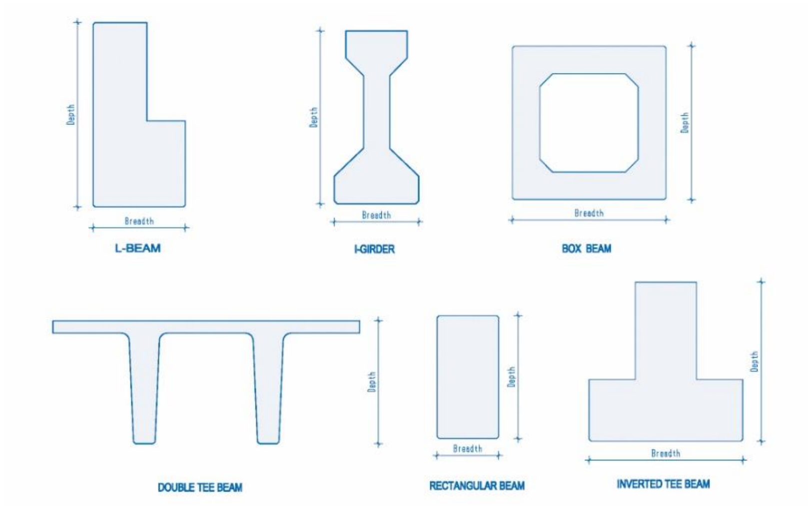


Fig. 14 Prefabricated beams (Precast, 2017)

4.1.4 Plastic-wood flooring:

Canals are extruded recycled plastic reinforced wood scrap tiles. This article is used for finishing in open environments.

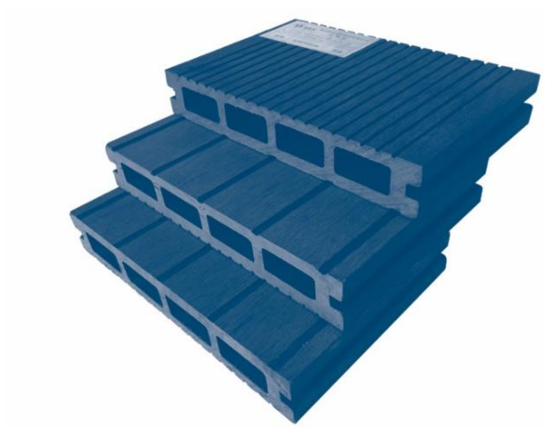


Fig. 15 Plastic - Wood Flooring modules (Alibaba, 2018)

4.1.5 Frame beams:

These are steel frames which are used to generate ductile structures for load supporting or roofing structures. Components are disposed of as triangles or square compositions. Frame beams are supported on structural elements like columns or foundations in bridges.

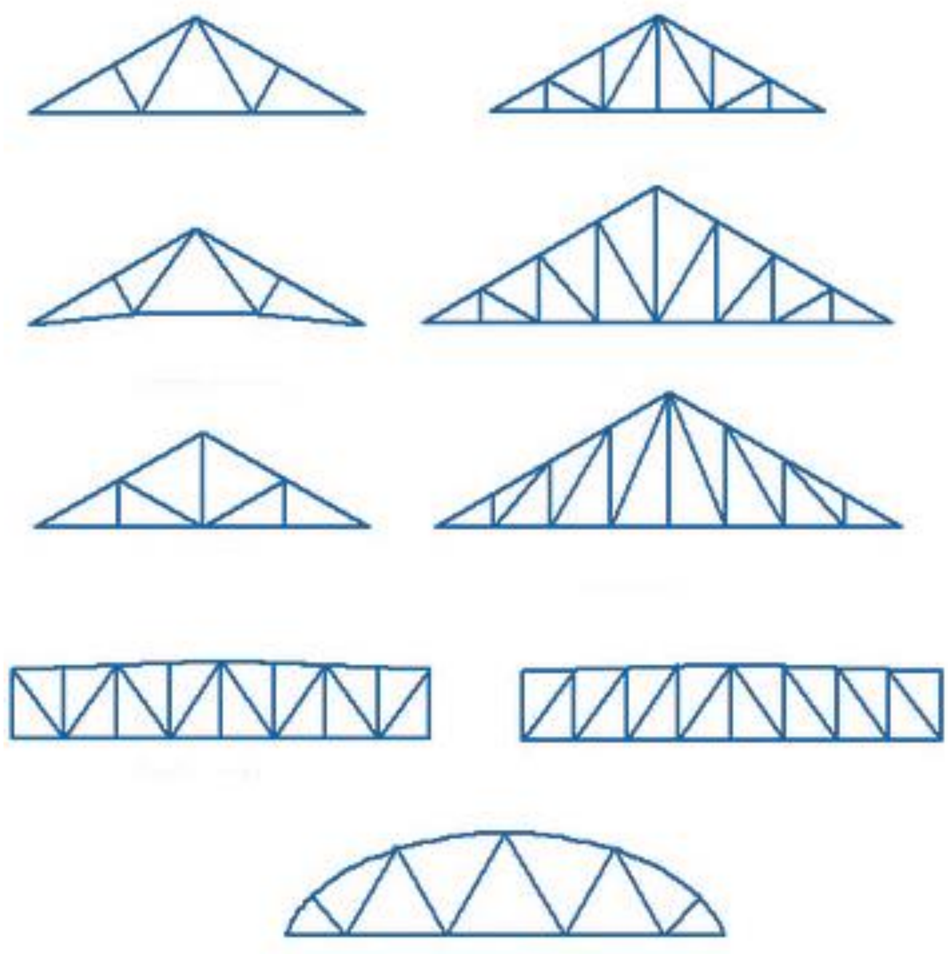


Fig. 16 Frame beams geometry (PBS, 2015)

4.1.6 Metal deck:

Modules are produced by bending. The sheet is bended to generate a profile capable to support a distributed load applied by concrete thanks to its self. Those are used as fix formwork; it means that modules are placed in the slab position containing cast concrete.

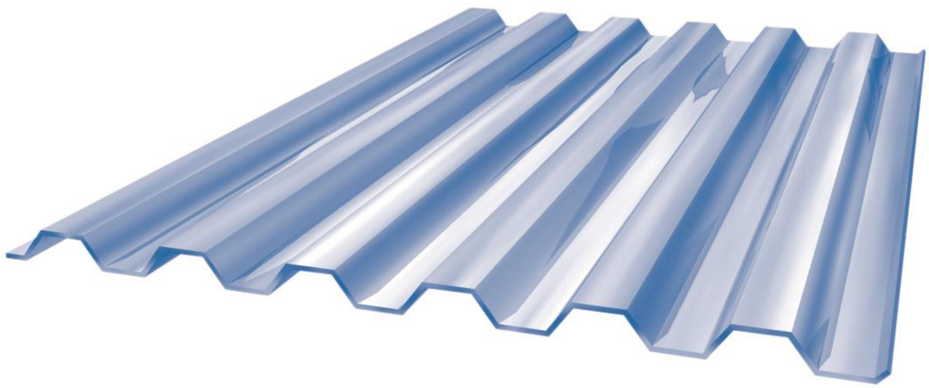


Fig. 17 Metal Deck module (CORDECK, 2017)

4.1.7 Bridge's structure:

The lower arc of a long bridge is capable to drive loading and dissipate vibrations produced by the duty. Shapes allows deformations. The useful characteristic of this geometry is that the viaduct is supported in two founds on each bridge's extremes.

Fig. 18 Tilos la Palma bridge (lower arc structure) (Wikipedia, 2018)

4.1.8 Handmade wood panel:

These are common used panels on local works out. Module's components are assembled with nails. It has prismatic shape, and in general, it is rectangular facing.

Fig. 19 Handmade wood panel (Author)

4.2 Profile abstraction

After geometric inspiration products analysis, it is being abstracting each profile from every article previously checked. The main proposal is to start ideas production from proper structural elements which are current working well on load.

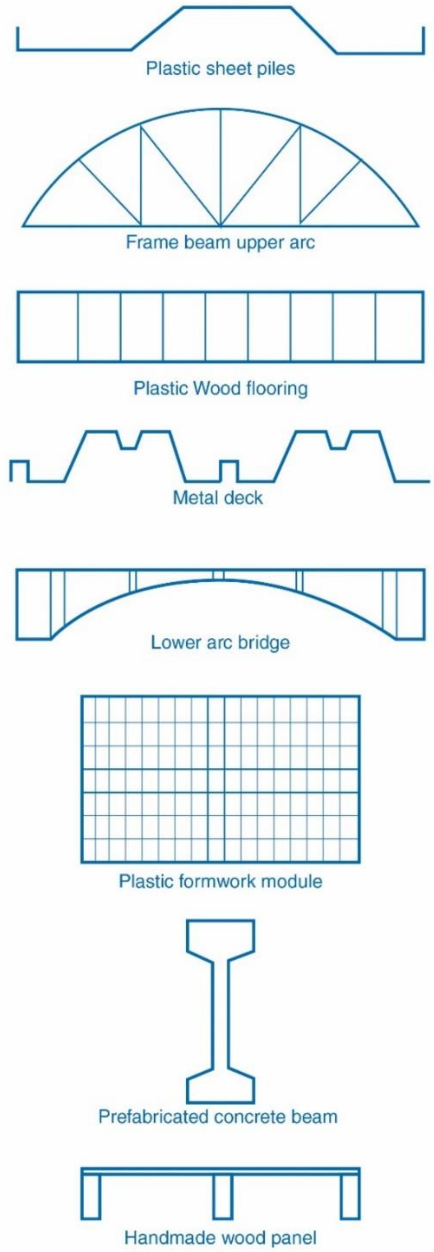


Fig. 20 Profiles abstraction (Author)

4.3 Design alternatives

Following the process, first sketches have been produced to generate alternatives for the panel; each idea is stablished to fulfil design parameters and needs. After merging primitive profiles explained before, there are presented four proposals for ideation to be later evaluated.

4.3.1 Piles plus Frame beams plus metal deck modules (P+B+M)

On this proposal, three profiles are merged to produce an outline that could be developed in an extruded panel which is capable to support loads whit out suffering changes or fractures in its self. Since plastic piles, frame beams and metal deck modules are working under high loads, in addition these are placed on the same position that the panel is working on, canals, reinforced bends and curves are projected on this product idea.

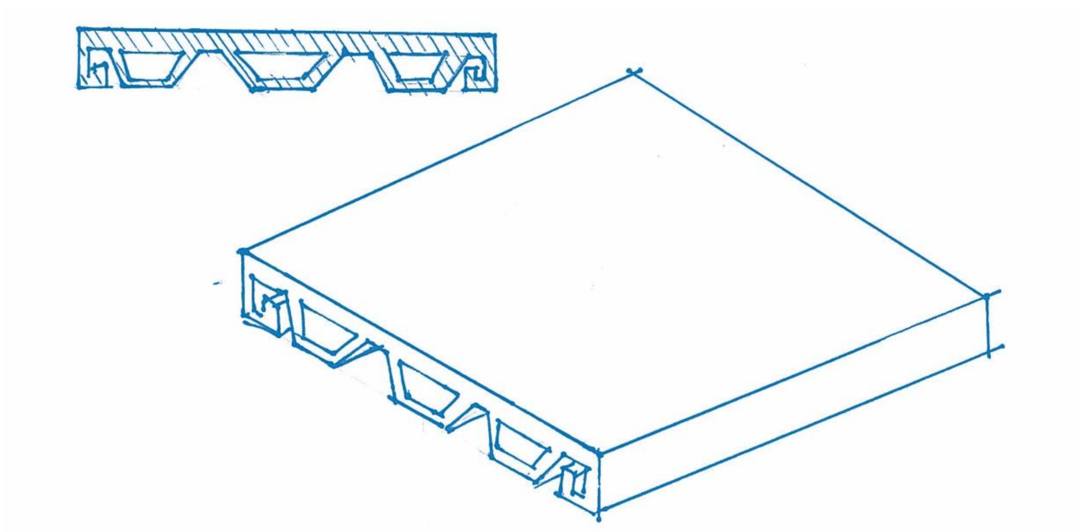


Fig. 21 Concept A (Author)

Fig. 22 Combined profiles for alternative A. (Author)

4.3.2 Plastic modules for columns and wall forms (Pm)

This idea is emerging from current plastic panels which are processed by injection method. The profile pretends to mimic the actual panel which is supporting high pressure produced by fresh concrete. Advantages of this based are low weight and the element to assembly panels between themselves. Since panel is rectangular, every structural component inside is scaled from the main sizes, and each one is transferring loads to the support.

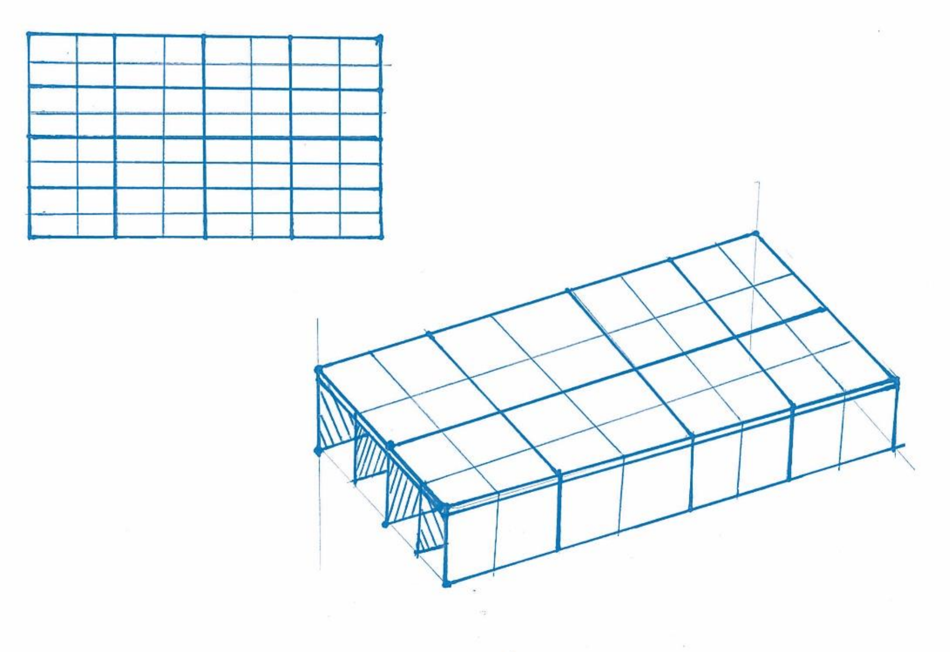


Fig. 23 Concept B. (Author)

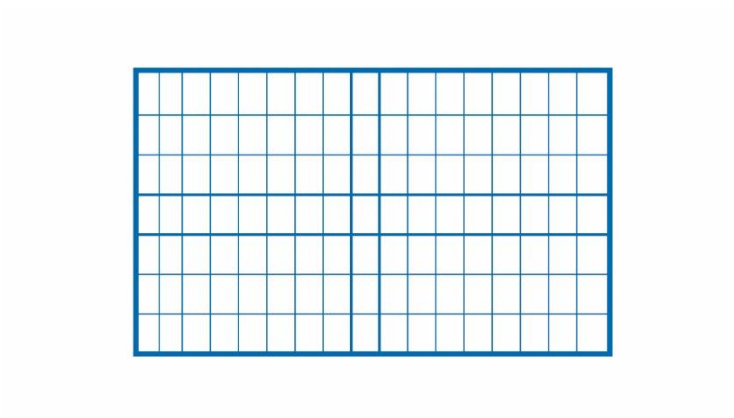


Fig. 24 Profile for alternative B. (Author)

4.3.3 Bridge's structure (Bs)

It is proposed a profile coming from an arch bridge where its elements along itself are supporting great loads and driven those to foundations at the extremes of the bridge. Given that a structure is a wider element, profile is proposed to be assembled for panel construction with "n" number of blocks.

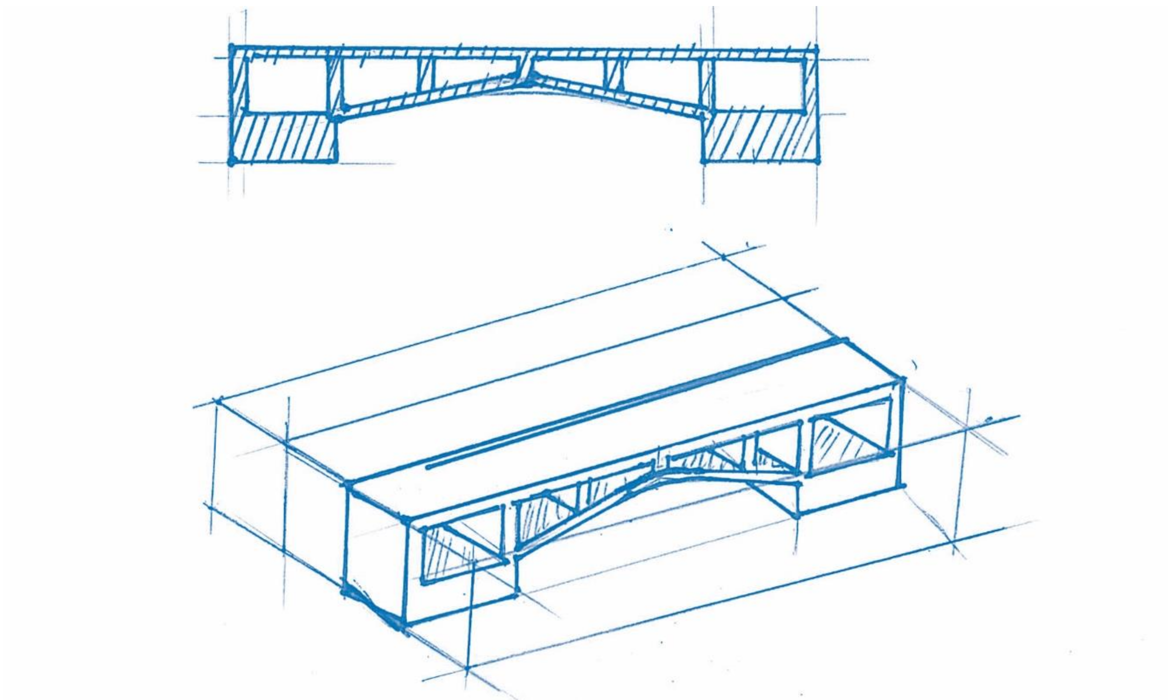


Fig. 25 Concept C. (Author)

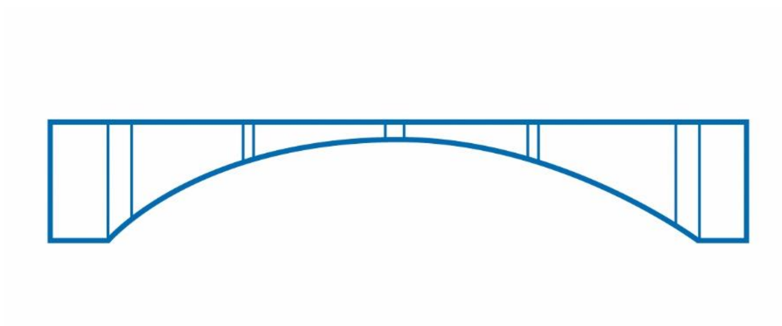


Fig. 26 Profile for concept C. (Author)

4.3.4 Wood handmade panel plus Prefabricated beams (W+P)

This is an idea to produce an imitated panel from the current used one on the analysed works out on the problem establishment. It is set to be assembled since there are two different profiles. The advantage of this conception is focused on the maintenance; if some set component is suffering damaging, it is replacing without throw away the rest of the panel's material. Thanks to the composition of itself, it is allowing the load fluence through elements to the supports.

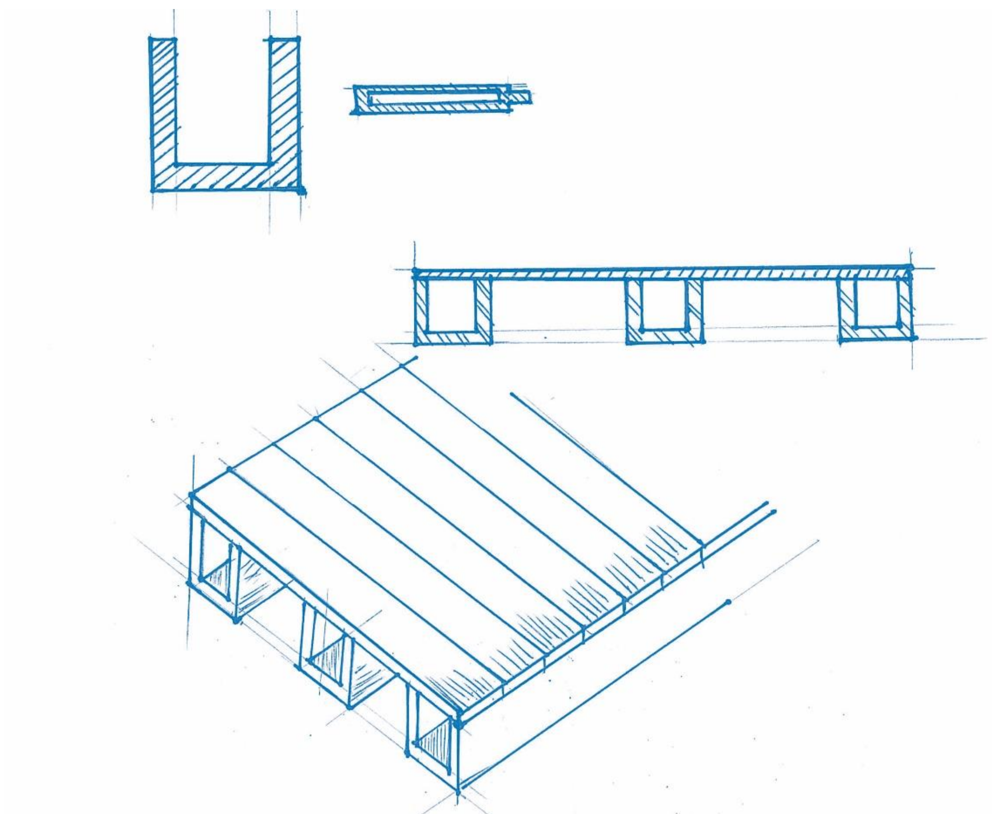


Fig. 27 Concept D. (Author)

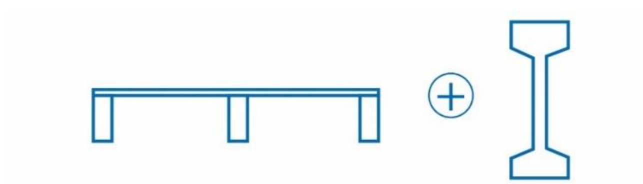


Fig. 28 Combined profiles for alternative D. (Author)

4.4 Final profiles and 3D modelling

After concepts proposal and first sketches, final profiles are obtained to project the module. parametric design of each idea is generated to understand better the volume and approximated geometry getting by the profile. Models are used on later simulations where the concept choice is done. Following, 3D projections are showed to figure out possibilities for the panel.

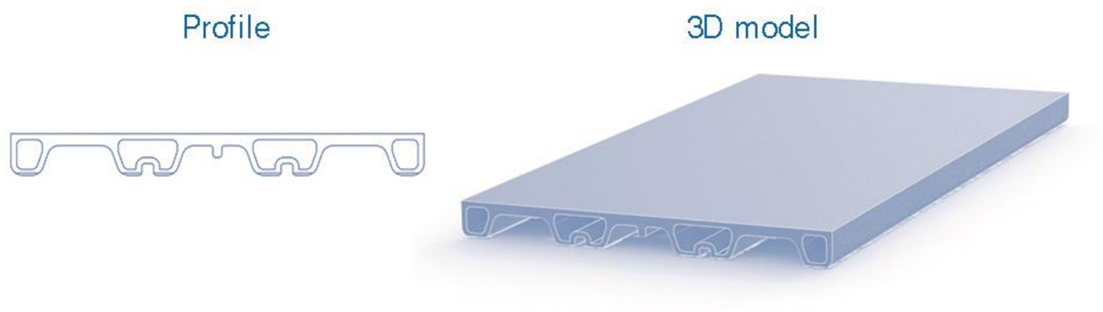


Fig. 29 3D modelling concept A (Author)

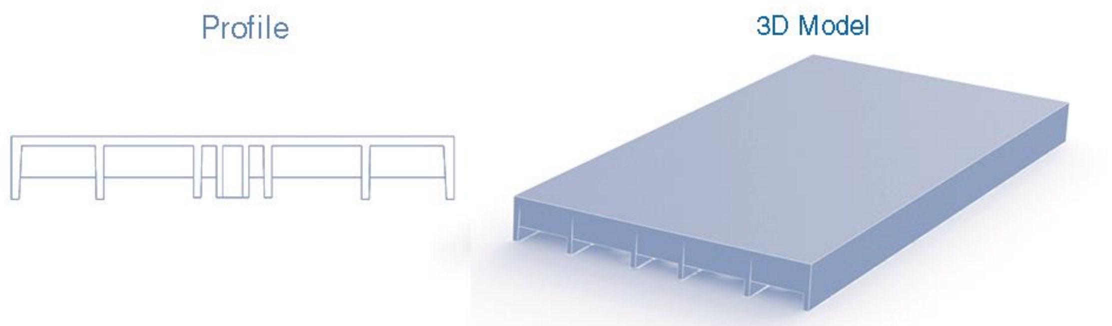


Fig. 30 3D modelling concept B (Author)

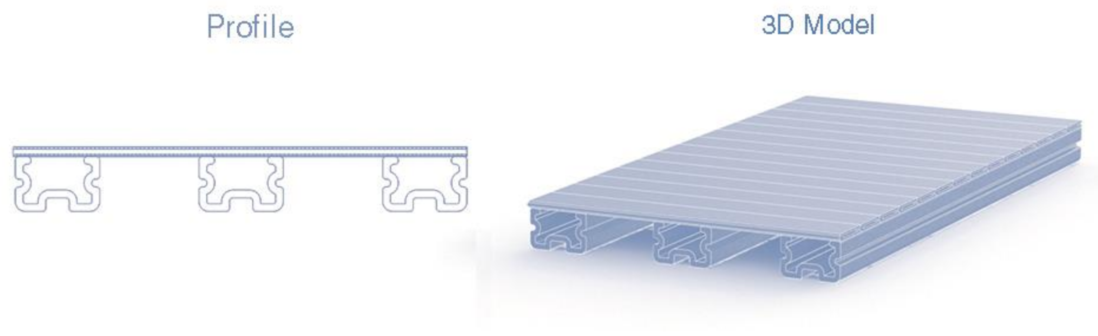


Fig. 31 3D modelling concept C (Author)

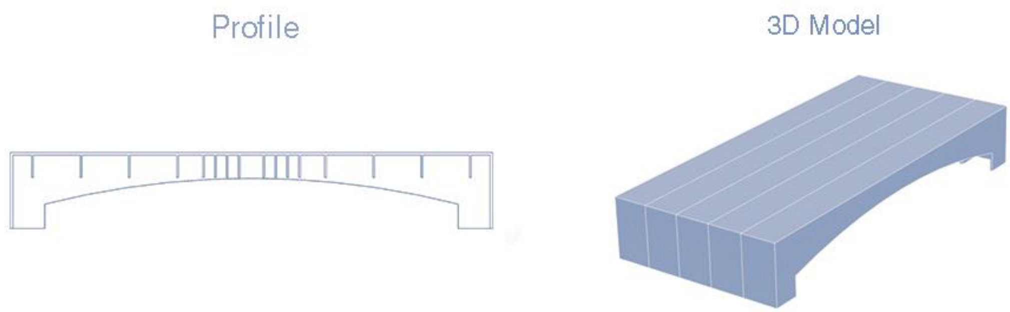


Fig. 32 3D modelling concept D (Author)

4.4.1 Simulation

Since 3D models have been generated with general dimensions which are specified at design parameters, it is performed a simulation on each parametric model. Next, it is described the simulation. Considered design parameters are cited and explained; then simulations are showed and analysed to select the best perform.

Simulation description

1. Parametric design is generated in Solidworks® software.

2. Following the ACI-347 indications for formwork's materials, where it is specified that plastic and composite materials can be used on sheathing components of setting formwork, in addition getting information about detected materials at the benchmark, a plastic is applying on the parametric model of each idea to be tested later.

3. Parameters for simulation:
    - Pressure: 6100kN/m2
    - Supports: 0,1 m along lower extremes of the panel
    - Material: Polyethylene (PE)

4. Parameters to analysed result are:
   It is examining the maximum panel displacement on bending.
   Allowed deformation: 3,8 [mm]

Following it is presented the simulation schema to understand where are located applied pressure and supports.

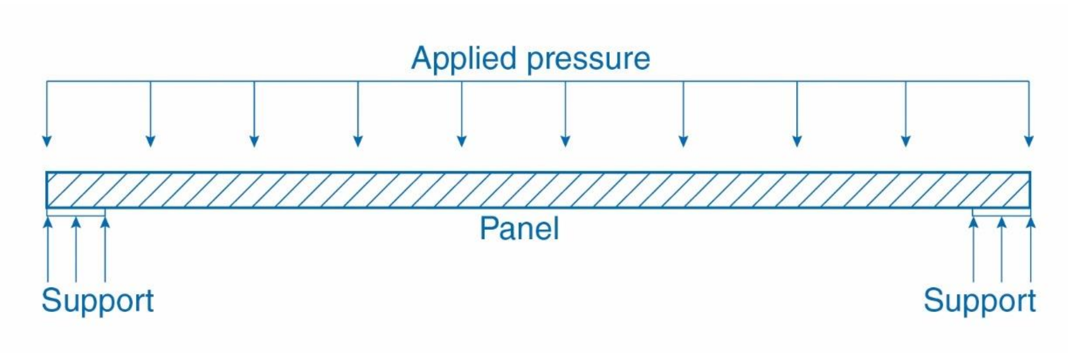


Fig. 33 Simulation schema (Author)

Results

Deformation images are shown for each proposal, where the critical deformation is put in red colour and minimum deformation in blue colour.

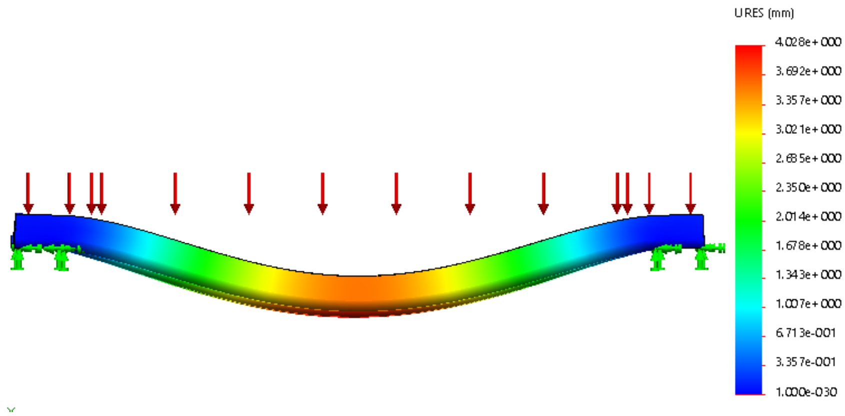


Fig. 34 Simulation results alternative A (Author)

Where the critical deformation is 4,02 mm.

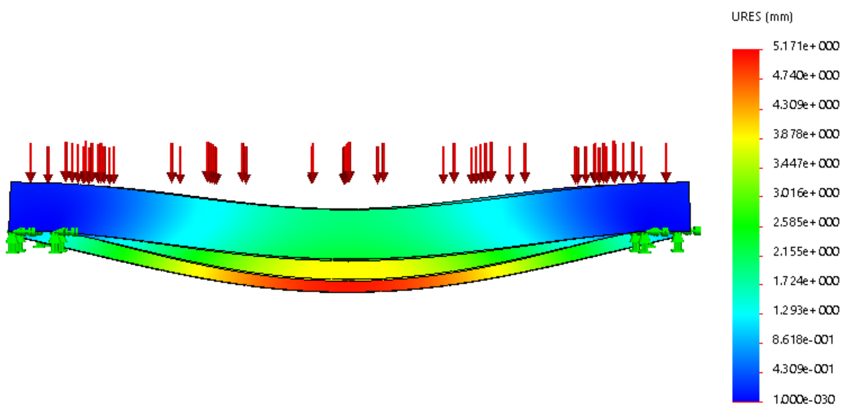


Fig. 35 Simulation results alternative B (Author)

Where the maximum deformation is 5,17 mm.

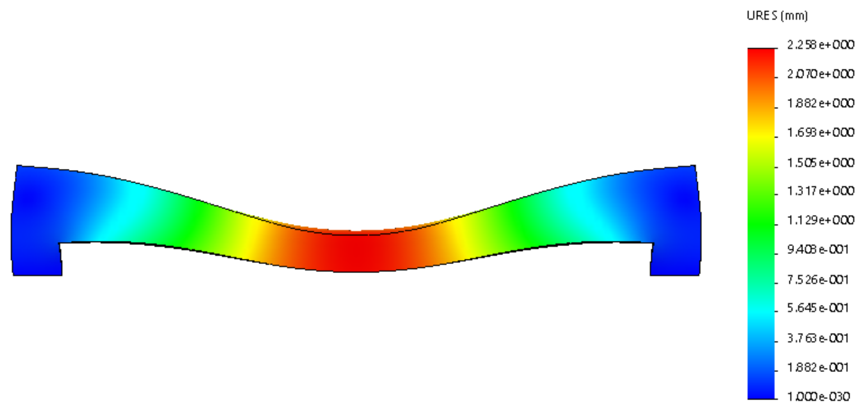


Fig. 36 Simulation results alternative C (Author)

Where the maximum deformation is 2,25 mm

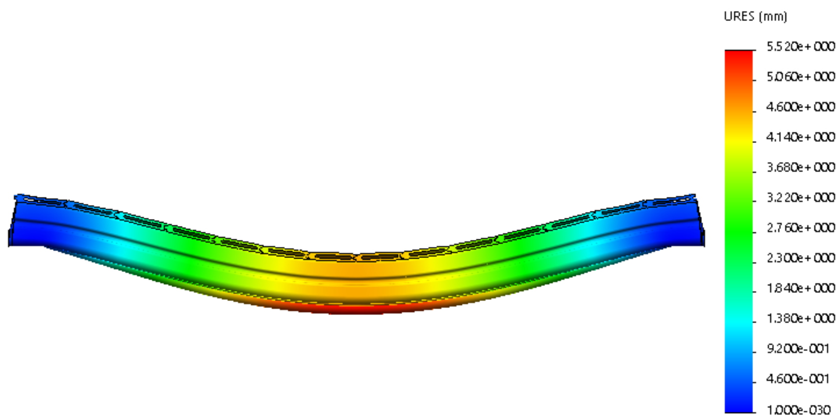


Fig. 37 Simulation results alternative D (Author)

Where maximum deformation is 5,52 mm.

Then, simulation results are gather in a table to do a comparison of them.

Table. 10 Maximum deformation in load

	Max. displacement (mm)	N° Components	Production process
A (P+B+M)	4,02	1	Extrusion
B (Pm)	5,71	1	Injection
C (Bs)	2,25	5	Injection
D (W+P)	5,52	17 (two modules)	Extrusion

(Author)

In conclusion, alternative C at first selection has reached less deformation than other three options for design.

4.5 Concept selection

After the simulation analysis where deformation quantities have been determined, it is done the concept selection through a matrix where parameters are evaluated and graded according to its performance on each concept.

Grades: To select a concept, it is established a scale to give grades for each proposal, where:

- 1: Fails
- 3: Fairly fulfil
- 5: Fulfil

Table. 11 Concept selection matrix

		CONC.	A	B	C	D
PARAMETER	Panel facing dimensions are: 1,40 * 0.7 m		5	5	1	5
	Panel's maximum deflexion on load is less than 3,8 mm		1	1	5	1
	Panel is supporting at least 610 kgf/m2 without suffering damages.		5	5	3	3
	Panel is produced with polymers or composites		5	5	5	5
	Panel is processed by plastic injection or extrusion method, it fulfils method's recommendations		3	1	3	5
	Panel is avoiding concrete stuck		5	5	3	3
	Panel is resistant to crashes, and hard treatment in work out		5	3	3	5
	Panel is resistant to environmental agents, also it does not suffer damage because contact with oils or chemical agents		5	5	5	5
	Panel's geometry is allowing to save space in storing and transport by trucks		3	3	3	3
		Grade	**37**	33	31	35

(Author)

In conclusion, after the matrix selection concept A has been fulfilled better than others with design parameters. Then, proposal A is being improved in design of details to later production by extrusion process.

5. DETAIL DESIGN

Concept A has been selected to be improved and refined to become product. Proposal was done to be extruded. So, according to the chapter 6 of Design for Manufacture, the numeral seven is explaining recommendations to get a producible profile. In addition, the concept must reach the minimum allowed deformation because at the first simulation on Solidworks® was not fulfilling it. Since the software is helping in the profile refining, panel has been put under design evaluation to get the efficient height and wall thickness to fulfil parameters.

5.1 Uniform wall thickness

Due to the studio result, wall thickness is modified to meet the recommendations by Bralla's manual to extrude a profile. It is considered a uniform wall thickness to get a better extruded piece, if this measure is changing along the outline, these are appearing defects regarding uneven plastic flow through die and the extrusion is getting cool at diverse temperatures. Corners are projected with same vortex to keep fluency on thickness.

5.2 Sharp vortices avoiding

Regarding to the avoidance of sharp corners and possible fails on those, also providing well flowing on material extrusion, angles in the profile are rounded. In addition, round corners are giving more load fluency on duty and those help to avoid any possible cracking by the sharp geometries.

5.3 Hollows

To avoid undesirable defects and uniform hardening, panel's profile is re-designed to skip great volumes of material and hollows along the module are added. Inner hollows are eliminated as much as possible to get a complete fluent profile for processing.

Then, after applying detail process on the panel's profile, the result was the following outline which is showing below:

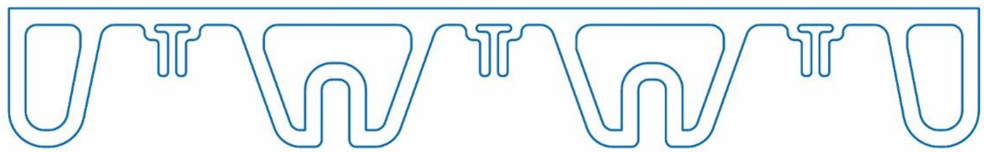


Fig. 38 Panel profile (Author)

5.4 Reinforcement and wall thickness re-design

To supply a well supporting to the panel, it has been necessary to redesign the profile for extrusion and insert into it central hollows and create an internal structure to avoid any failure when module is on duty and it is experimenting concrete pressure.

Following CES Edu-pack® indications for processes and regarding to extrusion process, it has been stablished a maximum thickness of 6,25 mm. At the re-design ending, it is proposed 3,6 mm wall thickness. However, there are current products for piping in which wall thickness is up to 12 mm, it allows to reach more than the specified size by the source.

Transition between primary concept and Definitive panel's profile is shown below to have a look of the outline development:

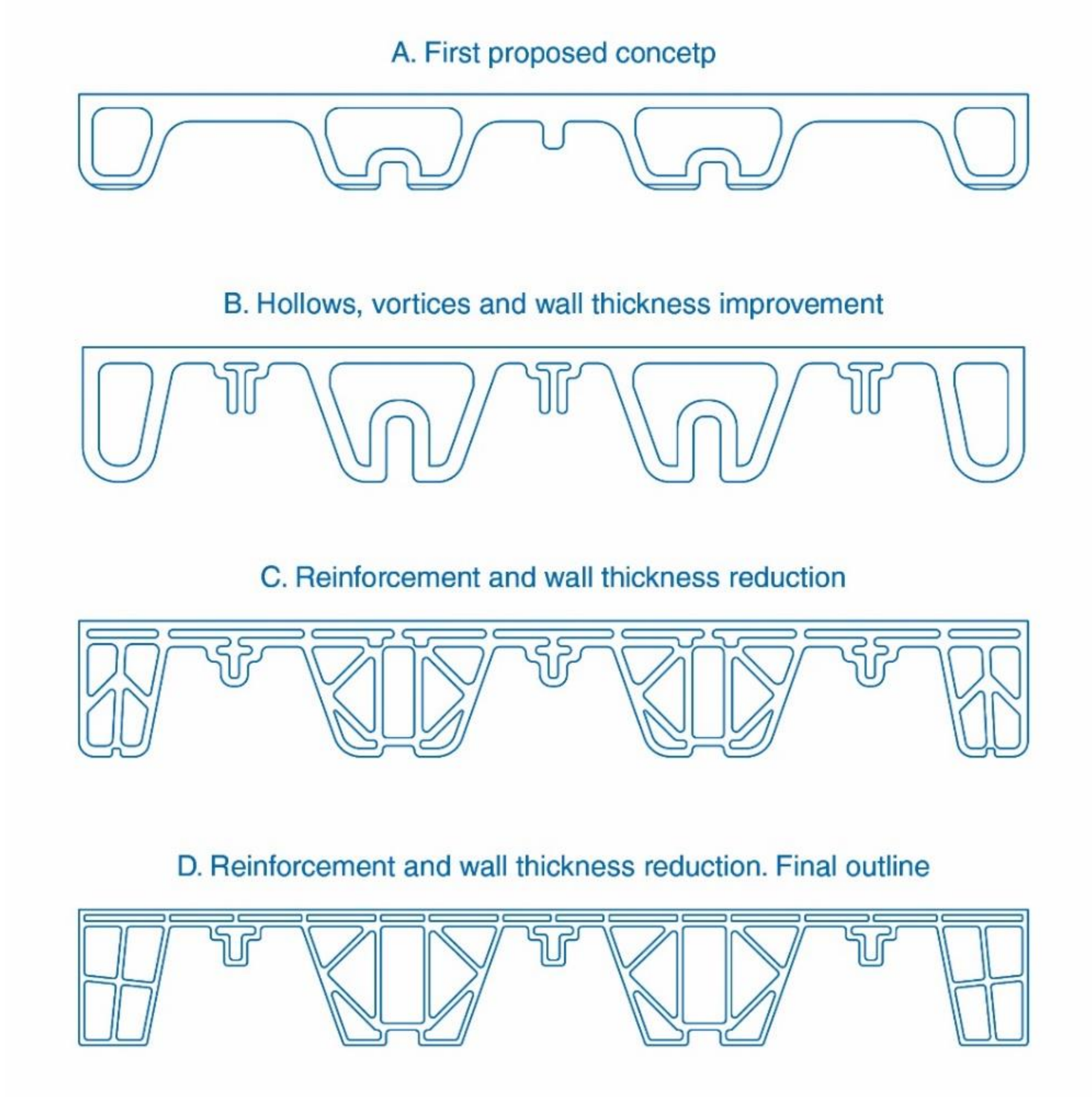


Fig. 39 Panel's profile development (Author)

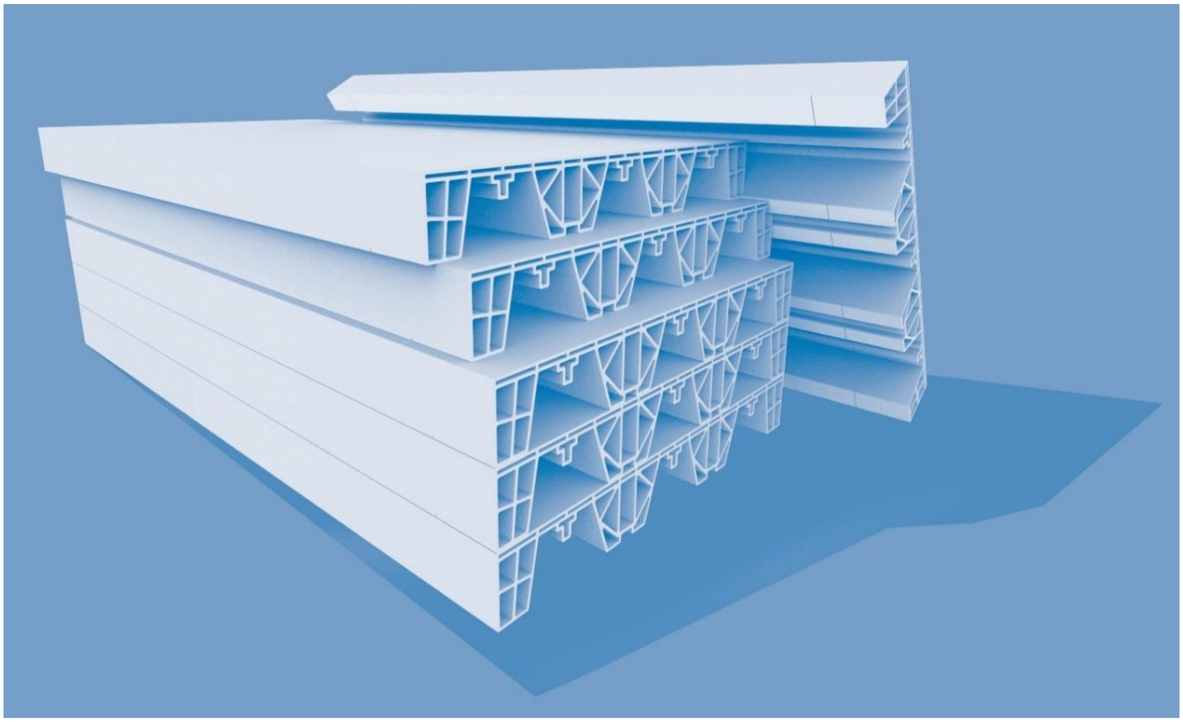


Fig. 40 Panel projection_01 (Author)

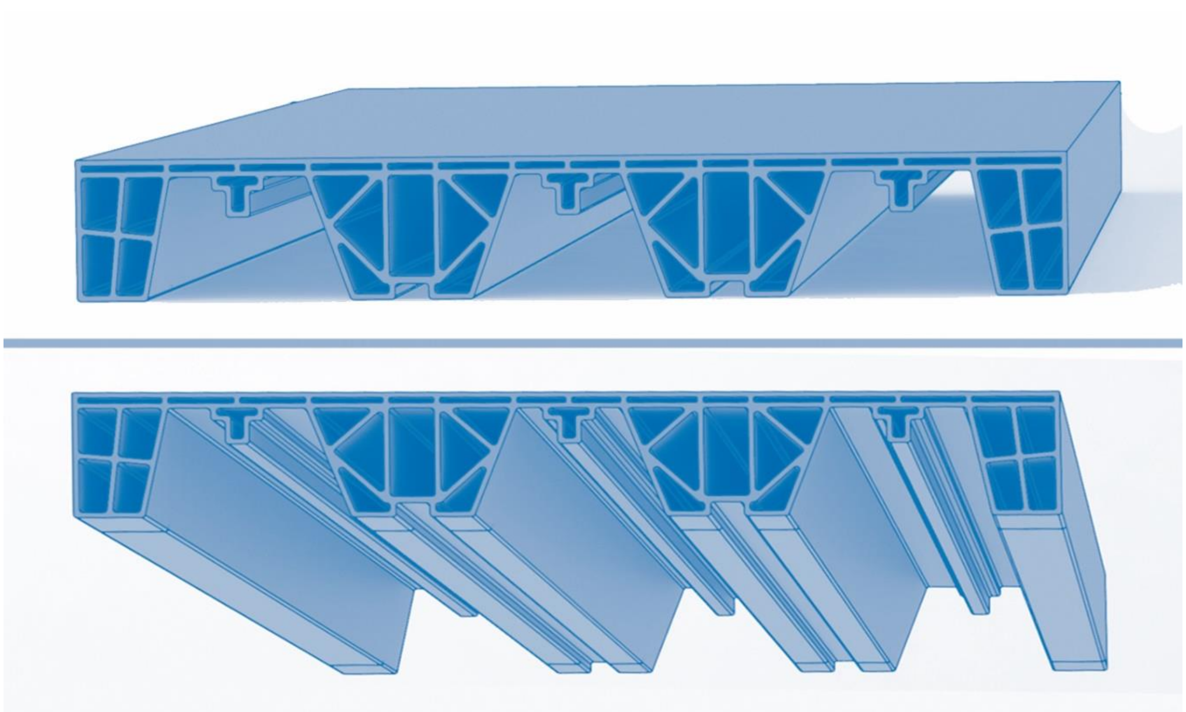


Fig. 41 Panel projection_02 (Author)

5.5 Material selection process

To do the product material selection it has been taken the list of them from benchmarking step. ABS, PP, PE and HDPE are applied in the 3D panel's model to do simulation of each material and to find out values regarding to the main design parameter which is maximum deformation in load.

Simulation description

Simulation's objective is to select the best material performance at duty. Following parameters for the test are listed:

1. Parametric design is generated in Solidworks® software.

2. Following the ACI-347 indications for formwork's materials, where it is specified that plastic and composite materials can be used on sheathing components of setting formwork, in addition getting information about detected materials at the benchmark, a plastic is applying on the parametric model of each idea to be tested later.

3. Parameters for simulation:
    - Pressure: 6100kN/m2
    - Supports: 0,1 m along lower extremes of the panel
    - Materials: HDPE - PE - PP - ABS

4. Parameters to analysed result are:
   It is examining the maximum panel displacement on bending.
   Allowed deformation: 3,8 [mm]

Results.

Deformation images are shown for each proposal, where the critical deformation is put in red colour and minimum deformation in blue colour.

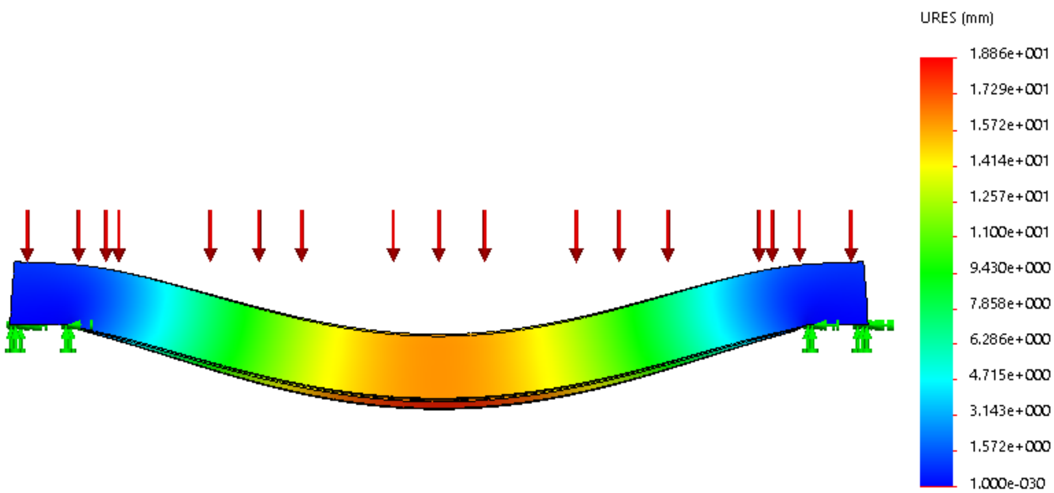


Fig. 42 Simulation results with PE (Author)

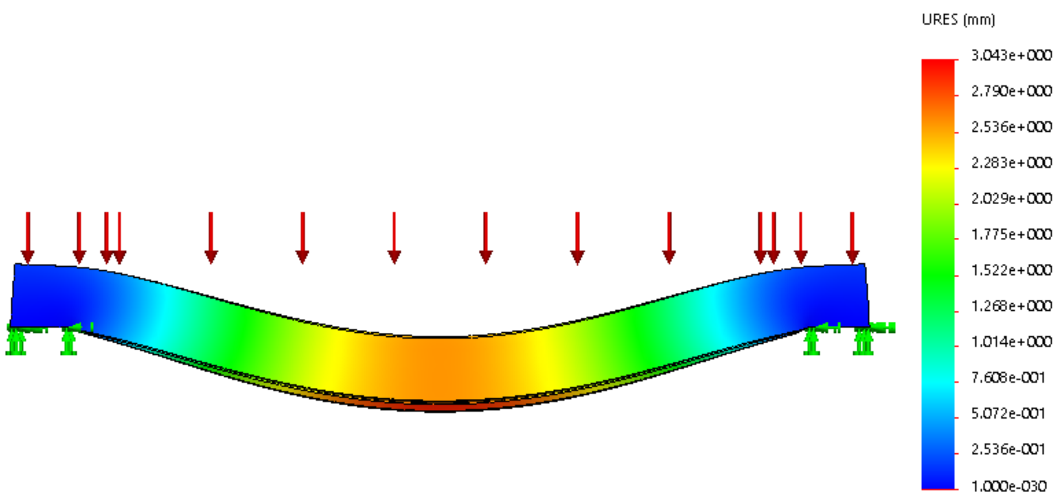


Fig. 43 Simulation results with HDPE (Author)

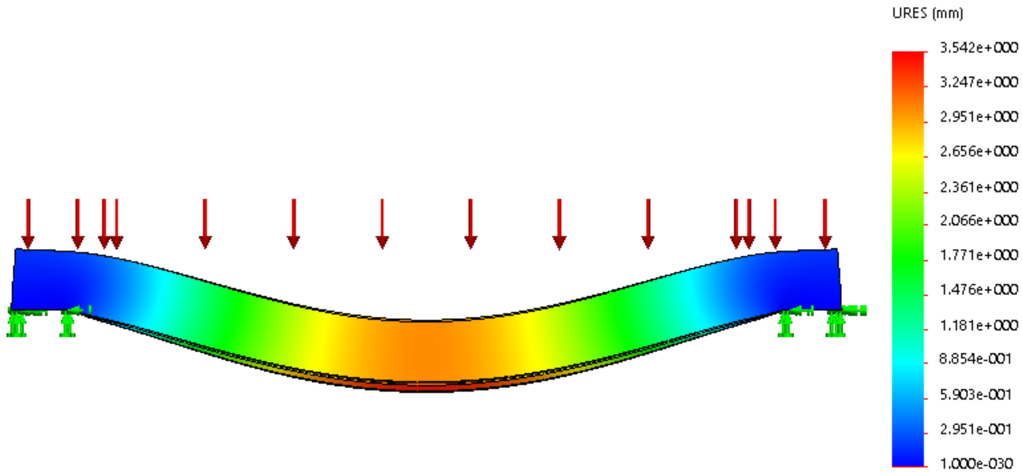


Fig. 44 Simulation results with PP (Author)

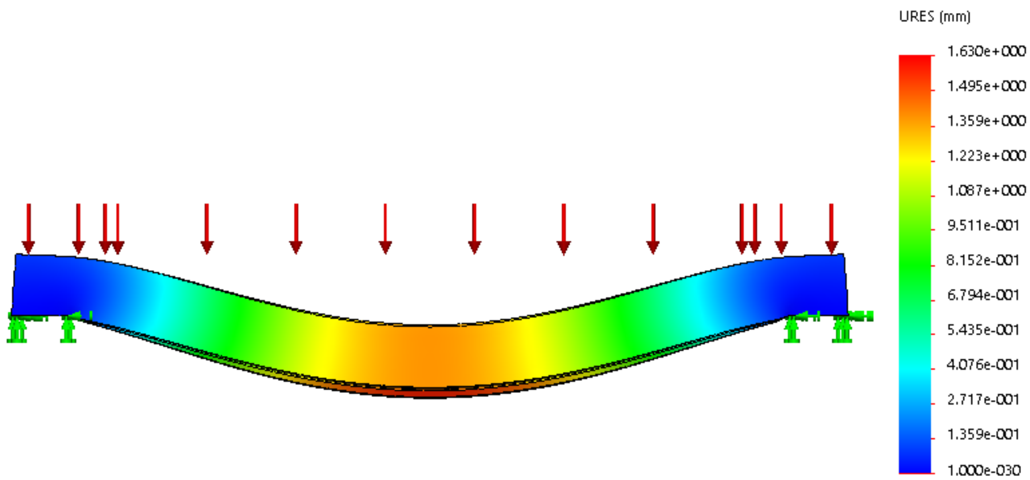


Fig. 45 Simulation results with ABS (Author)

After simulations with all materials applied on the 3D model, critical bending of each one is listed in the table 13.

Table. 12 Maximum deformation for materials in load

Material	Max. displ. (mm)
PE	18,8
HDPE	3,04
PP	3,51
ABS	1,63

(Author)

Then, parameters for selection are listed and evaluated in a matrix to get the best and most convenient for the panel.

Selection parameters

- **Mechanical properties:** It is analysed the Yield strength of each material.
- **Processability:** From 1 to 5 where 5 is the best performance in moulding, and according to materials datasheets it is qualified this parameter.
- **Density:** It is checked the density of each material to notice which is the less dens.
- **Price per kg:** Price is analysed for costing.
- **Rigidity:** It is determined by the maximum bending of each material on the simulation.

Table. 13 Qualification matrix for materials

	Parameter	Units	PE	HDPE	PP	ABS	Qualification
Mech. Prop	Yield	MPa	20	31	37,2	51	20%
Process	Mouldable		4	4	4	4	5%
Weight	Density	Kg/m3	960	952	910	1210	40%
Costing	Price/kg	Euro	3,52	3,04	3,51	1,63	20%
Rigidity	Bending	mm	18,8	3,04	3,51	1,63	5%
		Qualification	35	35	**45**	30	

(Author)

In conclusion, Polypropylene is the selected material to be use for panel extrusion. Although ABS is realizing the best perform in load with 1,63 mm bended, is has been decided to give to this parameter just the 5% of weighing due to most of materials are fulfilling this requirement, also processability is 5% because polymers satisfy it. In addition, parameters as mechanical properties (Yield strength), density and price are scored with the highest percentages because it is necessary to establish differences between polymers and select the best.

5.6 Rigidity improvement

Well perform of the polypropylene has been noticed in the last step of material selection. With3,51 mm bended it is reaching the maximum deformation parameter which is 3,8 mm, it means fulfilling by 0,3 mm. However, it is important to improve material rigidity to decrease as much as possible its deformation.

Analysing composite materials, it is noticed that mechanical properties of those are increasing when polypropylene is reinforced with fibres or talc. So, to decrease the material bending, Fibre Glass, Calcium Carbonate ($CaCO_3$) at 20% of total composition are tested on the simulation to carry out the perform of them in load.

Simulation description

Simulation's objective is to select the best material performance at duty. Following parameters for the test are listed:

1. Parametric design is generated in Solidworks® software.

2. Following the ACI-347 indications for formwork's materials, where it is specified that plastic and composite materials can be used on sheathing components of setting formwork, in addition getting information about detected materials at the benchmark, a plastic is applying on the parametric model of each idea to be tested later.

3. Parameters for simulation:
   - Pressure: 6100kN/m2
   - Supports: 0,1 m along lower extremes of the panel
   - Materials: PP + 20%Glass Fibre – PP + 20%$CaCO_3$

4. Parameters to analysed result are:

It is examining the maximum panel displacement on bending.

Allowed deformation: 3,51 [mm]

Results.

Deformation images are shown for each proposal, where the critical deformation is put in red colour and minimum deformation in blue colour.

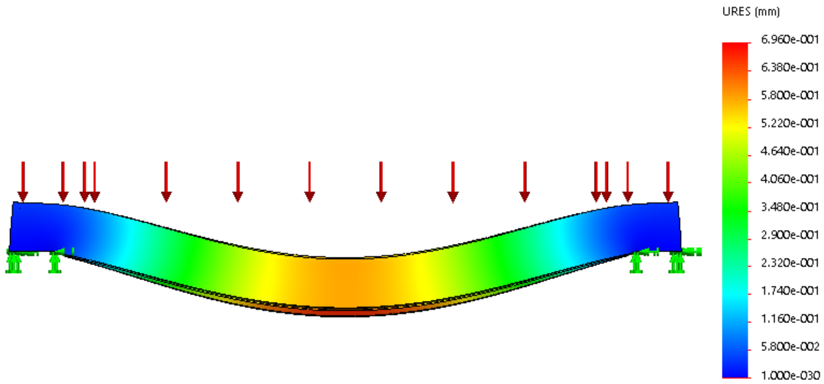


Fig. 46 Simulation results with PP 20%Glass Fibre (Author)

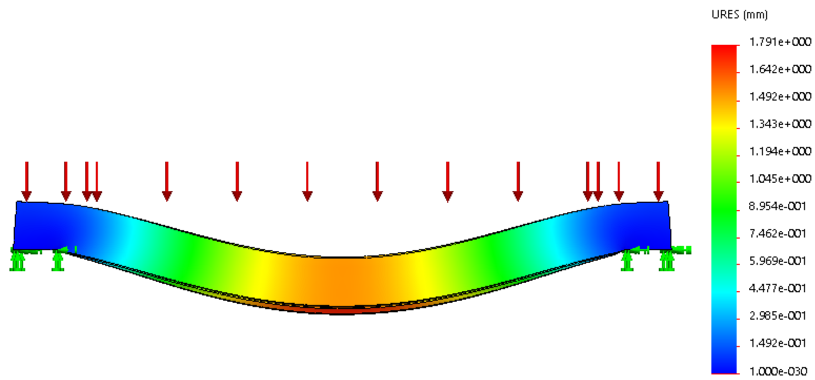


Fig. 47 Simulation results with PP 20%CaCO3 (Author)

Table. 14 Qualification matrix materials reinforced

	Parameter	Units	PP 20%GlassF	PP 20% CaC03	Qualification
Mech. Prop	Yield strength	MPa	59,9	30,6	30%
Process	Mouldable		2	2	5%
Weight	Density	Kg/m3	1080	1060	20%
Costing	Price/kg	Euro	1,83	1,64	20%
Rigidity	Bending	mm	0,06	1,79	15%
		Qualification	**50**	45	

(Author)

Simulation results and parameters have shown the PP - 20%Glass Fibre reinforced as the best option to be applied in the panel production. To be sure that the material is useful for the product and for profile dimensions regarding to thickness and wider, it has been done a study of product references.

A research made by J. L. Thomason and M. A. Vlug in Nederland is shown as results that long fibre reinforcement on PP in concordance to filled material, properties regarding to mechanical perform are improved. After a test applied on samples, tensile and flexural properties have grown. (Thomason & Vlug, 1996)

Material research companies and producers are developing improvements on fibre glass reinforcements in plastics such PP.

According to Plasticomp Inc. (PLasticomp, 2017) company from United States which is developing materials for moulding process, there are improvements on mechanical properties and durability of components made of fibreglass reinforcement.

Sumgait Technology park Inc. (Technology, 2017)is currently producing pipes with PP Glass fibre reinforcement for domestic hot water net. Pipes are extruded with three different layers and the wall thickness is determined by water pressure to be experiment. Thickness are measured from 2,7 to 12 mm and are depending on pipe diameter too.

So, after cited researchers and companies it is possible to conclude that existing studies and products are supporting the selected material PP 20%Glass Fibre filled for panel design proposal.

5.7 Panel approximated production costing per square meter

To estimate the product costing, parameters to evaluate have been set in CES Edupack software. To compare price per panel, it has done a quotation of a current module produced by injection moulding at Geoplast company which was cited in the benchmark as product reference.

Quotation has been done by a website of the company (Adtomall, 2018) where it was specified the following info:

Minimum order: 100 m2
Price / m2: 45€
Panel cover area: 0,96 m2
Number of panels: 1042

To do a comparison between current products and panel's design proposal, the costing analysis at the software is given by the parameters:

Batch: 10000 pz.
Capital write-off time: 10 years
Component length: 1,4 m
Component mass: 18,4 kg
Discount rate: 5%
Load Factor: 0,5
Material cost: 1,8 €/kg
Overhead rate: 131,4 €/hr

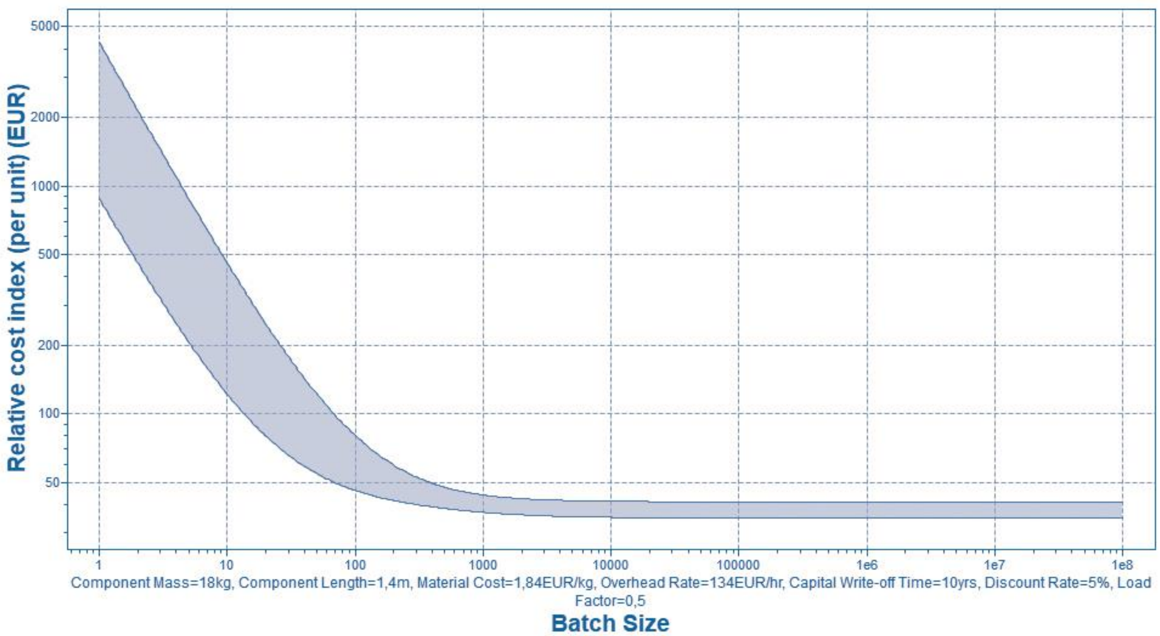


Fig. 48 Production cost plot (Author)

Plot has shown by 10 years projection, the price per panel would be between 35€ and 45€

6. CONCLUSIONS

It has been realized a literature analysis and interviews with workers and experts in construction where is was investigate types of formwork and their use into the workout, in addition it was inquire into problems of moulding for fresh concrete during use and dismount of the system. In consequence there was stablished needs and linked design requirements to maintenance and number of uses of panels on duty. Nevertheless, it was determined the main inconvenient regarding to plyboard material (wood) and environmental conditions which are affecting itself by the use and time.

It was done a concept generation to give problems solution. A validation of generated ideas was realised where profiles, and performance on duty were checked to select a final concept. In addition, the bets concept has been developed in detail to achieve design parameters.

Mechanical performance has been calculated through CAD/CAM where final 3D modelling of the panel was tested in a static simulation at Solidworks® software. The module has settled under pressure of 6100 N/m2 where results have shown that panel accomplishes with the supporting of applied load by fresh concrete and formwork system components with a maximum deformation of 0,06 mm.

A costing approximation has been calculated at CES Edupack software to compare the process cost with a current product on the market. It was stablished that production cost for the proposed panel is roundly 40€. However final price per square meter of the actual product in plastic is 58€, it would be pertinent to realize a later costing analysis to stablish the final price for the Plastic Panel for Slab Formwork.

6.1 Limitations

During the project development, it was noticed the need to be in permanent contact with direct users of the formwork, but it was not possible because geographical inconvenient. Although an expert was always helping through callings and emails; to be inside this kind of construction filed would give more information to stablish a better solution and product proposal.

Despite it was gotten info regarding to current products in the market, patents and researching in formwork for concrete, cough data from companies was limited because there were brochures with general contain but neither materials specifications, not prices were showed on those.

The production of a prototype was not possible because it wasn't a sponsor who hold it to do a physical test. However, expert's support and got info from them was not paid.

6.2 Future work

Workers and experts have expressed their interest in the production of the plastic panel. They have told that it would help the work at slabs casting. In addition, they have suggested to proposing moulds also for columns and beams. Most of them have agreed with a business model regarding to renting of plastic formwork for concrete at those regions due to the far distances from main cities of the country. So, it is proposed to continue the panel's research and development to satisfy those needs expressed by people who work at construction field in faraway zones of Colombia.

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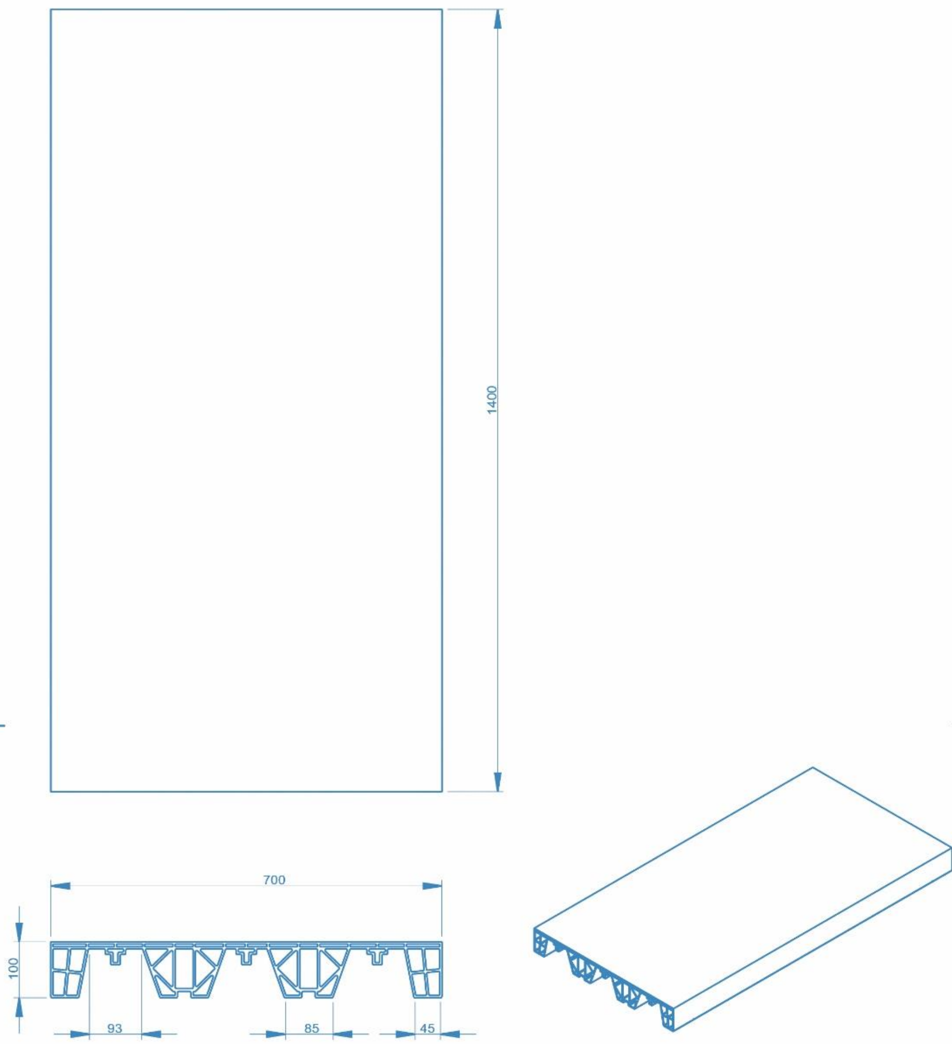
ANEXOS



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PABLO GELVEZ M.		07/04/2018

STUDENTE	DOCENTI DI STAFF
Pablo Gelvez	Roberto Chiesa

TIPO DI DOCUMENTO Document type	Disegno generale
PROGETTO Project	PLYBOARD
INSIEME Assembly	Complessivo di concepimento
GRUPPO Sub-assembly drawing	
SOTTOGRUPPO Sub-assembly drawing	
PARTICOLARE Part	

Rev	App'd	Date
01		
02		
03		
04		

CODICE - Part number

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Scale 1:20

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Corso di Laurea in
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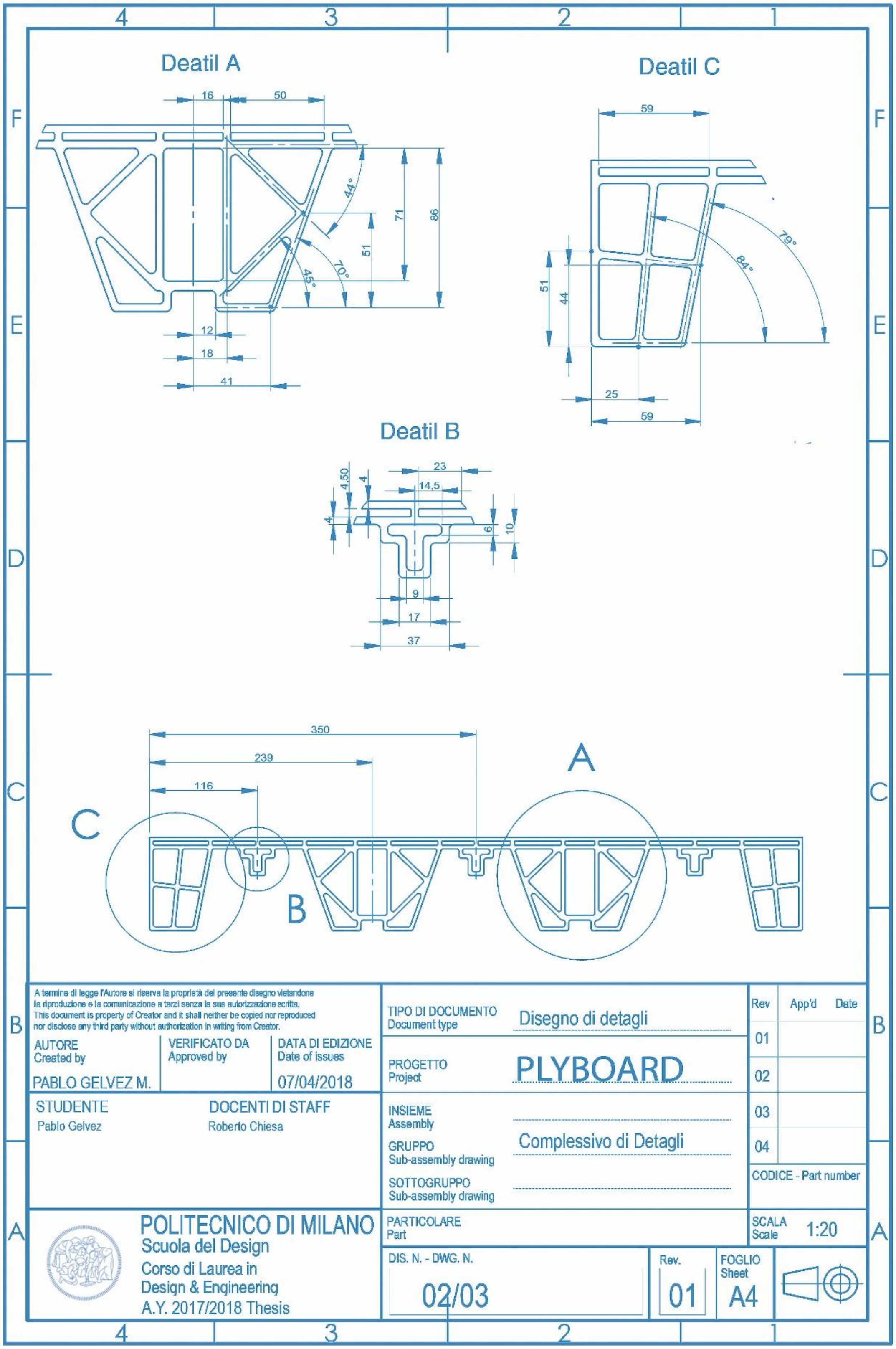

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ABS (extrusion)
General information
Designation
Acrylonitrile Butadiene Styrene (Extrusion)
Tradenames
Abistir, Abscom, Absolac, Abstron, Accucomp, Alcom, Allen, Altech, Anjacom, Ashlene, Astalac, Badalac, Bulksam, Certene, Cevian, Cevian-V, Cheng, Claradex, Clariant, Colorrx, Cycolac, Delta, Diamond, Dynacom, Edgetek, Electrafil, Elix, Encom, Epitec, Estadiene, Evosource, Excelloy, Ghaed, Hival, Hylac, Isopak, Jackdaw, Jamplast, Kaneka, Kralastic, Kumho, Kumhosunny, LNP Stat-Loy, Lustran, Magnum, Malecca, Micholac, Neftekhim, Next, Next Signature, Nexus, Nilac, Novakral, Novalloy-E, Novodur, Omnitech, Permastat, Plaslube, Polimaxx, Polyabs, Poly-Elek, Polylac, Polylan, Polyman, Ponacom, Pryme, Radici, Ramshine, Retelan, Ronfalin, Rotec, Royalite, Santac, Sattler, Saxalac, Shinko-Lac, Sicoflex, Sindustris, Sinkral, Spartech, Starex, Stylac, Tairilac, Taitalac, Tarodur, Techno, Tenogel, Terez, Terluran, Toyolac, Trilac, Tynab, Tyne, Veroplas, Zgpc
Typical uses
Safety helmets; camper tops; automotive instrument panels and other interior components; pipe fittings; home-security devices and housings for small appliances; communications equipment; business machines; plumbing hardware; automobile grilles; wheel covers; mirror housings; refrigerator liners; luggage shells; tote trays; mower shrouds; boat hulls; large components for recreational vehicles; weather seals; glass beading; refrigerator breaker strips; conduit; pipe for drain-waste-vent (DWV) systems.
Composition overview
Compositional summary
Block terpolymer of acrylonitrile (15-35%), butadiene (5-30%), and Styrene (40-60%).

Material family		Plastic (thermoplastic, amorphous)			
Base material		ABS (Acrylonitrile butadiene styrene)			
Polymer code		ABS			

Composition detail (polymers and natural materials)

Polymer		100			%

Price

Price	*	2,15	-	2,54	EUR/kg
Price per unit volume	*	2,19e3	-	2,75e3	EUR/m^3

Physical properties

Density		1,02e3	-	1,08e3	kg/m^3

Mechanical properties

Young's modulus		2	-	2,9	GPa
Yield strength (elastic limit)		29,6	-	44,1	MPa
Tensile strength		30	-	50	MPa
Elongation		20	-	100	% strain
Compressive modulus		1,03	-	2,68	GPa
Compressive strength	*	35,9	-	69	MPa
Flexural modulus		1,2	-	2,8	GPa
Flexural strength (modulus of rupture)		40	-	80	MPa
Shear modulus	*	0,319	-	1,03	GPa
Bulk modulus	*	2,76	-	2,9	GPa
Poisson's ratio		0,394	-	0,422	
Shape factor		6,3			
Hardness - Vickers	*	9	-	13	HV
Hardness - Rockwell M	*	54	-	60	
Hardness - Rockwell R		75	-	115	

Fatigue strength at 10^7 cycles	*	12	-	20	MPa
Mechanical loss coefficient (tan delta)	*	0,0138	-	0,0446	
Impact & fracture properties					
Fracture toughness		1,9	-	2,1	MPa.m^0.5
Impact strength, notched 23 °C		7,9	-	63	kJ/m^2
Impact strength, notched -30 °C		5,44	-	12,1	kJ/m^2
Impact strength, unnotched 23 °C		108	-	130	kJ/m^2
Impact strength, unnotched -30 °C		66,7	-	80	kJ/m^2
Thermal properties					
Glass temperature		88	-	120	°C
Heat deflection temperature 0.45MPa		77	-	113	°C
Heat deflection temperature 1.8MPa		77	-	104	°C
Maximum service temperature	*	62	-	77	°C
Minimum service temperature		-45	-	-35	°C
Thermal conductivity	*	0,226	-	0,235	W/m.°C
Specific heat capacity		1,39e3	-	1,41e3	J/kg.°C
Thermal expansion coefficient		108	-	234	µstrain/°C
Electrical properties					
Electrical resistivity		3,3e21	-	3e22	µohm.cm
Dielectric constant (relative permittivity)		2,8	-	3,2	
Dissipation factor (dielectric loss tangent)		0,003	-	0,006	
Dielectric strength (dielectric breakdown)		13,8	-	19,7	MV/m
Comparative tracking index		400	-	600	V
Magnetic properties					
Magnetic type		Non-magnetic			
Optical properties					
Refractive index		1,53	-	1,54	
Transparency		Opaque			
Critical materials risk					
Contains >5wt% critical elements?		No			
Absorption & permeability					
Water absorption @ 24 hrs		0,2	-	0,45	%
Water vapor transmission		2,04	-	3,2	g.mm/m².day
Permeability (O2)		47,3	-	78,5	cm³.mm/m².day.atm
Processing properties					
Polymer injection molding		Excellent			
Polymer extrusion		Excellent			
Polymer thermoforming		Excellent			
Linear mold shrinkage		0,4	-	0,7	%
Melt temperature		177	-	260	°C
Mold temperature		50	-	70	°C
Molding pressure range	*	55	-	172	MPa
Durability					
Water (fresh)		Excellent			
Water (salt)		Excellent			
Weak acids		Excellent			
Strong acids		Limited use			
Weak alkalis		Acceptable			
Strong alkalis		Excellent			

Organic solvents	Unacceptable
Oxidation at 500C	Unacceptable
UV radiation (sunlight)	Poor
Flammability	Highly flammable

Primary production energy, CO2 and water

Embodied energy, primary production		90,6	-	99,9	MJ/kg

Sources

95 MJ/kg (Kemna et al. 2005); 95 MJ/kg (Franklin Associates, 2008); 95.3 MJ/kg (PlasticsEurope, 2010); 95.3 MJ/kg (Hammond and Jones, 2008)

CO2 footprint, primary production		3,45	-	3,81	kg/kg

Sources

3.32 kg/kg (Kemna et al. 2005); 3.76 kg/kg (Hammond and Jones, 2008); 3.8 kg/kg (PlasticsEurope, 2010)

Water usage	*	167	-	185	l/kg

Processing energy, CO2 footprint & water

Polymer extrusion energy	*	5,78	-	6,39	MJ/kg
Polymer extrusion CO2	*	0,434	-	0,48	kg/kg
Polymer extrusion water	*	4,81	-	7,22	l/kg
Polymer molding energy	*	17,6	-	19,5	MJ/kg
Polymer molding CO2	*	1,32	-	1,46	kg/kg
Polymer molding water	*	12,2	-	18,2	l/kg
Coarse machining energy (per unit wt removed)	*	0,925	-	1,02	MJ/kg
Coarse machining CO2 (per unit wt removed)	*	0,0694	-	0,0767	kg/kg
Fine machining energy (per unit wt removed)	*	4,98	-	5,5	MJ/kg
Fine machining CO2 (per unit wt removed)	*	0,373	-	0,413	kg/kg
Grinding energy (per unit wt removed)	*	9,48	-	10,5	MJ/kg
Grinding CO2 (per unit wt removed)	*	0,711	-	0,786	kg/kg

Recycling and end of life

Recycle		True			
Embodied energy, recycling	*	30,7	-	34	MJ/kg
CO2 footprint, recycling	*	1,17	-	1,29	kg/kg
Recycle fraction in current supply		3,8	-	4,2	%
Downcycle		True			
Combust for energy recovery		True			
Heat of combustion (net)	*	37,6	-	39,5	MJ/kg
Combustion CO2	*	3,06	-	3,22	kg/kg
Landfill		True			
Biodegrade		False			

PE-MD (molding and extrusion)

General information

Designation

Medium density polyethylene / MDPE (medium density, branched homopolymer)

Tradenames

AEI, Alathon, AXELERON, Borealis PE, BorSafe, Borstar, CERTENE, CONTINUUM, DOW MDPE, Eltex, Epolene, Ethylplus, ETILINAS, FINGERPRINT, Formolene, HIPLEX, INEOS HDPE, INEOS Wire & Cable, Kazan MDPE, Kemcor, KW Plastics, LITEN, Lumicene, Marlex, MARPOL® MD, Moharamplast MDPE, NEFTEKHIM PE, Petrothene, Qenos PE, Ravago Compounds, Ravalene, RECLAIR, SCLAIR, TIPELIN, Titanvene, TOTAL PETROCHEMICALS Polyethylene, Trithene, VENELENE, YUCLAIR

Typical uses

Packaging, Piping, Wire & cable jacketing, Film, Tanks, Bags, General Purpose, Industrial applications, Liners, Fittings, Containers, Food packaging, Electrical and Electronical, Blending, Automotive, Outdoor applications, Toys, Shrink wrap, Adhesives, Pipe coatings, Natural gas distribution, Building materials, Laminates, Chemical Process, Household goods, Blow molding applications, Bottles, Caps

Composition overview

Compositional summary

$(CH_2-CH_2)_n$

Material family	Plastic (thermoplastic, semi-crystalline)
Base material	PE-MD (Polyethylene, medium density)
Polymer code	PE-MD

Composition detail (polymers and natural materials)

Polymer		100			%

Price

Price	*	1,24	-	1,3	EUR/kg
Price per unit volume	*	1,15e3	-	1,23e3	EUR/m^3

Physical properties

Density		931	-	946	kg/m^3

Mechanical properties

Young's modulus		0,75	-	0,8	GPa
Yield strength (elastic limit)		16	-	20	MPa
Tensile strength		27,5	-	33	MPa
Elongation		500	-	800	% strain
Elongation at yield		9	-	15	% strain
Compressive strength	*	15	-	22	MPa
Flexural modulus		0,65	-	0,73	GPa
Flexural strength (modulus of rupture)		15	-	19,3	MPa
Hardness - Shore D		53	-	63	
Fatigue strength at 10^7 cycles	*	11,5	-	12,7	MPa

Impact & fracture properties

Impact strength, notched 23 °C		40	-	65	kJ/m^2
Impact strength, notched -30 °C		5	-	8	kJ/m^2
Impact strength, unnotched 23 °C		590	-	600	kJ/m^2
Impact strength, unnotched -30 °C		590	-	600	kJ/m^2

Thermal properties

Melting point		123	-	127	°C
Glass temperature		-273	-	-75	°C
Heat deflection temperature 0.45MPa		51,6	-	64,1	°C

Heat deflection temperature 1.8MPa		35	-	43	°C
Vicat softening point		106	-	121	°C
Thermal conductivity		0,48			W/m.°C
Specific heat capacity		2,3e3			J/kg.°C
Thermal expansion coefficient		50	-	150	µstrain/°C

Electrical properties

Electrical resistivity		1e21	-	1e22	µohm.cm
Dielectric constant (relative permittivity)		2,3	-	2,5	
Dissipation factor (dielectric loss tangent)		4e-4	-	0,001	
Dielectric strength (dielectric breakdown)		20	-	22	MV/m

Magnetic properties

Magnetic type	Non-magnetic

Optical properties

Transparency	Translucent

Critical materials risk

Contains >5wt% critical elements?	No

Absorption & permeability

Water absorption @ 24 hrs	0,02	%

Processing properties

Polymer injection molding	Excellent			
Polymer extrusion	Excellent			
Polymer thermoforming	Acceptable			
Linear mold shrinkage	3,3			%
Melt temperature	210	-	250	°C

Durability

Water (fresh)	Excellent
Water (salt)	Excellent
Weak acids	Excellent
Strong acids	Acceptable
Weak alkalis	Acceptable
Strong alkalis	Acceptable
Organic solvents	Limited use
Oxidation at 500C	Unacceptable
UV radiation (sunlight)	Poor
Flammability	Highly flammable

Primary production energy, CO2 and water

Embodied energy, primary production	*	76	-	83	MJ/kg
CO2 footprint, primary production	*	2,76	-	3,04	kg/kg
Water usage		64	-	70	l/kg

Processing energy, CO2 footprint & water

Polymer extrusion energy	*	5,76	-	6,35	MJ/kg
Polymer extrusion CO2	*	0,432	-	0,476	kg/kg
Polymer extrusion water	*	4,99	-	7,19	l/kg
Polymer molding energy	*	16,5	-	18,2	MJ/kg
Polymer molding CO2	*	1,24	-	1,36	kg/kg
Polymer molding water	*	12,1	-	17,5	l/kg
Coarse machining energy (per unit wt removed)	*	0,66	-	0,73	MJ/kg
Coarse machining CO2 (per unit wt removed)	*	0,05	-	0,055	kg/kg
Fine machining energy (per unit wt removed)	*	2,32	-	2,6	MJ/kg
Fine machining CO2 (per unit wt removed)	*	0,175	-	0,193	kg/kg
Grinding energy (per unit wt removed)	*	4,2	-	4,6	MJ/kg
Grinding CO2 (per unit wt removed)	*	0,31	-	0,35	kg/kg

Recycling and end of life

Recycle		True			
Embodied energy, recycling	*	25,7	-	28,4	MJ/kg
CO2 footprint, recycling	*	0,94	-	1,03	kg/kg
Recycle fraction in current supply		8	-	9	%
Downcycle		True			
Combust for energy recovery		True			
Heat of combustion (net)		44	-	46,2	MJ/kg
Combustion CO2		3,06	-	3,22	kg/kg
Landfill		True			
Biodegrade		False			

PE-HD (general purpose, molding & extrusion)

General information

Designation

High density polyethylene / HDPE (homopolymer)

Tradenames

Accucomp, Alathon, Alcudia, Arak, Asrene, Axeleron, Bapolene, Borcell, Borcoat, Borealis, Bormed, Borpex, Borsafe, Borstar, Bretene, Certene, Colorrx, Continuum, Daelim, Delta, Dow Health+, Dowlex, Egyptene, Eleme, El-Lene, Eltex, Eraclene, Etilinas, Evalene, Evolue-H, Exelene, Formolene, G-Lene, G-Lex, Halene, Hanwha, Hiplex, Hival, Hivorex, Hi-Zex, Hostalen, Hypel, Icorene, Indothene, Ineos, Innoplus, J-Rex, Kazan, Kemcor, Lanufene, Lumicene, Lupolen, Lutene, Marflex, Marlex, Marpol, Midilena, Mtegrity, Neftekhim, Nexus, Novapol, Novatec, Paxon, Petilen, Petrothene, Plexar, Polimaxx, Polycompo, Ponacom, Primatop, Prixene, Purell, Qenos, Quadrant, Ravago, Relene, Rigidex, Sabic Vestolen, Safrene, Samsung Total, Sclair, Seetec, Snolen, Surespec, Surpass, Taborex, Taisox, Tipelin, Titanex, Titanvene, Titanzex, Toler, Total, Unilex, Unithene, Unival, Venelene, Vestolen, Yanshan, Yuclair, Yuhwa, Yuzex

Typical uses

Pipes; toys; bowls; buckets; milk bottles; crates; tanks; containers; film for packaging; blown bottles for food.

Composition overview

Compositional summary

(CH2CH2)n, typical n=10,000-20,000

Material family		Plastic (thermoplastic, semi-crystalline)			
Base material		PE-HD (Polyethylene, high density)			
Polymer code		PE-HD			

Composition detail (polymers and natural materials)

Polymer		100			%

Price

Price	*	1,44	-	1,48	EUR/kg
Price per unit volume	*	1,37e3	-	1,42e3	EUR/m^3

Physical properties

Density		952	-	965	kg/m^3

Mechanical properties

Young's modulus		1,07	-	1,09	GPa
Yield strength (elastic limit)		26,2	-	31	MPa
Tensile strength		22,1	-	31	MPa
Elongation		1,12e3	-	1,29e3	% strain
Compressive modulus	*	1,07	-	1,09	GPa
Compressive strength	*	18,6	-	24,8	MPa
Flexural modulus		0,997	-	1,55	GPa
Flexural strength (modulus of rupture)	*	30,9	-	43,4	MPa
Shear modulus	*	0,377	-	0,384	GPa
Bulk modulus	*	2,15	-	2,26	GPa
Poisson's ratio	*	0,41	-	0,427	
Shape factor		4,6			
Hardness - Vickers	*	8	-	10	HV
Hardness - Rockwell M	*	31	-	35	
Hardness - Rockwell R	*	45	-	55	
Fatigue strength at 10^7 cycles	*	8,84	-	12,4	MPa
Mechanical loss coefficient (tan delta)	*	0,0367	-	0,0374	

Impact & fracture properties

Fracture toughness	*	1,52	-	1,82	MPa.m^0.5
Impact strength, notched 23 °C		6,14	-	18,6	kJ/m^2
Impact strength, notched -30 °C		3,33	-	16,3	kJ/m^2
Impact strength, unnotched 23 °C		590	-	600	kJ/m^2
Impact strength, unnotched -30 °C		590	-	600	kJ/m^2

Thermal properties

Melting point		130	-	137	°C
Glass temperature		-125	-	-90	°C
Heat deflection temperature 0.45MPa		79	-	91	°C
Heat deflection temperature 1.8MPa	*	44	-	77	°C
Maximum service temperature		113	-	129	°C
Minimum service temperature		-82	-	-72	°C
Thermal conductivity		0,461	-	0,502	W/m.°C
Specific heat capacity		1,75e3	-	1,81e3	J/kg.°C
Thermal expansion coefficient		106	-	198	µstrain/°C

Electrical properties

Electrical resistivity		3,3e24	-	3e25	µohm.cm
Dielectric constant (relative permittivity)		2,2	-	2,4	
Dissipation factor (dielectric loss tangent)		4e-4	-	6e-4	
Dielectric strength (dielectric breakdown)		17,7	-	19,7	MV/m
Comparative tracking index		600			V

Magnetic properties

Magnetic type	Non-magnetic

Optical properties

Refractive index	1,53	-	1,55	
Transparency	Translucent			

Critical materials risk

Contains >5wt% critical elements?	No

Absorption & permeability

Water absorption @ 24 hrs	0,005	-	0,01	%
Water vapor transmission	0,0283	-	0,0425	g.mm/m².day
Permeability (O2)	49,8	-	69,4	cm³.mm/m².day.atm

Processing properties

Polymer injection molding	Excellent			
Polymer extrusion	Excellent			
Polymer thermoforming	Excellent			
Linear mold shrinkage	1,5	-	4	%
Melt temperature	177	-	274	°C
Mold temperature	30	-	50	°C
Molding pressure range	82,5	-	103	MPa

Durability

Water (fresh)	Excellent
Water (salt)	Excellent
Weak acids	Excellent
Strong acids	Acceptable
Weak alkalis	Excellent
Strong alkalis	Excellent
Organic solvents	Limited use
Oxidation at 500C	Unacceptable

UV radiation (sunlight)		Fair			
Flammability		Highly flammable			

Primary production energy, CO2 and water

Embodied energy, primary production		74,9	-	82,5	MJ/kg

Sources

66.8 MJ/kg (Franklin Associates, 2008); 76.7 MJ/kg (PlasticsEurope, 2010); 76.7 MJ/kg (Hammond and Jones, 2008); 77 MJ/kg (Kemna et al. 2005); 80 MJ/kg (Shen and Patel, 2008); 83.3 MJ/kg (Franklin Associates, 2010); 89.8 MJ/kg (Thiriez and Gutowski, 2006)

CO2 footprint, primary production		2,65	-	2,92	kg/kg

Sources

1.9 kg/kg (PlasticsEurope, 2010); 1.92 kg/kg (Franklin Associates, 2008); 1.93 kg/kg (Hammond and Jones, 2008); 5.39 kg/kg (Voet, van der and Oers, van, 2003)

Water usage	*	55,3	-	61,1	l/kg

Processing energy, CO2 footprint & water

Polymer extrusion energy	*	5,9	-	6,52	MJ/kg
Polymer extrusion CO2	*	0,442	-	0,489	kg/kg
Polymer extrusion water	*	4,86	-	7,29	l/kg
Polymer molding energy	*	20,8	-	23	MJ/kg
Polymer molding CO2	*	1,56	-	1,73	kg/kg
Polymer molding water	*	13,5	-	20,2	l/kg
Coarse machining energy (per unit wt removed)	*	0,688	-	0,76	MJ/kg
Coarse machining CO2 (per unit wt removed)	*	0,0516	-	0,057	kg/kg
Fine machining energy (per unit wt removed)	*	2,6	-	2,88	MJ/kg
Fine machining CO2 (per unit wt removed)	*	0,195	-	0,216	kg/kg
Grinding energy (per unit wt removed)	*	4,73	-	5,23	MJ/kg
Grinding CO2 (per unit wt removed)	*	0,355	-	0,392	kg/kg

Recycling and end of life

Recycle		True			
Embodied energy, recycling	*	25,4	-	28,1	MJ/kg
CO2 footprint, recycling	*	0,898	-	0,993	kg/kg
Recycle fraction in current supply		8,02	-	8,86	%
Downcycle		True			
Combust for energy recovery		True			
Heat of combustion (net)	*	44	-	46,2	MJ/kg
Combustion CO2	*	3,06	-	3,22	kg/kg
Landfill		True			
Biodegrade		False			

PP (homopolymer, high flow)

General information

Designation

Polypropylene (Homopolymer, high flow)

Tradenames

A. Schulman PP; Acclear; Accpro; Acctuf; Accucomp; Achieve; Addilene; Adflex; Adpro; Adstif; Akrolen; Albis PP; Alphacan; Amoco PP; Aanpro; Aplax; Appryl; Aqualoy; ARCO PP; Arcoplen; Armlen; Arpak; Arpro; Astryn; AtofinaPolypropylene; Azdel; Bapolene; Bergaprop; Bicor; Borealis PP; Borflow; Bormed; Borstar; Braskem PP; Bras-Tec; Bynel; Capilene; Carboprene; Carmelstat; Cefor; Clyrell; Compel; Compotene; Comshield; Corton; Cosmoplene; Cotene; CP PrymeE Polypropylene; Cuyolen; DaelimPoly; Dafnelen; DaicelPP; Danapro; Daplen; Daploy; Delta; Denilen; DEP; Dexflex; DigiLyte; Domolen; Dow Polypropylene; Ecoplast PP; El-Pro; EltexP; Endura; Epsilon; EquistarPP; Escalloy; Esdash; Estaprop; Eticourt; Extron; ExxonMobil PP; Exxpol Enhance; Exxtral; FerrexNewfoamer; Ferro PP; Ferrolene; Fiberfil; Finapro; FHR Polypropylene; Flametec; Formolene; Fortilene; Gapex; Globalene; Global PP; Grand Polpro; Haiplen; Halene; Hi-Fax; Hi-Glass; Hipol; Hishiplate; Hival; HMS; Hopelen; Hostacen; Hostacom; Hostalen PP; Huntsman PP; Hyosung PP; Hypro; Icorene; Inertec; Ineos PP Med; Innovene PP; Inspire; Ipiranga; Isplen; Jazz; Kelburon; Kopelen; Koylene; Koylene ADL; Latene; Lupol; Luvogard; M. Holland; Mafill; Magnacomp; Malen-P; Marlex PP; Maspolene; Maxbatch; Maxpro; Maxxam; Metallyte; Metocene; Microthene; Moplen; Mosten; Multipro; Network Polymers PP; Neviprop; Newstren; Niplene; Nissen; Noblen; Nortuff; Novatec; Novolen; Oleform; Olehard; Olesafe; OppalyteTrespaphan; Osstyrol; Palprop; Percom; Permastat; Petoplen; Petrothene; Pinnacle PP; Piolen; Plastiflam; Polene; Polifin PP; Polifor; Polybatch; Polycom; Polycomp; Polyfill; Polyflam; Polyfort; Polystone; Polyvance; Ponalen; Pre-Elec; Procom; Pro-Fax; Prolen; Propak; Propilco PP; Propilven; Propylux; Protec; Proteus; Purell; Qenos PP; Ranplen; Refax; Repol; Repolen; Reptol; Retpol; Rexene; Rhetech PP; Rotothon; Sabic PP; Samsung Total; Sanalite; Sanren; Saxene; Scolefin; Seetec; Sequel; Simona; Sinpolene; Spartech Polycom; Spolen; StaMax; Stamylan; Starpylen; Strandfoam; Sunlet; Sunoco PP; Syntegum; Taboren; Taffen; Taipolene; Tairipro; Talcoprene; Tatren; Tecafine; Teknoplen; Terez; Thermolen; Thermylene; Tipcolene; Tipplen; TITANPRO; Topilene; Torayfan; Total Petrochemicals Polypropylene; Tracolen; Trapylen; Trilen; Trilene; Umastyr; Valmax; Valtec; Vamplem; Vylene; Vyon; Wintec; WPP; Xenopren; Xmod; Yuhwa; Yuplene; Zeral

Typical uses

Containers, Thin-Walled; Cups; Toys; Fibers, Staple; Filaments; Yarn, BCF; Film, Bi-axially Oriented; Film, Cast; Blow Molding Applications; Film, Oriented; Appliance Components; Automotive Interior Parts; Electrical/Electronic Applications; Packaging, Cosmetic; Furniture; Filtration Media; Textile Applications; Packaging, Food; General Purpose; Parts, Thin-walled; Molds/Dies/Tools; Packaging, Thin-walled; BCF Multi-filaments; Fabrics, Disposable; Spun Bonding; Containers, Food; Handles; Household Goods; Vials; Writing Instruments; Parts, Engineering; Automotive Exterior Parts; Color Concentrates; Non-wovens, Spunbond; Stationary Supplies; Bags; Non-wovens; Hospital Goods; Packaging, Rigid; Lids; Coating Applications; Fiber, Slit-Film; Fibers, Hi-speed Slit-film; Labware; Laminates; Fabrics; Rope; Twine; Yarn, Course Weaving; Automotive Electronics; Automotive Instrument Panel; Valves/Valve Parts; Packaging, Pharmaceutical; Coatings, Foil; Coatings, Non-Wovens; Coatings, Paper; Personal Care; Carpet Backing; Trays, Support; Agricultural Applications; Industrial Applications; Food Applications, Non-specific; Blending; Liners; Automotive Under the Hood; Electrical Parts; Drinkware, Disposable; Packaging, Media; Coatings, Fabric; Ribbons; Sheet; Wire & Cable Applications; Kitchenware; Construction Applications; Consumer Applications; Parts, Thick-walled; Outdoor Furnishings; Straws, Drinking; Cosmetics; Monofilaments; Sporting Goods; Tool/Tote Box; Yarn, Flat-High Tenacity; Belts/Belt Repair; Strapping; Foam; Lawn and Garden Equipment; Body Implants; Packaging, Medical; Buckets; bowls; general mechanical parts; bottle crates; medical components; washing machine drums; pipes; battery cases; bottles; bottle caps; bumpers; films for packaging; fibers for carpeting and artificial sports surfaces.

Composition overview

Compositional summary

(CH2-CH(CH3))n - isotactic

Material family		Plastic (thermoplastic, semi-crystalline)			
Base material		PP (Polypropylene)			
Polymer code		PP			

Composition detail (polymers and natural materials)

Polymer		100			%

Price

Price	*	1,3	-	1,35	EUR/kg
Price per unit volume	*	1,16e3	-	1,23e3	EUR/m^3

Physical properties

Density		898	-	908	kg/m^3

Mechanical properties

Young's modulus		1,37	-	1,58	GPa
Yield strength (elastic limit)		31,9	-	36,4	MPa
Tensile strength		22,5	-	33,5	MPa
Elongation strain		52,1	-	232	%
Elongation at yield strain		8,09	-	11,1	%
Compressive modulus	*	1,37	-	1,58	GPa
Compressive strength	*	39,9	-	41,9	MPa
Flexural modulus		1,33	-	1,61	GPa
Flexural strength (modulus of rupture)		34,4	-	51,4	MPa
Shear modulus	*	0,519	-	0,532	GPa
Bulk modulus	*	2,5	-	2,56	GPa
Poisson's ratio	*	0,399	-	0,407	
Shape factor		4,9			
Hardness - Vickers		10			HV
Hardness - Rockwell M		60	-	76	
Hardness - Rockwell R		95	-	104	
Hardness - Shore D		64	-	69	
Hardness - Shore A	*	94	-	99	
Fatigue strength at 10^7 cycles	*	10,7	-	11,2	MPa
Mechanical loss coefficient (tan delta)	*	0,0265	-	0,0278	

Impact & fracture properties

Fracture toughness	*	1,66	-	1,75	MPa.m^0.5
Impact strength, notched 23 °C		2,26	-	3,17	kJ/m^2
Impact strength, notched -30 °C		1,29	-	1,52	kJ/m^2
Impact strength, unnotched 23 °C		61,6	-	73,9	kJ/m^2
Impact strength, unnotched -30 °C		14,3	-	15,7	kJ/m^2

Thermal properties

Melting point		161	-	170	°C
Glass temperature		-14	-	-6	°C
Heat deflection temperature 0.45MPa		92,7	-	111	°C
Heat deflection temperature 1.8MPa		50,5	-	66,9	°C
Vicat softening point		143	-	164	°C

Maximum service temperature	95,1	-	114	°C
Minimum service temperature	* -17	-	-3	°C
Thermal conductivity	* 0,205	-	0,214	W/m.°C
Specific heat capacity	1,66e3	-	1,7e3	J/kg.°C
Thermal expansion coefficient	81,1	-	109	µstrain/°C

Electrical properties

Electrical resistivity	2,55e23	-	1,63e24	µohm.cm
Dielectric constant (relative permittivity)	2,16	-	2,24	
Dissipation factor (dielectric loss tangent)	1,96e-4	-	2,04e-4	
Dielectric strength (dielectric breakdown)	17,6	-	18,4	MV/m
Comparative tracking index	600			V

Magnetic properties

Magnetic type	Non-magnetic

Optical properties

Refractive index	1,48	-	1,5
Transparency	Translucent		

Critical materials risk

Contains >5wt% critical elements?	No

Absorption & permeability

Water absorption @ 24 hrs	0,0195	-	0,0205	%
Water absorption @ sat	0,195	-	0,205	%
Water vapor transmission	0,118	-	0,184	g.mm/m².day
Permeability (O2)	58,3	-	99,7	cm³.mm/m².day.atm

Processing properties

Polymer injection molding	Excellent			
Polymer extrusion	Excellent			
Polymer thermoforming	Acceptable			
Linear mold shrinkage	1,4	-	1,96	%
Melt temperature	203	-	251	°C
Mold temperature	11,9	-	38,4	°C
Molding pressure range	18,6	-	95,6	MPa

Durability

Water (fresh)	Excellent
Water (salt)	Excellent
Weak acids	Excellent
Strong acids	Excellent
Weak alkalis	Excellent
Strong alkalis	Excellent
Organic solvents	Excellent
Oxidation at 500C	Unacceptable
UV radiation (sunlight)	Poor
Flammability	Highly flammable

Notes

Currently NOT UL tested but expected to pass the HB test

Primary production energy, CO2 and water

Embodied energy, primary production	72,6	-	80,1	MJ/kg

Sources

49.1 MJ/kg (Argonne National Laboratory); 64.7 MJ/kg (Potting and Blok, 1996); 73 MJ/kg (Kemna et al. 2005); 73.4 MJ/kg (PlasticsEurope, 2010); 75.5 MJ/kg (Sullivan and Gaines, 2010); 83 MJ/kg (Thiriez and Gutowski, 2006); 115 MJ/kg (Hammond and Jones, 2008)

CO2 footprint, primary production		3,13	-	3,45	kg/kg

Sources

1.97 kg/kg (Kemna et al. 2005); 2 kg/kg (PlasticsEurope, 2010); 5.88 kg/kg (Voet, van der and Oers, van, 2003)

Water usage	*	37,3	-	41,2	l/kg

Processing energy, CO2 footprint & water

Polymer extrusion energy	*	5,88	-	6,5	MJ/kg
Polymer extrusion CO2	*	0,441	-	0,488	kg/kg
Polymer extrusion water	*	4,85	-	7,28	l/kg
Polymer molding energy	*	20,4	-	22,6	MJ/kg
Polymer molding CO2	*	1,53	-	1,69	kg/kg
Polymer molding water	*	13,3	-	20	l/kg
Coarse machining energy (per unit wt removed)	*	0,905	-	1	MJ/kg
Coarse machining CO2 (per unit wt removed)	*	0,0679	-	0,075	kg/kg
Fine machining energy (per unit wt removed)	*	4,78	-	5,28	MJ/kg
Fine machining CO2 (per unit wt removed)	*	0,358	-	0,396	kg/kg
Grinding energy (per unit wt removed)	*	9,08	-	10	MJ/kg
Grinding CO2 (per unit wt removed)	*	0,681	-	0,753	kg/kg

Recycling and end of life

Recycle		True			
Embodied energy, recycling	*	24,6	-	27,2	MJ/kg
CO2 footprint, recycling	*	1,06	-	1,17	kg/kg
Recycle fraction in current supply		5,26	-	5,81	%
Downcycle		True			
Combust for energy recovery		True			
Heat of combustion (net)	*	44	-	46,2	MJ/kg
Combustion CO2	*	3,06	-	3,22	kg/kg
Landfill		True			
Biodegrade		False			

PP (homopolymer, 20% glass fiber)

General information

Designation

Polypropylene (Homopolymer, 20% glass fiber)

Tradenames

Bergaprop; Acclear; Accpro; Acctuf; Achieve; Addilene; Adflex; Adpro; Akrolen; Alphacan; Aplax; Appryl; Aqualoy; Arcoplen; Armlen; Arpak; Arpro; Astryn; AtofinaPolypropylene; Azdel; Bapolene; Bicor; Borstar; Bras-Tec; Bynel; Capilene; Carboprene; Carmelstat; Cefor; Clyrell; Compel; Compotene; Comshield; Corton; Cosmoplene; Cotene; Cuyolen; DaelimPoly; Dafnelen; DaicelPP; Danapro; Daplen; Denilen; DEP; Dexflex; DigiLyte; Dow; EL-Pro; EltexP; Endura; Epsilon; EquistarPP; Escalloy; Esdash; Estaprop; Eticourt; Extron; Exxpol Enhance; Exxtral; FerrexNewfoamer; Ferrolene; Fiberfil; Finapro; Flametec; Formolene; Fortilene; Grand Polpro; Haiplen; Halene; Hi-Fax; Hi-Glass; Hishiplate; HMS; Hopelen; Hostacen; Hostacom; Hostalen PP; Hyosung PP; Hypro; Inertec; Inspire; Isplen; Jazz; Kelburon; Kopelen; Koylene; Latene; Lupol; Luvogard; Mafill; Magnacomp; Malen-P; Marlex; Maxbatch; Maxpro; Maxxam; Metallyte; Metocene; Microthene; Moplen; Mosten; Multipro; Neviprop; Newstren; Niplene; Nissen; Noblen; Nortuff; Novatec; Novolen; Oleform; Olehard; Olesafe; OPPalyteTrespaphan; Osstyrol; Palprop; Percom; Permastat; Petoplen; Petrothene; Piolen; Plastiflam; Polene; Polifor; Polycom; POLYfill; Polyflam; Polyfort; Polystone; Polyvance; Ponalen; Pre-Elec; Procom; Pro-Fax; Prolen; Propak; Propilven; Propylux; Protec; Proteus; Ranplen; Refax; Repol; Repolen; Reptol; Retpol; Rexene; Rotothon; Sanalite; Sanren; Saxene; Scolefin; Seetec; Sequel; Simona; Sinpolene; Spolen; StaMax; Stamylan; Starpylen; Strandfoam; Sunlet; Syntegum; Taboren; Taffen; Taipolene; Tairipro; Talcoprene; Tatren; Tecafine; Teknoplen; Terez; Thermolen; Thermylene; Tipplen; Topilene; Torayfan; Tracolen; Trapylen; Trilen; Trilene; Umastyr; Valmax; Valtec; Vamplem; Vylene; Vyon; Wintec; WPP; Xenopren; Yuhwa; Zeral; ACCUTECH; Adell PP; Albis PP; Muehlstein Compounds; Delta; POLIFOR; GAPEX; GAPEX HP; RYLENE; Jackdaw PP; McCann PP; OMNI; Primefin; Pro; RTP Compounds; NILENE; Spartech Polycom; Matrixx; Tipcolene; TRANSMARE

Typical uses

Appliance Components; Automotive Interior Parts; Industrial Applications; Furniture; Connectors; Electrical/Electronic Applications; General Purpose; Housings; Valves/Valve Parts; Automotive Under the Hood; White Goods & Small Appliances; Pump Parts; Sporting Goods; Textile Applications; Structural Parts; Lawn and Garden Equipment; Construction Applications; Consumer Applications; Parts, Engineering; Irrigation Applications; Buckets; bowls; general mechanical parts; bottle crates; toys; medical components; washing machine drums; pipes; battery cases; bottles; bottle caps; bumpers; films for packaging; fibers for carpeting and artificial sports surfaces.

Composition overview

Compositional summary

(CH2-CH(CH3))n - isotactic + 20% glass filler

Material family		Plastic (thermoplastic, semi-crystalline)			
Base material		PP (Polypropylene)			
% filler (by weight)		20			%
Filler/reinforcement		Glass			
Filler/reinforcement form		Short fiber (<5mm)			
Polymer code		PP-GF20			

Composition detail (polymers and natural materials)

Polymer		80			%
Glass (fiber)		20			%

Price

Price	*	1,75	-	1,83	EUR/kg
Price per unit volume	*	1,78e3	-	1,98e3	EUR/m^3

Physical properties

Density		1,01e3	-	1,08e3	kg/m^3

Mechanical properties

Young's modulus		3,9	-	5,02	GPa
Yield strength (elastic limit)		44,8	-	59,9	MPa
Tensile strength		54,2	-	67,5	MPa
Elongation		3,23	-	4,48	% strain
Elongation at yield		3,25	-	4,14	% strain
Compressive modulus	*	3,9	-	5,02	GPa
Compressive strength	*	50,2	-	56,2	MPa
Flexural modulus		3,39	-	4,13	GPa
Flexural strength (modulus of rupture)		81,2	-	107	MPa
Shear modulus	*	1,6	-	1,65	GPa
Bulk modulus	*	5,3	-	5,43	GPa
Poisson's ratio	*	0,359	-	0,366	
Shape factor		7,4			
Hardness - Vickers	*	15	-	16	HV
Hardness - Rockwell M		62	-	78	
Hardness - Rockwell R		90	-	99	
Hardness - Shore D		73	-	77	
Hardness - Shore A		88	-	93	
Fatigue strength at 10^7 cycles	*	23,6	-	24,8	MPa
Mechanical loss coefficient (tan delta)	*	0,0138	-	0,0145	

Impact & fracture properties

Fracture toughness	*	3,03	-	3,18	MPa.m^0.5
Impact strength, notched 23 °C		5,61	-	8,13	kJ/m^2
Impact strength, notched -30 °C		6,14	-	7,2	kJ/m^2
Impact strength, unnotched 23 °C		27,2	-	39,6	kJ/m^2
Impact strength, unnotched -30 °C		15,7	-	27,1	kJ/m^2

Thermal properties

Melting point		169	-	178	°C
Glass temperature		-14	-	-6	°C
Heat deflection temperature 0.45MPa		142	-	163	°C
Heat deflection temperature 1.8MPa		128	-	148	°C
Vicat softening point		146	-	167	°C
Maximum service temperature		106	-	125	°C
Minimum service temperature	*	-17	-	-3	°C
Thermal conductivity		0,284	-	0,295	W/m.°C
Specific heat capacity	*	1,69e3	-	1,72e3	J/kg.°C
Thermal expansion coefficient		42,9	-	45,1	µstrain/°C

Electrical properties

Electrical resistivity		9,9e23	-	1,01e24	µohm.cm
Dielectric constant (relative permittivity)		2,75	-	2,86	
Dissipation factor (dielectric loss tangent)		9,8e-4	-	0,00102	
Dielectric strength (dielectric breakdown)		20,9	-	21,9	MV/m
Comparative tracking index		600			V

Magnetic properties

Magnetic type		Non-magnetic

Optical properties

Transparency		Opaque			
Critical materials risk					
Contains >5wt% critical elements?		No			
Absorption & permeability					
Water absorption @ 24 hrs		0,0111	-	0,0393	%
Processing properties					
Polymer injection molding		Excellent			
Polymer extrusion		Limited use			
Polymer thermoforming		Acceptable			
Linear mold shrinkage		0,279	-	0,774	%
Melt temperature		216	-	241	°C
Mold temperature		37,3	-	64,8	°C
Molding pressure range		70,4	-	110	MPa
Durability					
Water (fresh)		Excellent			
Water (salt)		Excellent			
Weak acids		Excellent			
Strong acids		Excellent			
Weak alkalis		Excellent			
Strong alkalis		Excellent			
Organic solvents		Excellent			
Oxidation at 500C		Unacceptable			
UV radiation (sunlight)		Poor			
Flammability		Highly flammable			
Notes					
Currently NOT UL tested but expected to pass the HB test					
Primary production energy, CO2 and water					
Embodied energy, primary production	*	68,5	-	75,5	MJ/kg
CO2 footprint, primary production	*	3,06	-	3,37	kg/kg
Water usage	*	86,1	-	95,2	l/kg
Processing energy, CO2 footprint & water					
Polymer extrusion energy	*	5,9	-	6,52	MJ/kg
Polymer extrusion CO2	*	0,442	-	0,489	kg/kg
Polymer extrusion water	*	4,86	-	7,29	l/kg
Polymer molding energy	*	20,8	-	23	MJ/kg
Polymer molding CO2	*	1,56	-	1,72	kg/kg
Polymer molding water	*	13,5	-	20,2	l/kg
Coarse machining energy (per unit wt removed)	*	0,958	-	1,06	MJ/kg
Coarse machining CO2 (per unit wt removed)	*	0,0719	-	0,0794	kg/kg
Fine machining energy (per unit wt removed)	*	5,31	-	5,86	MJ/kg
Fine machining CO2 (per unit wt removed)	*	0,398	-	0,44	kg/kg
Grinding energy (per unit wt removed)	*	10,1	-	11,2	MJ/kg
Grinding CO2 (per unit wt removed)	*	0,76	-	0,84	kg/kg
Recycling and end of life					
Recycle		False			
Recycle fraction in current supply		0,1			%
Downcycle		True			
Combust for energy recovery		True			
Heat of combustion (net)	*	35,2	-	37	MJ/kg
Combustion CO2	*	2,45	-	2,57	kg/kg
Landfill		True			
Biodegrade		False			

PP (homopolymer, 20% calcium carbonate)
General information
Designation
Polypropylene (Homopolymer, 20% calcium carbonate)
Tradenames
Bergaprop; Acclear; Accpro; Acctuf; Achieve; Addilene; Adflex; Adpro; Akrolen; Alphacan; Aplax; Appryl; Aqualoy; Arcoplen; Armlen; Arpak; Arpro; Astryn; Atofinapolypropylene; Azdel; Bapolene; Bicor; Borstar; Bras-Tec; Bynel; Capilene; Carboprene; Carmelstat; Cefor; Clyrell; Compel; Compotene; Comshield; Corton; Cosmoplene; Cotene; Cuyolen; Daelimpoly; Dafnelen; Daicelpp; Danapro; Daplen; Denilen; Dep; Dexflex; Digilyte; Dow; El-Pro; Eltexp; Endura; Epsilon; Equistarpp; Escalloy; Esdash; Estaprop; Eticourt; Extron; Exxpol Enhance; Exxtral; Ferrexnewfoamer; Ferrolene; Fiberfil; Finapro; Flametec; Formolene; Fortilene; Grand Polpro; Haiplen; Halene; Hi-Fax; Hi-Glass; Hishiplate; Hms; Hopelen; Hostacen; Hostacom; Hostalen Pp; Hyosung Pp; Hypro; Inertec; Inspire; Isplen; Jazz; Kelburon; Kopelen; Koylene; Latene; Lupol; Luvogard; Mafill; Magnacomp; Malen-P; Marlex; Maxbatch; Maxpro; Maxxam; Metallyte; Metocene; Microthene; Moplen; Mosten; Multipro; Neviprop; Newstren; Niplene; Nissen; Noblen; Nortuff; Novatec; Novolen; Oleform; Olehard; Olesafe; Oppalytetrespaphan; Osstyrol; Palprop; Percom; Permastat; Petoplen; Petrothene; Piolen; Plastiflam; Polene; Polifor; Polycom; Polyfill; Polyflam; Polyfort; Polystone; Polyvance; Ponalen; Pre-Elec; Procom; Pro-Fax; Prolen; Propak; Propilven; Propylux; Protec; Proteus; Ranplen; Refax; Repol; Repolen; Reptol; Retpol; Rexene; Rotothon; Sanalite; Sanren; Saxene; Scolefin; Seetec; Sequel; Simona; Sinpolene; Spolen; Stamax; Stamylan; Starpylen; Strandfoam; Sunlet; Syntegum; Taboren; Taffen; Taipolene; Tairipro; Talcoprene; Tatren; Tecafine; Teknoplen; Terez; Thermolen; Thermylene; Tipplen; Topilene; Torayfan; Tracolen; Trapylen; Trilen; Trilene; Umastyr; Valmax; Valtec; Vamplem; Vylene; Vyon; Wintec; Wpp; Xenopren; Yuhwa; Zeral; A.D. Compound Pp; Accutech; Adell Pp; Muehlstein Compounds; Delta; Ferrex; Ferro Pp; Rylene; Mccann Pp; Omni; PMC Ep; Primefin; RTP Compounds; Spartech Matrixx; Tipcolene; Tyne Olefins
Typical uses
Appliances; Automotive Applications; Household Goods; General Purpose; Furniture; Lawn and Garden Equipment; Construction Applications; Consumer Applications; Industrial Applications; Containers, Food; Structural Parts; Electrical Parts; Toys; Outdoor Furnishings; Parts, Thin-walled; Buckets; bowls; general mechanical parts; bottle crates; medical components; washing machine drums; pipes; battery cases; bottles; bottle caps; bumpers; films for packaging; fibers for carpeting and artificial sports surfaces.
Composition overview
Compositional summary
(CH2-CH(CH3))n - isotactic + 20% CaCO3 filler

Material family	Plastic (thermoplastic, semi-crystalline)			
Base material	PP (Polypropylene)			
% filler (by weight)	20			%
Filler/reinforcement	Mineral			
Filler/reinforcement form	Particulate			
Polymer code	PP-MD20			

Composition detail (polymers and natural materials)

Polymer	80			%
Calcium carbonate (powder)	20			%

Price

Price	* 1,59	-	1,64	EUR/kg
Price per unit volume	* 1,66e3	-	1,73e3	EUR/m^3

Physical properties

Density	1,04e3	-	1,06e3	kg/m^3

Mechanical properties

Young's modulus	1,58	-	1,82	GPa
Yield strength (elastic limit)	26,3	-	30,6	MPa
Tensile strength	14,8	-	19,6	MPa
Elongation	35,2	-	90,7	% strain
Elongation at yield	4,99	-	8,77	% strain
Compressive modulus	* 1,58	-	1,82	GPa
Compressive strength	* 46,4	-	48,8	MPa
Flexural modulus	1,61	-	1,92	GPa
Flexural strength (modulus of rupture)	40,1	-	48,1	MPa
Shear modulus	* 0,599	-	0,614	GPa
Bulk modulus	* 2,72	-	2,79	GPa
Poisson's ratio	* 0,394	-	0,401	
Shape factor	5,9			
Hardness - Vickers	* 8	-	9	HV
Hardness - Rockwell M	49	-	51	
Hardness - Rockwell R	88	-	92	
Hardness - Shore D	68	-	73	
Hardness - Shore A	93	-	97	
Fatigue strength at 10^7 cycles	* 6,64	-	6,97	MPa
Mechanical loss coefficient (tan delta)	* 0,027	-	0,0283	

Impact & fracture properties

Fracture toughness	* 1,16	-	1,22	MPa.m^0.5
Impact strength, notched 23 °C	3,45	-	4,69	kJ/m^2
Impact strength, notched -30 °C	2,32	-	3,21	kJ/m^2
Impact strength, unnotched 23 °C	47,8	-	57,4	kJ/m^2
Impact strength, unnotched -30 °C	39,4	-	47,3	kJ/m^2

Thermal properties

Melting point	167	-	198	°C
Glass temperature	-14	-	-6	°C
Heat deflection temperature 0.45MPa	93,2	-	112	°C
Heat deflection temperature 1.8MPa	50,7	-	67,1	°C
Vicat softening point	142	-	163	°C
Maximum service temperature	* 74,3	-	91,9	°C
Minimum service temperature	* -17	-	-3	°C
Thermal conductivity	0,225	-	0,234	W/m.°C
Specific heat capacity	* 1,69e3	-	1,73e3	J/kg.°C
Thermal expansion coefficient	62,2	-	63,7	µstrain/°C

Electrical properties

Electrical resistivity	9,9e23	-	1,01e24	µohm.cm
Dielectric constant (relative permittivity)	2,75	-	2,86	
Dissipation factor (dielectric loss tangent)	0,0049	-	0,0051	
Dielectric strength (dielectric breakdown)	19,6	-	20,4	MV/m
Comparative tracking index	600			V

Magnetic properties

Magnetic type	Non-magnetic

Optical properties

Transparency	Opaque

Critical materials risk

Contains >5wt% critical elements?		No			

Absorption & permeability

Water absorption @ 24 hrs		0,0195	-	0,0205	%

Processing properties

Polymer injection molding		Acceptable			
Polymer extrusion		Limited use			
Polymer thermoforming		Acceptable			
Linear mold shrinkage		1,4	-	1,67	%
Melt temperature		202	-	227	°C
Mold temperature		37,6	-	53,3	°C
Molding pressure range		3,93	-	7,28	MPa

Durability

Water (fresh)		Excellent			
Water (salt)		Excellent			
Weak acids		Excellent			
Strong acids		Acceptable			
Weak alkalis		Excellent			
Strong alkalis		Excellent			
Organic solvents		Excellent			
Oxidation at 500C		Unacceptable			
UV radiation (sunlight)		Poor			
Flammability		Highly flammable			

Notes

Currently NOT UL tested but expected to pass the HB test

Primary production energy, CO2 and water

Embodied energy, primary production	*	63,4	-	69,9	MJ/kg
CO2 footprint, primary production	*	2,9	-	3,2	kg/kg
Water usage	*	32,4	-	35,8	l/kg

Processing energy, CO2 footprint & water

Polymer extrusion energy	*	5,87	-	6,48	MJ/kg
Polymer extrusion CO2	*	0,44	-	0,486	kg/kg
Polymer extrusion water	*	4,84	-	7,27	l/kg
Polymer molding energy	*	19,9	-	22	MJ/kg
Polymer molding CO2	*	1,49	-	1,65	kg/kg
Polymer molding water	*	13,1	-	19,6	l/kg
Coarse machining energy (per unit wt removed)	*	0,906	-	1	MJ/kg
Coarse machining CO2 (per unit wt removed)	*	0,0679	-	0,0751	kg/kg
Fine machining energy (per unit wt removed)	*	4,78	-	5,28	MJ/kg
Fine machining CO2 (per unit wt removed)	*	0,359	-	0,396	kg/kg
Grinding energy (per unit wt removed)	*	9,09	-	10	MJ/kg
Grinding CO2 (per unit wt removed)	*	0,681	-	0,753	kg/kg

Recycling and end of life

Recycle		True			
Embodied energy, recycling	*	21,5	-	23,8	MJ/kg
CO2 footprint, recycling	*	0,984	-	1,09	kg/kg
Recycle fraction in current supply		0,1			%
Downcycle		True			
Combust for energy recovery		True			
Heat of combustion (net)	*	35,2	-	37	MJ/kg
Combustion CO2	*	2,45	-	2,57	kg/kg
Landfill		True			
Biodegrade		False			