Professional MBA
Automotive Industry

ACADEMY FOR CONTINUING EDUCATION

SLOVENSKÁ TECHNICKÁ UNIVERZITA V BRATISLAVE

Presence of aluminium extrusions in automotive industry and its impact on sustainability

A Master's Thesis submitted for the degree of
“Master of Business Administration”

supervised by
Dr. František Simančík

Ing. Viktor Fára

11929266

Vienna, 17.11.2022

Affidavit

I, **ING. VIKTOR FÁRA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "PRESENCE OF ALUMINIUM EXTRUSIONS IN AUTOMOTIVE INDUSTRY AND ITS IMPACT ON SUSTAINABILITY", 74 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

Vienna, 17.11.2022

_____

Signature

Acknowledgement

I am very grateful to my supervisor, Dr. Ing. František Simančík, for the time he has invested in the reviews, discussions, advice and comments related to my work on this document, as well as sharing the enthusiasm on my thesis project. I would like to thank to the company Hydro Extruded Solutions for the support in my studies on the MBA program, providing also internal sources for my work, as well as many contacts needed to complete it. Last but not least, the thanks goes to my family members for their patience and support through the months of my studies in this program.

Table of Contents

ABSTRACT

Aluminium, also called the metal of the future, is used more and more in different kind of industries, including the automotive industry. It has gained attention from the moment that the mankind has realized its characteristics, and therefore the potential of usage in all possible segments of industry, up to the level of the products of everyday life. This Master Thesis aims to understand what could be the future variations of the combination of this element with others ones, and how these “progressive materials”, where aluminium powder extruded products belong, can influence its application in real life, in relation to the topic of the sustainability. Sustainability is on the highest agenda of both car manufacturers and final consumers as well, not only from the aspect of product durability and possible lifetime presence in the circular economy, but also from the point of view of cost feasibility.

The first part of this document approaches the topic form an academic perspective, starting by the presentation of challenges and trends of the industry within the aluminium world of extrusions. Consequently, brief presentation of the Hydro group, supporting the explanation about the basic parameters of the aluminium element, classic production process, application of the current portfolio of products in the segment of the automotive industry, is provided.

The second part is a natural continuation to the first, explaining the theoretical information about the progressive aluminium materials with a comparison against regular casted alloys materials.

The third part contains methodology applied by the author in the process of research on the possible application of “progressive materials”, by gathering data from the field thru a survey executed in the company where the author is presently working in this area of research and development.
The survey is presented in a detailed way, with the explanation of the different fields of the question that are presented to the business partners from the automotive sector, that were aimed to be questioned based on their multiple years of experience in the segment, as well as their journey of implementation of new products, technologies and also new raw materials. The survey was conducted having in scope European partners only, although these are present with their activities also in other regions of the world.

Following, in the same part, an analysis from the provided data is provided, with the investigation and study of different relationships between various areas of questions. An understanding for the relation of possible application in real life production and its feasibility, both cost wise and as a sustainable solution, is looked for.

The outcome of this of this master thesis shows, that there is a connection between the sustainability and its cost, and the sustainability perspective prevails on the cost sensitivity. The result confirms that the sustainability factor is more important from the perspective of the application of “progressive materials” which influences the application in the circular economy with its impact on the environment, rather than the financial aspect of an application of such solution, on the long run.

Key words: Aluminium Extrusion, Material Substitution, Aluminium Powders, Sustainability

1. INTRODUCTION TO RESEARCH TOPIC

The author of this document is leading a mid-size production plant of Aluminium Extrusions, Anodizing Surface Treatment and Fabrication of aluminium components, located in Žiar nad Hronom, Slovakia. Currently, with eighteen years of experience in this area, gained in the fields of procurement, project management, logistics and finance, is executing more than four years the role of Managing Director, leading this plant of nearly five hundred employees. The topic of new progressive materials, being aluminium powder extrusions the main one, has been introduced to the author by his former superior, that has tirelessly inculcated that these materials will become the new standards in the aluminium industry, and that the development of such niche segment of material will materialize into a one-of-a-kind and incomparable competitive advantage on the market.

This advantage thru its uniqueness can be the generator of added value, that will be highly appreciated by the customers, and help them in finding advanced solutions to the challenges of their own customers. Throughout the many years of delivering solutions to the customer of HESK, the author understood that the cutting-edge solution can represent a quantum leap from the basic regular supplier to the top of line supplier, with state-of-the-art solution providing the competitive advantage, rather than a regular aluminium component.

Hydro Extruded Solutions, as the biggest aluminium solution provider in the area of aluminium extrusions with further processing, together with its Operational Excellence centres, gives the opportunity to investigate and include this topic it this MT, and utilize the outcome of it in future marketing activities related to the promotion of such solutions.

1.1. The Objective

Sustainability and the need to reduce the carbon footprint of products used in the automotive sector are at the top of nearly every company's list of business priorities. The suppliers understand that the future success of their business models is strongly linked to the ability of providing solutions that are covering sustainable sourcing, production and delivery. But not only that. The integration of the products in the circular economy, giving possibility of choosing of materials that are recyclable or

reusable, is also demanded by the final customers. Their awareness of the development of the environment, with dramatic changes happening in global climate, are also influencing the customer behaviour. Underlined with the latest developments on the Energy Crisis and war in Europe, the customers are looking for solutions that will grant better possibility of their co-existence with the already so stressed environment. This document will help to understand those basic thru the possibility of usage of innovative materials and their impact on the sustainability.

The input source of knowledge to the research work:

a) Available publications, textbooks, articles from the field of aluminium extrusions, powder extrusions, internal knowledge materials from the HE Group
b) Own empirical experience, based on the experience from the performed roles and the related gained knowledge in various these positions within the aluminium industry (also connected to the automotive segment, mainly from the last 5 years of experience)
c) Research conducted within the Group, where the author is executing a leading role, thru carrying out of a structured survey towards business partners form the applicable segment within the scope of the Company and the Group

This MT is to understand and evaluate the following hypothesis:

- Overall, the material substitution contributes to the sustainability of solutions
- The key stakeholders in the process influence are the ignition of the change, that drives the companies to sustainable solutions
- The cost perspective of a change in materials is perceived as rather less important comparing to the competitive advantage of the solution, that can achieve profitability on the long run

1.2. Introduction to the Hydro group

Hydro is an industry leader dedicated to a sustainable future. Its mission is to build more sustainable society by transforming natural resources into creative and effective products and solutions. Hydro is an energy and aluminium firm. Hydro is a major industrial corporation that develops sustainable enterprises and collaborations. It advances industries that are significant to individuals and society. Since 1905, Hydro has transformed natural resources into useful products for people and companies, while providing a safe and secure work environment for our 31,000 workers in over 140 locations and 40 countries.

Figure 1: Hydro Operations key data (Hydro Annual Report, 2021)

Hydro now owns and runs a variety of enterprises and has stakes in sustainable sectors. Hydro is present in a wide range of market categories including aluminium, energy, metal recycling, renewables, and batteries through its enterprises, bringing a unique depth of knowledge and expertise. Hydro is devoted to paving the road toward a more sustainable future by transforming natural resources into goods and solutions in an innovative and efficient manner, hence building more viable civilizations.

The main areas of operations, its inputs and outputs can be described as follows:

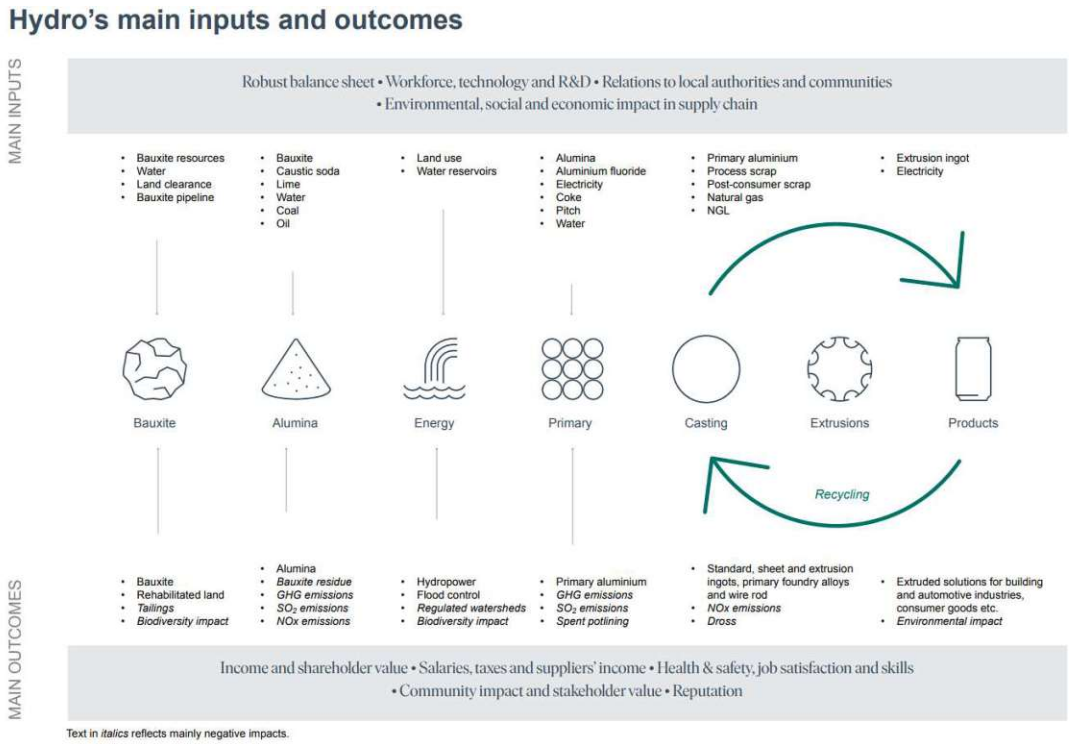


Figure 2: Operational input and outputs (Hydro Annual Report, 2021)

Hydro 2025 will put the corporation at the forefront of sectors that matter for the environment, the circular economy, and society. The primary distinction is that Hydro has a solid platform to build upon, with 115 years of experience in establishing sustainable enterprises. Thousands of engaged people worldwide in the energy and aluminium industries. In several areas, Hydro is the industry leader in terms of technology and expertise.

Hydro Extrusions, one of Hydro's major divisions, serves clients in many industries, from automotive and mass transportation to construction, electronics, offshore, and marine. In addition to supplying low-carbon solutions through the Hydro CIRCAL and Hydro REDUXA product lines, business expertise assist in the design and production of bespoke extrusions and fully fabricated components. (Norsk Hydro AS, 2022) (Norsk Hydro, 2020)

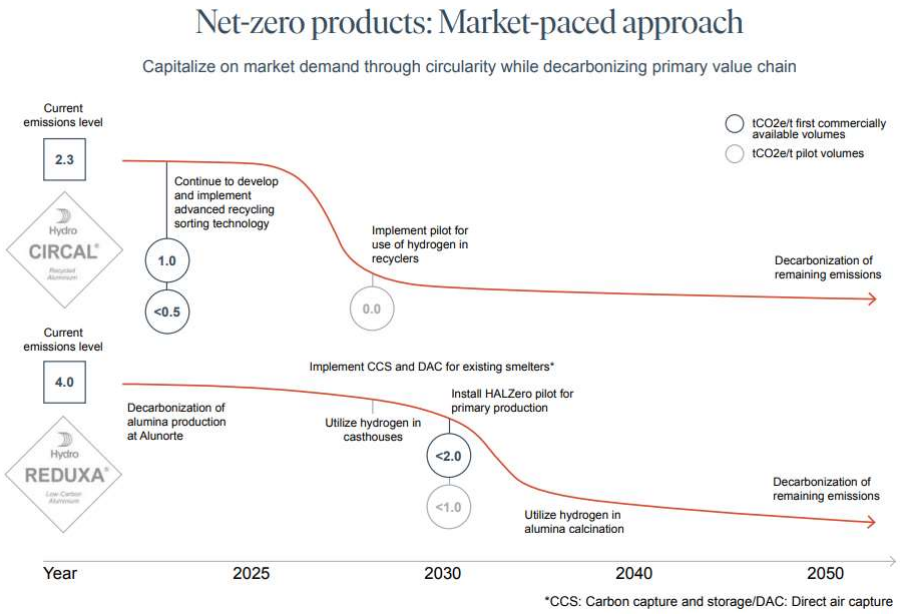


Figure 3: Low Carbon solutions by Hydro (Hydro Annual Report, 2021)

The overall strategy transposes into increase profitability and promote sustainability. The combination of aluminium derived from renewable sources and our technological advantage provides us a unique position on the market. In addition to that, the aim of the organization is to grow forward and beyond aluminium solutions, taking advantage of the skillset, that have made it achieve the position of a leader in the segment of the industry for year of its history. (Hydro A.S., 2022) (Hydro Annual Report 2021, 2022)

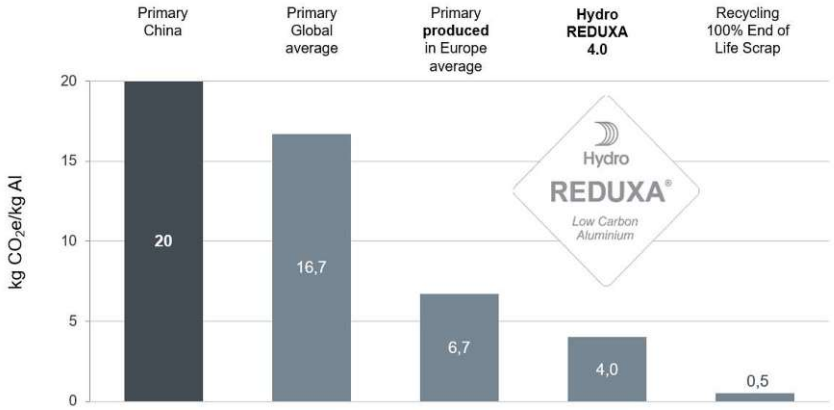


Figure 4: Aluminium Carbon Footprints by Origin (Hydro internal analyses, 2021; European averages: EAA 2018; Global average: IAI 2018; China average: IAI 2017|

But it is not only material itself that is the contributor to the sustainability. It is also the processes, from the acquisition or purchasing of input materials, thru the process of production, until the process of delivery of the solution to the customer. A more and

more focused area for the sustainability is the sourcing of different kind of resources that makes the production possible. Below, an example of impact on the emissions to air, when comparing different kind of energy that has been used.

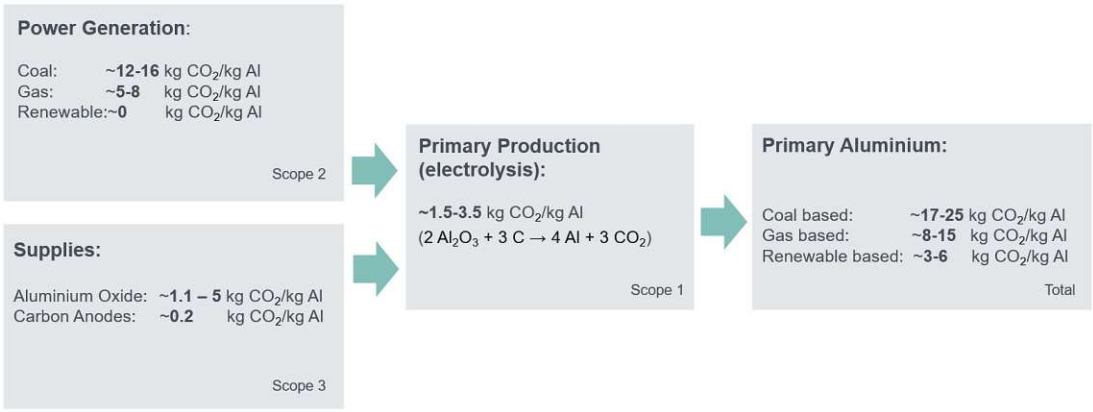


Figure 5: Carbon Footprint of Primary Aluminium (Hydro Sustainability Road, 2021)

When looking at the different factors that influence the total carbon footprint of the materials, the type of energy that has been engaged for the production process is decisive.

1.3. Introduction to Aluminium

Aluminium is a natural element in our daily life, being the third most present element in Earth's crust, after oxygen and silicon. This presence makes us understand as one of the metals that we might consider unlimited as from the perspective of availability of raw materials. Approximately 8 percent of Earth's crust consists of aluminium in the form of minerals, where Bauxite is one such mineral, with a high content of aluminium.

When comparing aluminium to other metals, we can find a vast number of benefits, mainly in area of its properties:

Weight - Aluminium has a density of 2,7 g/cm3, being this is approximately one-third of the density of steel.

Strength - Aluminium alloys have tensile strengths in the interval from 70 to 700 MPa and the ones used for extrusions are positioned in the range 150 – 300 MPa. Comparing it to different grades of the steel, aluminium will not become brittle at low temperatures, all the contrary, the strength will increase. At higher temperatures, the strength of aluminium actually decreases. When exposed to temperatures more than 100°C for prolonged periods, the strength will be influenced in the sense that the weakening has to be taken into consideration.

Malleability - The good malleability of aluminium, which is essential for extruding profiles, is also exploited for rolling into strip or foil, as well as in other bending and forming operations, hot or cold.

Machining - Aluminium is easy to machine using most methods, such as milling, drilling, cutting, punching and bending. The energy requirement during machining is relatively low.

Joining - Features that facilitate joining are often incorporated in the extruded profile. Welding like Fusion welding or the Friction Stir Welding (FSW), different types of bonding and taping are some of the used methods.

Conductivity - Aluminium is a very good conductor of electricity and heat. An aluminium conductor is about 50% lighter than the weight of a copper conductor possessing the same conductivity.

Reflectivity - Aluminium gives a very good reflection results, both for visible light and radiated heat.

Screening – generally, the better are the conditions of conductivity, the better is also the shielding property of the material. EMC Sealed alu-boxes can impede the electromagnetic radiation with high efficiency.

Barrier properties - Aluminium foil is impermeable to water, gases, odors, bacteria and light.

Corrosion resistance - Aluminium reacts with the oxygen in the air to form an extremely thin layer of oxide, just a few hundredths of a micron thick. This layer is dense and provides excellent corrosion protection. The oxide layer is self-repairing if damaged. Anodizing increases the thickness of the oxide layer and thus reinforces the natural corrosion protection. For the application in exteriors, where severe weather conditions may occur, layer thicknesses may vary between 15 - 25 µm, based and the assumed corrosion risk, or structural deterioration by external factor. One of the aluminium principal properties is its durability in neutral environment as well as in slightly acidic one. In very acidic conditions or on the opposite alkaline conditions, corrosion of the material is inevitable.

Non-magnetic material - Aluminium is para-magnetic material, therefore is widely used in magnetic resonance (MR) imaging equipment, with the aim to avoid magnetic fields interference that would occur.

Non-toxic - After oxygen and silicon, aluminium is the most common element in the Earth's crust. Aluminium is also naturally occurring in the food sources. (SAPA, 2018)

1.3.1. Introduction to Aluminium Billets and general Aluminium Extrusion

Aluminium billets are the input (raw) material for the extrusion process, and are produced directly via the continuous casting of molten metal, or then indirectly by the process of hot rolling of an ingot. The billets are usually produced from aluminium that has been added different elements, i.e. aluminium that has been alloyed. The production facility called foundry prepares recipes of raw aluminium with elements (minerals, metals,…) to achieve different compositions that form the alloys, and therefore various grades of aluminium. After the combination of the mentioned elements, the material is smelted, and consequently a cleansing of impurities that are

present is executed. The metal is then poured into casting pits, where then is applied high pressure. This is to eliminate the air that is present in form of bubbles, and to achieve the desired structure of the molecules. The result is a solid cylindrical shape. Billets can also be processed consequently to create bar stocks or wires. Summarizing, the alloys are casted in the form of billets, that are used for extrusions of e.g., automotive, transport, aerospace, industrial parts as well as different other applications like building and construction, electrical, home and furniture applications, packaging, or electronics. The very important parameter is the recyclability, as the alloys can be casted out of primary metal, but they can be also produced as secondary aluminium.

Pure aluminium is relatively soft, so if higher strength is desired or needed, this can be achieved by the already mentioned alloying or working the material in its cold status. The available aluminium on the market, used in the industry, is generally alloyed with multiple elements (see figure below).

The output of the process will consist of an alloy that will have specific characteristics and properties, that derive from the elements that has been added. Obviously, the different application of the final product will mean a specific choice of the suitable alloy.

Inside Hydro, a system of alloys identification is in place. This nomenclature has been established on an international level for already decades. More specifically, the numbering of the alloys is always containing in the very first digit the so-called family code. The family is based on the element, that is mostly present in the alloy. The European standard uses the same codes.

Alloying element	Alloy code	Alloy type
Pure aluminium	1000 series	Non-hardenable
Copper	2000 series	Hardenable
Manganese	3000 series	Non-hardenable
Silicon	4000 series	Non-hardenable
Magnesium	5000 series	Non-hardenable
Magnesium + silicon	6000 series	Hardenable
Zinc	7000 series	Hardenable
Other alloying elements	8000 series	

Figure 6: Alloy coding, Internal materials Hydro A.S.

Extrusion as such can be explained as a process of giving a specific shape to the material that is extruded from (i.e. the raw material). The primary (or remelted) aluminium billet is heated up in a billet oven to a temperature of 400 - 500 °C, making the structural grid of the material softer, allowing further pushing through a form (called extrusion die, see figure below). The form possesses the customer required shape. This die has to be also heated to a similar temperature, otherwise the temperature differences of the materials could result in cracks. Extruded material exits from the extrusion press as elongated piece of this shape. (Bonnell Aluminium, 2022)

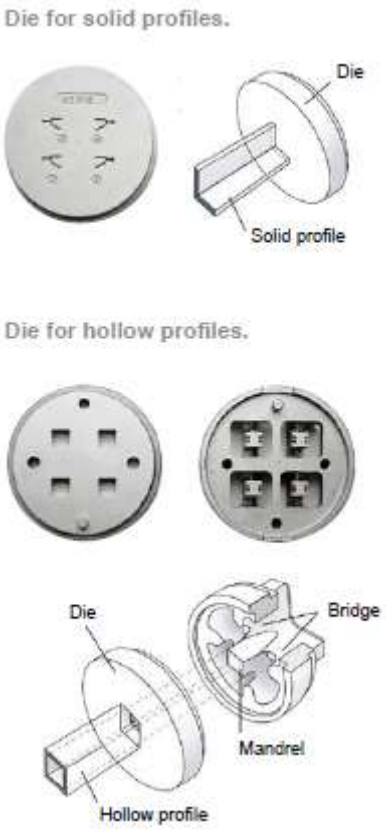


Figure 7: Extrusion tooling types – flat and hollow dies (Hydro Design Manual, 2021).

The profile itself is consequently cooled down by air or water quench on the runout table, and after that stretched to a straight form, relieving all of its internal material stress. The last operation is then final cutting, that is normally then followed by the ageing, i.e. heat treatment in an ageing furnace at the level 180 °C– 220 °C for several hours to achieve desired mechanical properties (like Yield strength and Elongation) (MatalCo Inc., 2022)

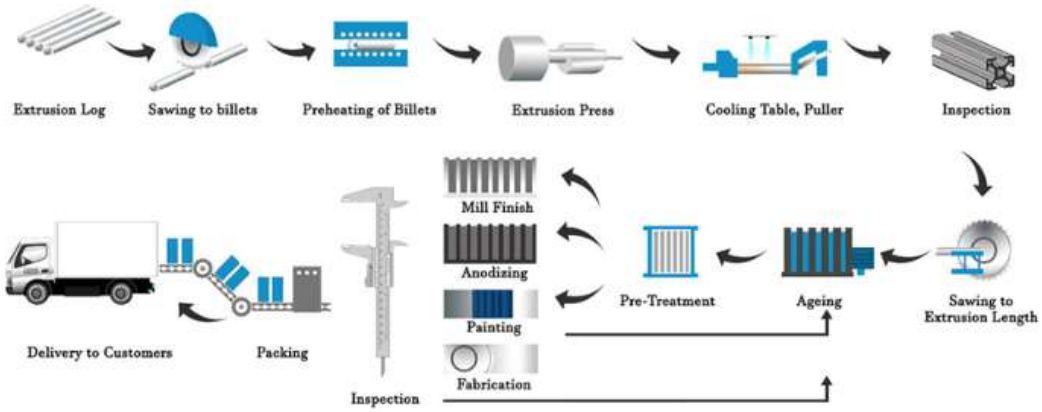


Figure 8: The process of Aluminium Extrusions (Mataluminium, www.mataluminium.com, 2022)

1.3.2. Aluminium Extrusions in the Automotive Segment

Aluminium is found in many solutions, ranging from new concepts for fish farming to next generation electrical infrastructure. And it is also increasingly being used in many of the new applications that are now found in vehicles.

Aluminium is long lasting, particularly because of its anti-corrosive capabilities. Because of this fact, it is natural that around 75% of overall aluminium that has been manufactured so far is still in utilization. This number is far lower for other materials. Aluminium is in fact one of the few materials that can be infinitely recycled without losing quality. The production of the primary aluminium is very energy intensive, while the process of recycling it consuming energy only in a fraction. In Hydro there several recycling plants with highly advanced sorting and remelting technology. The effect is that we only use 5% of the energy when we recycle it, compared to what it takes to produce primary aluminium. And what is positive to note is that more than 90% of the aluminium is being recycled in the automotive industry.

Car producers currently use aluminium in a wide range of semi-finished and fabricated components made from both foundry alloys, sheets and extrusions.

When it comes to aluminium extrusions, an increasing trend in the penetration of the content is happening throughout the whole portfolio of vehicle classes as described below

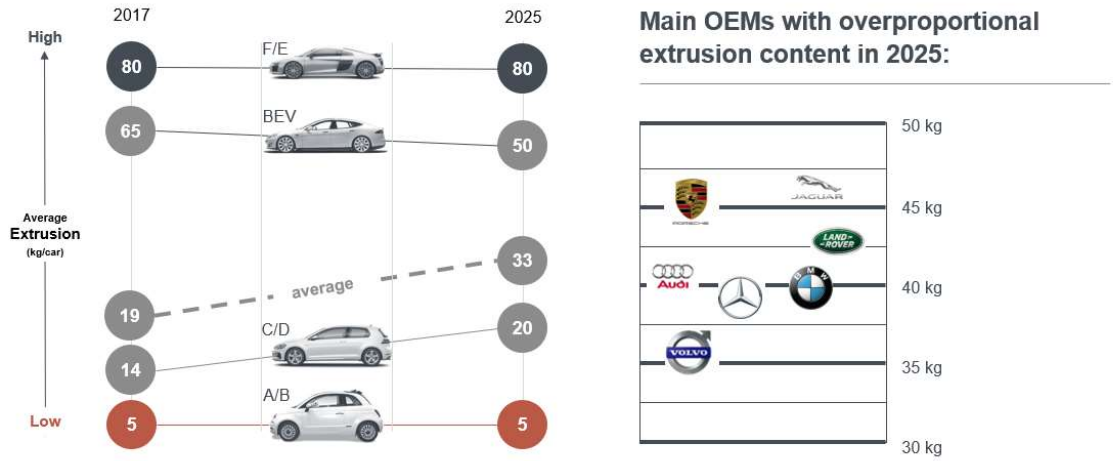


Figure 9: Aluminium extrusion content penetration within classes of vehicle (Hydro Automotive presentation, 2021)

It is observed that the new electrical vehicles that are now hitting the road are changing the car industry; both from material selection, design and production standpoints, but also how the cars are being used. The current applications of aluminium commonly used in cars are

- Body and closures
- Crash management systems
- Front and rear subframes
- Suspension parts, axle links and wheels
- Powertrain
- Heat transfer applications and heat shields
- Battery packs, battery cooling and cables
- Interior, dashboard and decoration

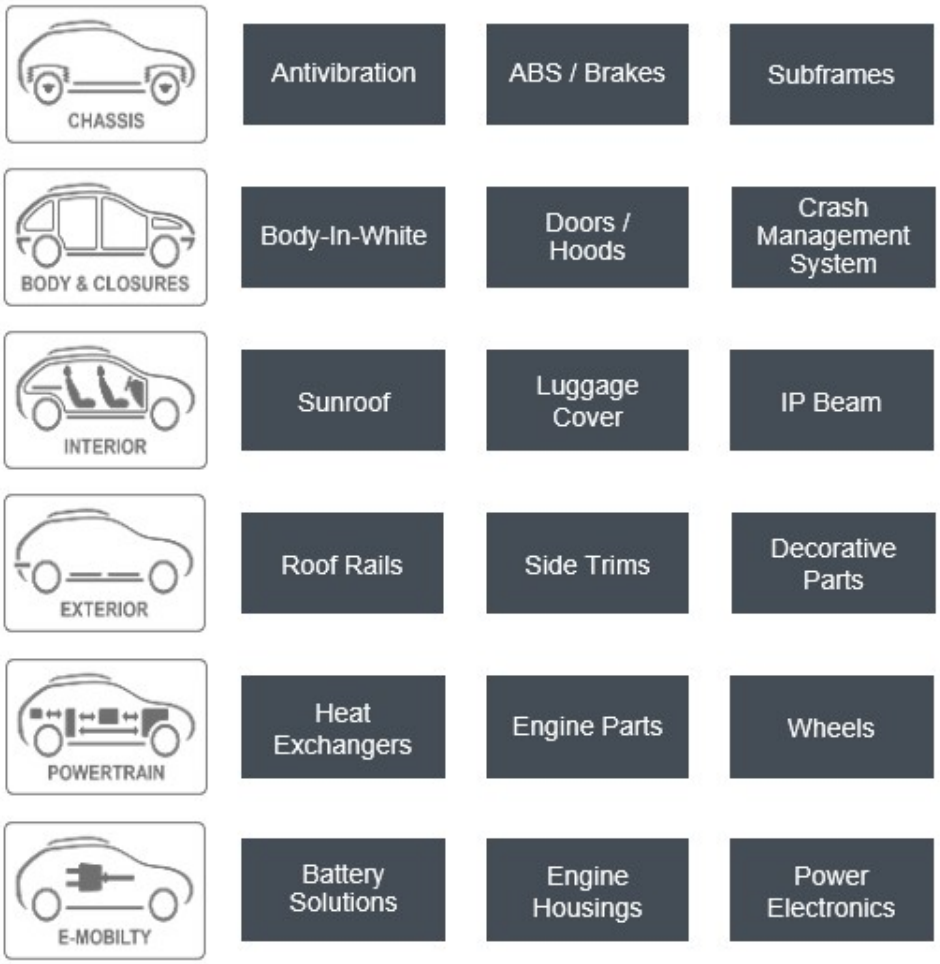


Figure 10: Applications categories and Product types in Automotive Extrusions (Hydro Automotive presentation, 2021)

1.4. Challenges faced in the automotive industry

It is evident that the majority of original equipment manufacturers (OEMs) prioritize sustainability. Reducing tailpipe emissions has been a priority for a long time, especially since governments have mandated extremely stringent emission reduction objectives for new automobiles. Currently, there is a heightened focus on decreasing the carbon footprint across the lifetime of a vehicle, and a number of OEMs have established life cycle specific goals.

To achieve these aggressive goals, a strategy of light weighting and focusing on less classic combustion engine vehicles will be required. A good example of approach is by Jaguar Land Rover (JLR), Volvo Cars and BMW companies. JLR has reduced CO2 emissions per vehicle by 50 percent since 2007 and target CO2 reduction further by 26 percent by using low carbon aluminium. Volvo Cars target to reduce carbon footprint in life cycle of vehicle by 40 percent by 2025 and become climate neutral by 2040. BMW Group has reduced CO2 emissions in the European fleet by 50 percent from 1995 and focus on the full life cycle carbon footprint in all new model development. (JLR, 2020) (Volvo Cars, 2020) (BMW Group, 2020)

One of the solutions to the reduction of the CO2 emissions is the path of the electric vehicle production, where is forecasted a very strong growth. There are varying forecasts for how fast this segment will grow, but what is evident is that these cars will continue to seize market share in the coming years. This is of course influenced by the focused innovation on this segment from all car manufacturers.

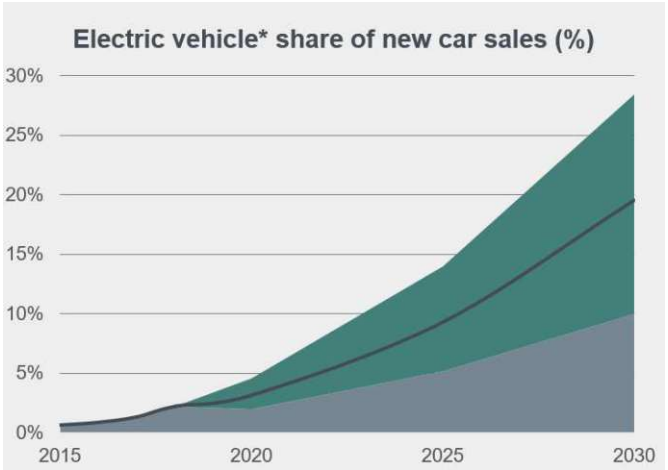


Figure 11: Forecast on Sales of electric and plug-in-hybrid vehicles (Hydro analysis, 2021; CRU International 2021)

In parallel to the electrification trend it is seen that the light weighting trend is continuing. One of the most well-known high volumes representatives of light weighting is the Ford-F150. By switching from steel to aluminium it was possible to reduce weight by over 300 kg.

The increasing use of aluminium is observed in many different applications and many OEMs introduce aluminium in models that have previously been based on steel. This has the effect that by 2025 the average aluminium content in European cars is expected to increase from 179 kg average to 199 kg. (DruckerFrontier, 2022)

The reason for the growth in aluminium usage, is that EVs typically have a significantly higher aluminium content. This is what is already applied when looking at current models, such as the BMW i3 or the Audi e-tron. There is a clear correlation; when EV volumes are increasing then aluminium usage follows.

Figure 12: Aluminium content in 2 specific vehicles (DuckerFrontier, European aluminium, 2019)

Light weighting is also a matter that is also applicable in the segment of electric vehicles, as these vehicles have large and heavy battery packs, especially in full electric vehicles. This is something that puts higher demand on the body structure as both passengers and batteries need to be kept safe in case of crash. Aluminium is

often used in these structures as it allows combining low weight and good strength and crash performance.

In electric vehicles there is also the additional need for more advanced thermal solutions, and due to it's suitable material properties aluminium is often used in these particular applications.

1.5. Trends to define the future of Aluminium Extrusion applications within the Automotive Industry

A- *Aluminium is the material used in the automotive sector, that grows with the highest pace compared to other materials*.

In a research commissioned by European Aluminium's Automotive & Transport Board, a projection by DuckerFrontier indicates that the number of used aluminium semis in the automobile production would grow by around 10 percent by 2025, from 179 kilograms now to roughly 200 kilograms.

Even if casting content is decreased due to the downsizing of internal combustion engines and the elimination of castings in the case of electrification, more than half of the volume will still remain in the form of aluminium castings. The utilization of rolled aluminium elements and extruded aluminium components will increase. The latter is anticipated to increase to around 33 kg per each automobile (approximately 27 kgs per vehicle in net). In percentage terms, extrusion content will increase the greatest.

Due to Ducker's reliance on LMC Automotive's study, this estimate may be conservative. This includes the EU-28, but excludes Turkey. (LMC AUTO, 2022)

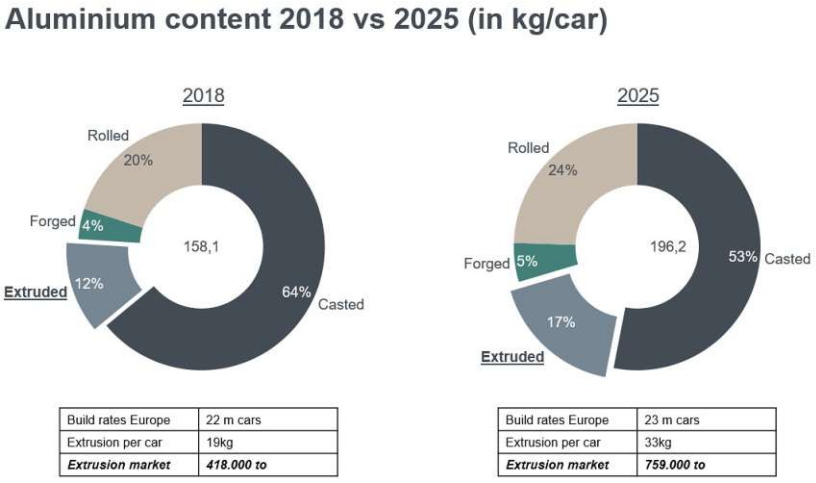


Figure 13: General aluminium content in a vehicle in EU (DuckerFrontier, European aluminium 2019)

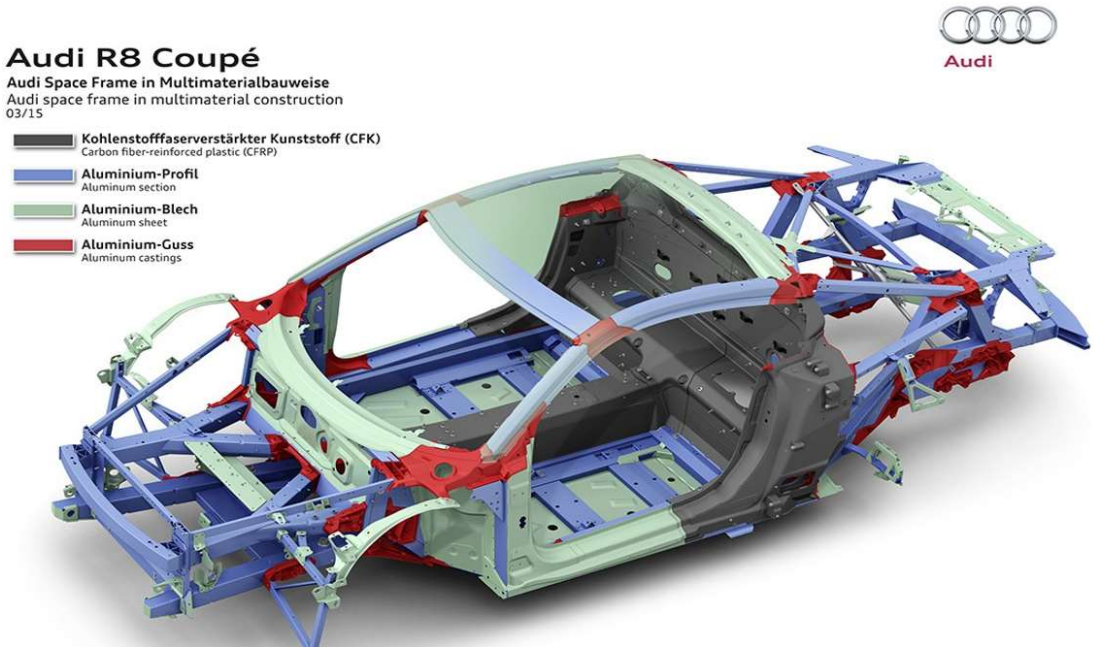


Figure 14: Example of Audi space frame with Aluminium Applications /extrusion in blue/ (Internal materials of Slovak Academy of Science, 2020)

B- *European automobile manufacturers will struggle to meet CO2 emission standards.*

According to the data in Ducker's 2019 report for European Aluminium, the European automakers are far from fulfilling their carbon dioxide emissions goals. They may even have to perform miracles.

Why? Due to the fact, that the average emissions from new automobile registrations rose from 119 grams per kilometer in 2017 to 121 grams per kilometer in 2018. The mentioned weight gain was influenced by increased sales of Sport Utility Vehicles, implementation delays of new technology, and increasing of sales of vehicles that are using diesel as fuel.

According to their 2020/21 goal, manufacturers must cut this value by 21 percent to 95 g/km. These objectives are not becoming any simpler. The European Commission toughened its passenger car CO2 emissions regulation for 2025 and 2030. They can be summarized as follows; a 15% decrease in 2025 (relative to 2021) and a total 37.5% decrease in 2030 (again relative to 2021). This is advantageous for aluminium because to the material's low weight, rigidity, and high strength.

The penalization of every gram that is over the limitation is set to 95€. This value will be multiplying the number of units sold over the year. Using the example of VW group without the premium brands, if the car manufacturers generally have a 3-4% profit margin on a vehicle (ranging nominally from 250€ to 3000€ per unit), the maximum overpass of the limit would be 32 grams, to achieve the break even point.

The main advantages of the usage of aluminium alloys are therefore:

- Low density (use of Al can result in ~300 kg weight savings for middle size car 1400 kg - ~20%)
- Excellent corrosion resistance
- High strength (energy absorption performance)
- Technological advantages (better handling, castability, extrudability)
- Excellent recyclability (95% of Al is recycled, about 50% of recycled Al is again used in cars)
- Cost of part from recycled Al ~ 26% of cost of the same part from primary Al

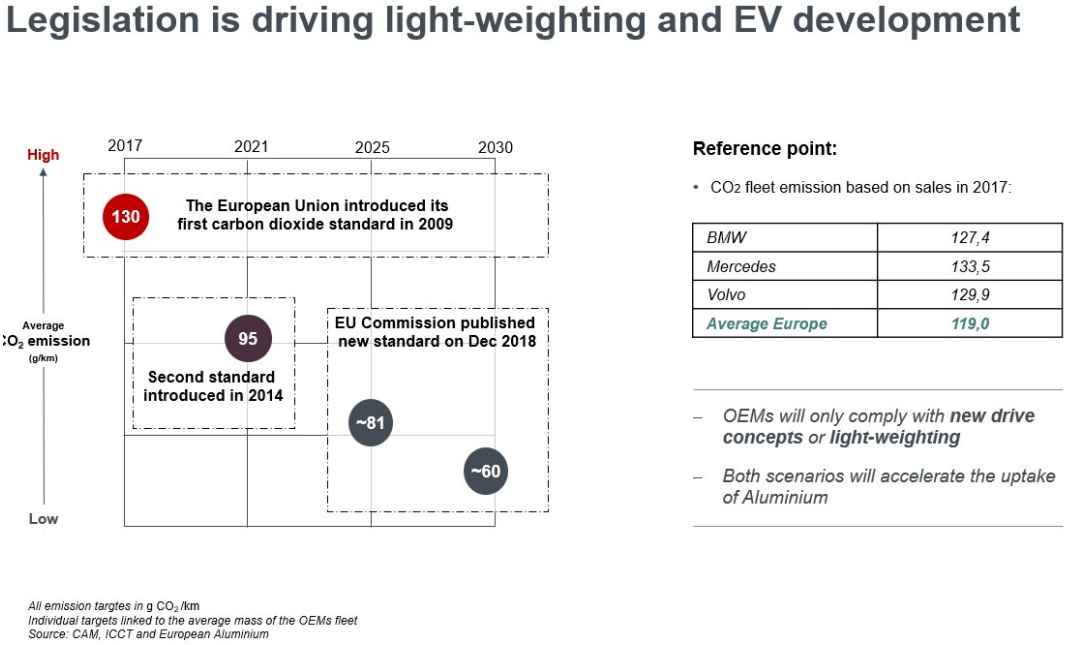


Figure 15: Emission limits on vehicles (CAM, ICCT, European Aluminium 2021)

Furthermore, the light-weighting is long term battle against the constantly raising total weight of vehicles. Looking on an example of the compact segment, like the 30X series from Peugeot fleet, we can observe a 37% increase of weight over a time span of 15 years.

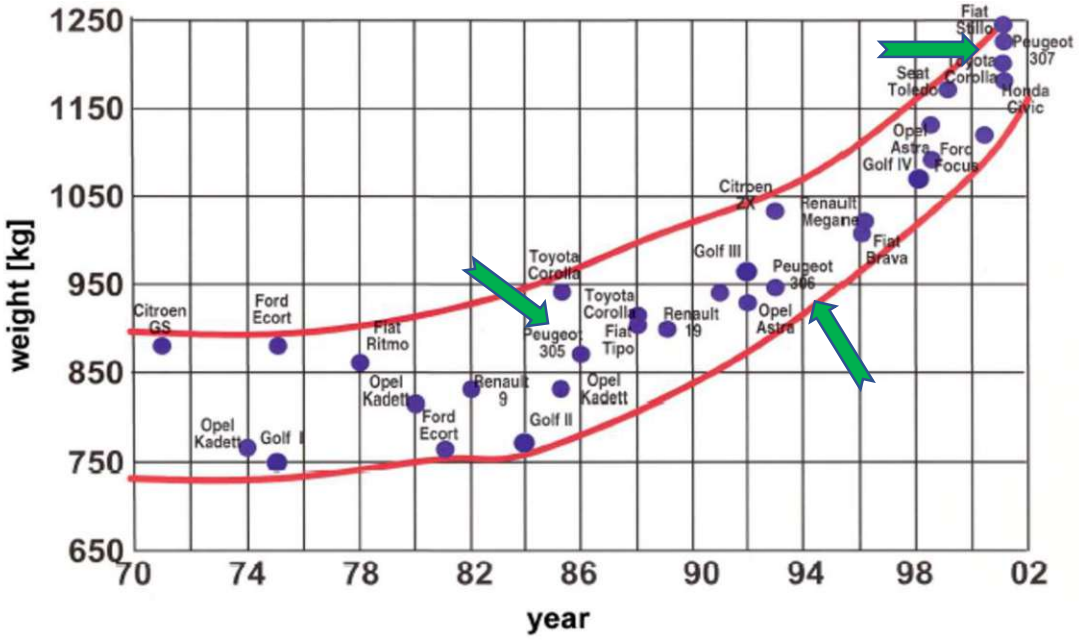


Figure 16: Weight evolution in a compact class car (Internal materials of Slovak Academy of Science, 2020)

The motivation for reduction is therefore clear, with the following main benefits:

- Energy savings (fuel economy) 0.6 l/100km for every 100 kg weight saving
- Reduced environmental impact (~3000 l fuel savings in the lifetime; ~20% reduction of emissions)
- Increased safety and reliability (higher stiffness, crash performance, reduced brake distance, better acceleration)
- Increased comfort (more volume, enhanced space for accessories)

C- *The demand for aluminium with low carbon content will rise*

European regulators are requiring significant reductions in CO2 emissions from automakers during the utilization of the vehicle fleets, prompting OEMs to replace more fossil fuel-powered vehicles with electric vehicles. This, consequently, will have an effect on how the OEMs choose the materials for their automobiles, because zero-emission vehicles have no tailpipe emissions. There will no longer be any use-phase emissions. However, it affects where and how the aluminium, and other material for the vehicles production, are manufactured. If OEMs consider replacement, recycled or low-carbon aluminium derived from renewable resources will certainly be required.

In addition, it is important to note that the complete life-cycle CO2 footprint of electric cars remains an important challenge, despite substantial developments in the field of batteries. The expected new recycling technologies for lithium, would represent a huge advance and would have a significant influence on the life-cycle footprint. (European Aluminium Association, 2022)

To minimize production-phase emissions, automakers must increase their usage of low-carbon materials in the coming years. It is here that the aluminium is one of the clear winners for the following two reasons:

1- Weight is crucial for e-mobility performance, and aluminium provides low weight, high strength, and recyclable properties

2- Low-carbon goods minimize aluminium's carbon footprint and increase its competitiveness versus other materials.

D- Sales of zero-emission and low-emission automobiles will increase considerably in the future.

Europe has poor sales of zero-emission and low-emission cars (ZLEV). In 2018, battery-electric cars accounted for 1% of new car sales in the EU, while hybrid-electric vehicles accounted for 3.3%.

Ninety-two percent of new vehicle sales involved vehicles powered by fossil fuels.

That was yesterday, though. Tomorrow? The EU intends for ZLEVs to account for 15 percent of total sales by 2025 and 35 percent by 2030. With a target to ban the internal combustion engines from productions on 2035. (Reuters, 2022)

This fact can make one assume that not only aluminium, but specially the low-carbon aluminium, will be a fundamental material well-positioned in the manufacturing of vehicles in the upcoming future. And let's not forget that fuel cell vehicles may become an option in the future. More specifically, a substantial part of aluminium extruded products (around 40 kg per unit produced) is used for the electric engine, electronics (power), hydrogen tank and the fuel cell system itself.

In the last ten years, within the automotive industry, both production of next generation of materials, as well as the ways of its production, has been based on significant

advances. The vehicles of the past were made completely of steel, however current automakers are switching to aluminium, magnesium, and composite materials that offer superior performance. In order to accommodate these new materials, new production methods are being implemented.

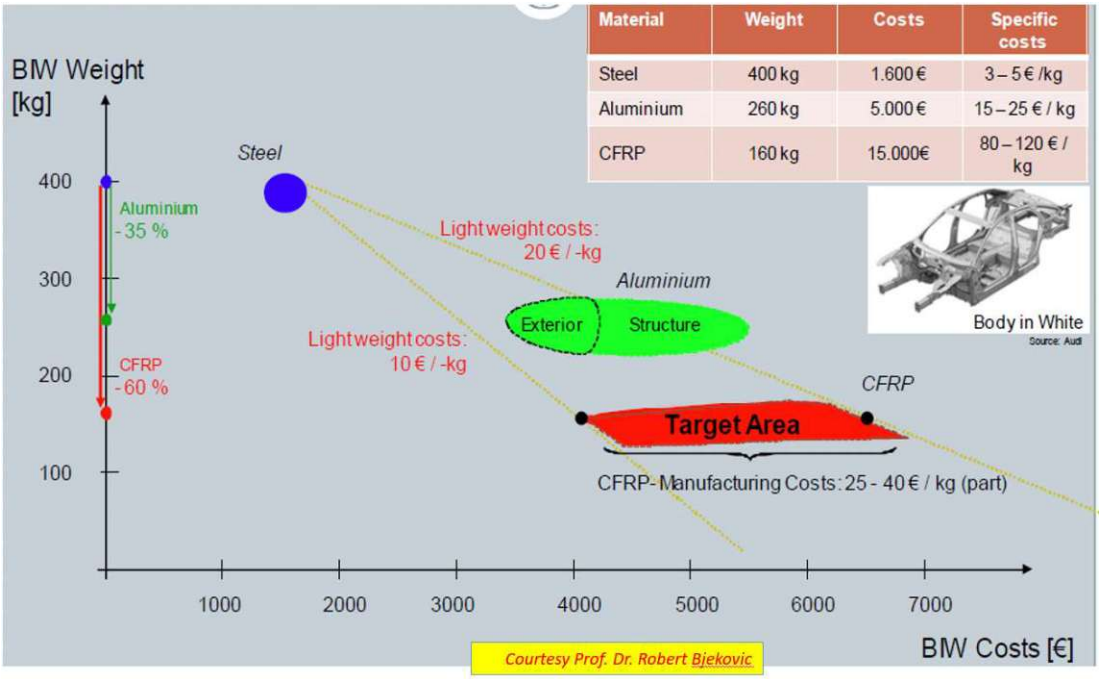


Figure 17: Relation between Body—in-White cost and weight, in Steel, Aluminium and Carbon (Internal materials of Slovak Academy of Science, 2020)

1.6. Implications of Al extrusions - summary

1.6.1. Benefits of Al extrusions

From the previous chapters it is now understood that regular aluminium extrusion has a limited area of application, mainly due to the fact that the mechanical properties are limited by the alloying elements. Still, even for the automotive industry, multiple alloys series are usable, because of the following:

A- The aluminium is 100% recyclable. This gives a top advantage when comparing to other materials, from the sustainability point of view

B- The aluminium is a great element of storage of energy. This fact brings to opposite outcomes:

- The primary metal requires huge amount of energy to be produced (which is a problem form the perspective of the cost and energy consumption), however
- The secondary (recycled) metal requires only 5% of initial energy need and therefore it represents an absolute costs advantage as well as lowest energy demand, from the sustainability perspective

C- The extruded material does not corrode nor deteriorates over time (when not affected by external factors)

D- Aluminium solutions offer lighter version to conventional materials like steel. The light weighting perspective has a direct and an indirect impact:

- Direct – lighter components influence the overall vehicle weight that directly impact the consumption of fuel, which at the end means cost effectiveness on running costs. This also represents sustainability approach when thinking about the scarcity of energy sources.
- Indirect – lower consumption means lower emission of CO2 which is strictly regulated and penalized in EU. This means also cost control over the fleet of the OEMs, which if violated, means that the final customers would be paying more when purchasing such vehicles (see previous chapters)

1.6.2. Constrains of Al extrusions

As mentioned before, there are also limitations that are connected to the aluminium extrusion solutions. The main consist in:

A- Energy requirements for producing the primary aluminium billets

B- The quality (levels of added elements) of the secondary recycled materials, that often represent an issue for the high demand application in the automotive segment (because they can affect the properties)

C- The limitations in the properties (see figure below), some of these are not allowing any influence now matter how we add alloying elements

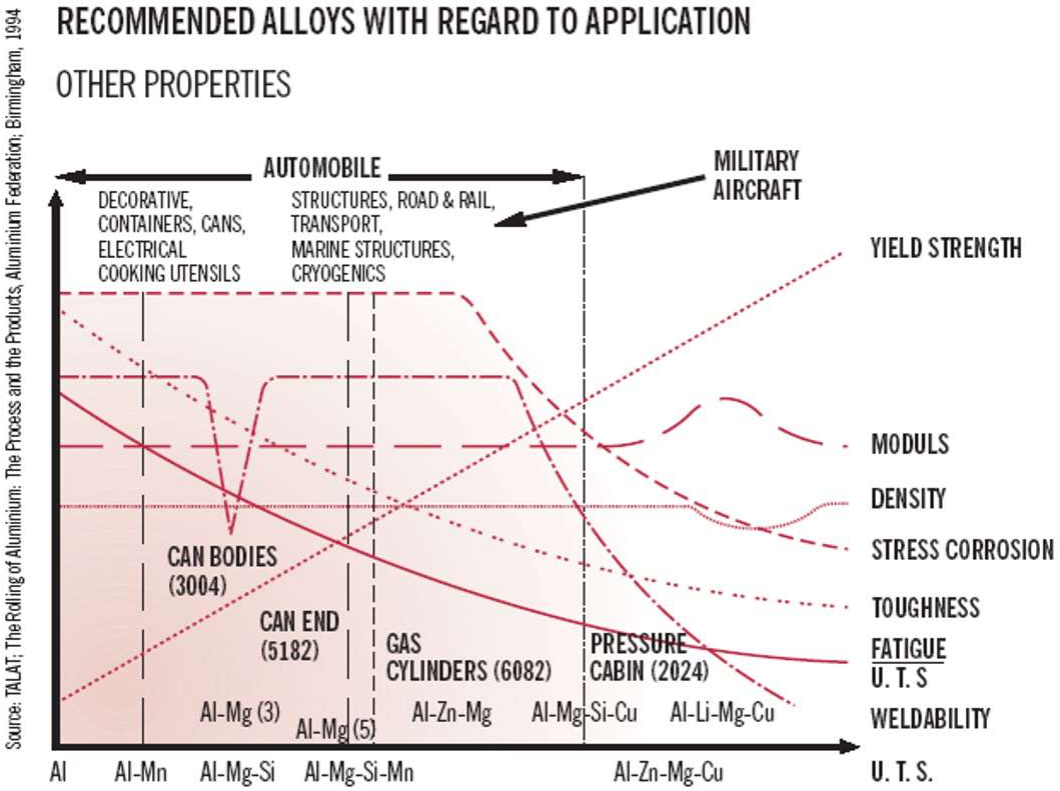


Figure 18: Relation of Alloys properties and their composition (TALAT, The Rolling of Aluminium: The Process and The Products, Aluminium Federation, Birmingham, 1994)

To overcome these constrains, a new approach has to be developed, as the customers do require more and more better material properties on solutions that must be lighter. A way out of this contradictory status, can be the application of next generation powder materials in aluminium extrusions, which is described in the next chapter.

2. KNOWLEDGE BASE ON PROGRESSIVE MATERIALS IN ALUMINIUM EXTRUSIONS

2.1. Definition of progressive materials

The development of progressively stronger materials is necessary to meet the rising demand for lighter aeronautical and automotive components. Aluminium alloys reinforced with different particles (composite materials) have been created for weight-critical applications due to their low density, and they have a higher specific strength than the primary matrix material. On one hand, the specific strength can be noticeably improved as well as the wear resistance. On the other hand, the ductility of such material is significantly lower during the process of adding the reinforcing particles to the main powder (Chelladurai, et al., 2020). The limited ductility and manufacturing issues of aluminium matrix composites (AMC) hinder their wider.

In AMCs, many reinforcing particles have been tested as reinforcing media. The most prevalent reinforcing particles are SiC, Al2O3, AlN, and TiC. In order to increase and improve the properties of the structure (i.e. improve microstructure, strength, hardness, density or resistance to wearing), various ratios of reinforcing particles are added and tested in the production processes like extrusion or isostatic pressing (CIP), or, these elements can be also mixed with base aluminium before the powder Compactation. (Amirkhanlou & Ji, 2020)

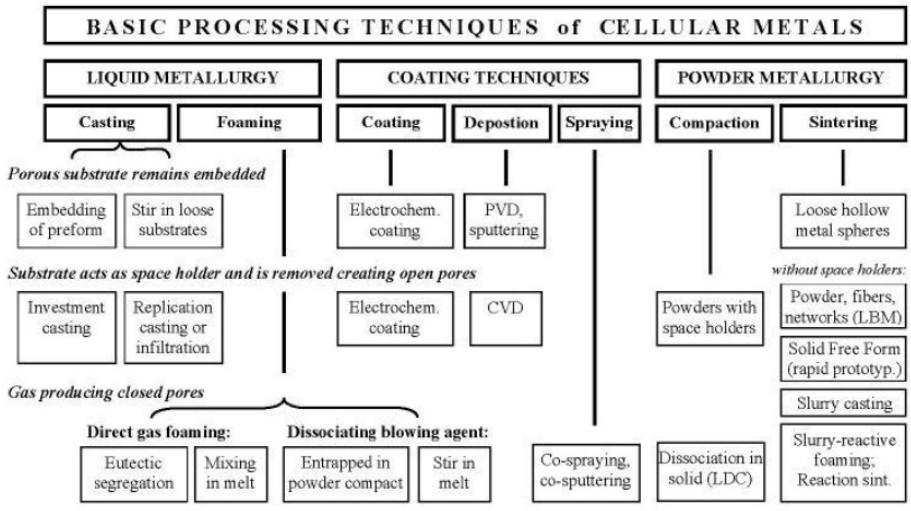


Figure 19: powder metallurgy within cellular metals (Critical Reviews in Solid State and Materials Sciences, vol 45, 2022)

2.2. Difference in the production of the raw material

The complexity difference between the processes can be simply described with the following scheme

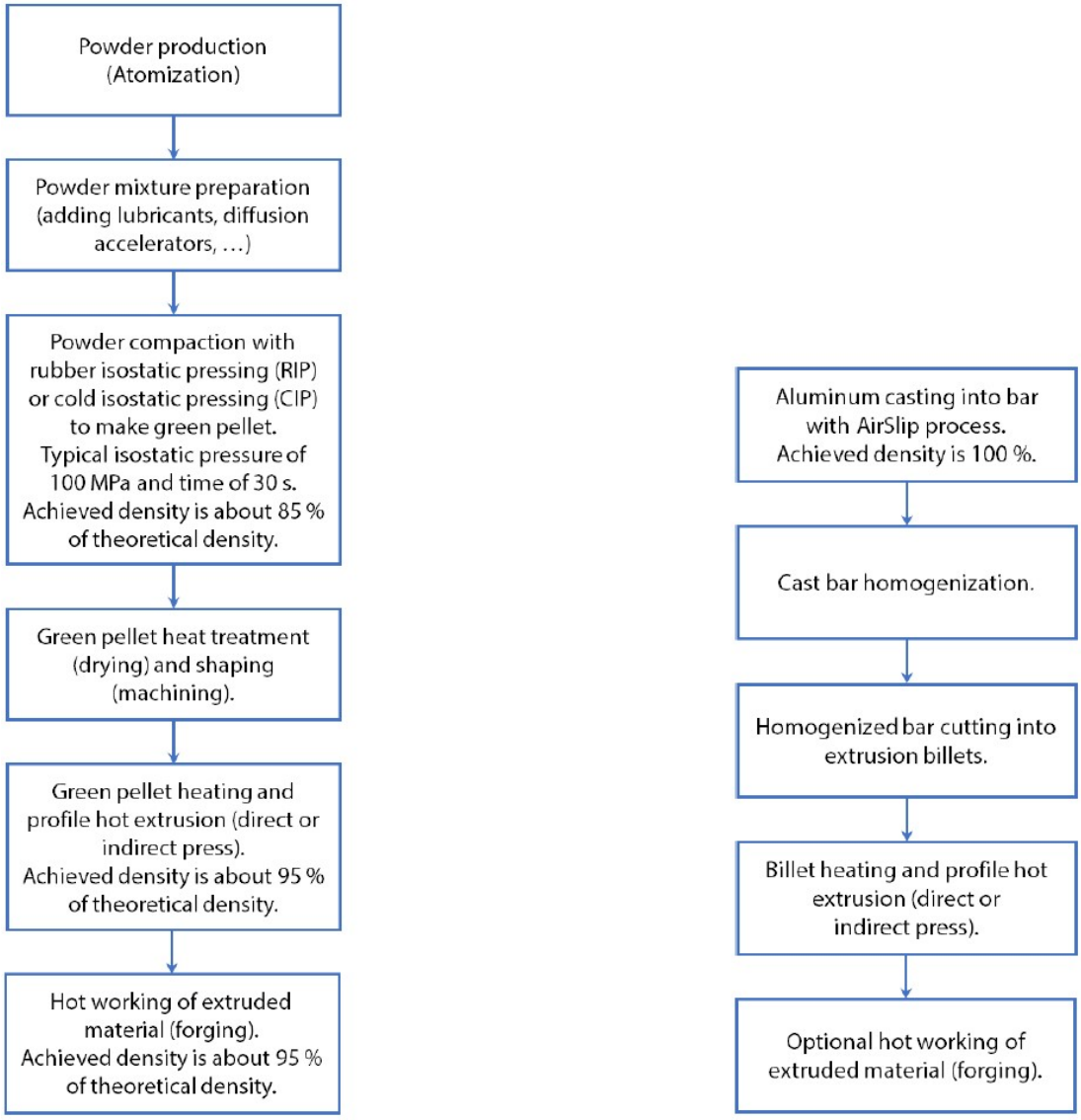


Figure 20: Production process of raw material followed by the extrusion of profile, comparing Powder Extrusions (left) and regular Casted extrusions ((Critical Reviews in Solid State and Materials Sciences, vol 45, 2022)

Mechanical Properties of the Extruded Material

For a general understanding, a comparison of the he mechanical properties of regularly extruded aluminium alloys and powder materials is presented below. The powder material is represented by Al 1080 and the regular alloy by AA 1050. Both materials are showing values right after the extrusion (direct or indirect), and the status after extrusion and the tempering (i.e. D+T / I+T). The tempering, or also denominated as annealing, was performed for a period of 20 h at a temperature level of 300°C. Consequent to this process, after measuring, we observe a minor decreasing in the ultimate tensile strength (UTS) and in the yield stress (YTS). The top values in UTS and YTS were detected in the extrusions that were performed in the direct method. On the other hand, after measuring the ductility, in the very same sampling, the values were the lowest.

The elongation at break (or also called strain at fracture) was approximately 2,35 times higher once we compare the values between indirect and direct extrusion in both cases, with and without the annealing.

When looking at the strength (both UTS and YTS), the results of the direct extrusion show quite similar values. This significantly differs from results of the indirect extrusion, that is approaching the behaviour pattern of the regular alloy extrusion as well (i.e. there is a significant value gap between UTS and YTS) . An indirect proportionality between the strengths and the ductility is visible on the chart. (Bombac D., 2020)

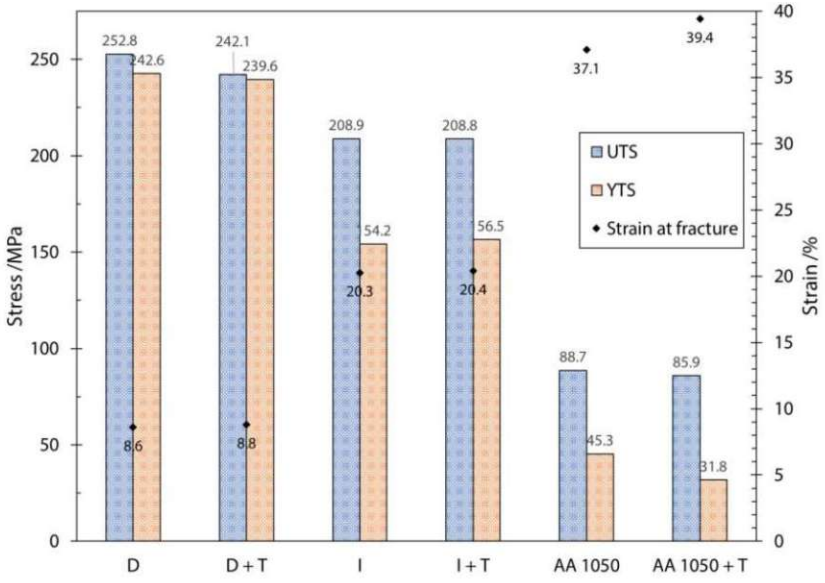


Figure 21: Mechanical properties of powder extrusion and classic casted material extrusions (Bombac & alt., In-Depth Comparison of an Industrially Extruded Powder and Ingot Al Alloys, 2020)

Main differences in extrusion of cast and powdered billets can be presented in challenges and benefits. The challenges are

- Powdered billet is always porous and less dense
- Possible reactions on the powder surfaces on heating of billets
- Low thermal conductivity of powdered billet, indirect heating necessary
- Lower strength of powdered billets – careful manipulation needed
- Backpressure at the beginning of extrusion advantageous
- For fragmentation of surface oxides and welding of powder particles is higher extrusion ratio necessary (at least 10:1)
- Powder extrusion requires higher pressing loads
- Powder extrusion is more sensitive to changes in extrusion rate
- Different thermal treatment must be applied for extruded powdered alloys, due to existence of pores and residual stresses
- Cutting of profiles is more complicated, especially when they contain hard ceramic particles

On the other hand, the requirements that are lying on the process can be then compensated by the following benefits, that are the main drivers to undergo the development of extrusion of such materials:

1. high alloying flexibility (extrusion possible also in case of hardly to extrude alloys)
2. efficient way for recycling of scrap (chips)
3. improved properties of conventional extrudable alloys (due to fine grain structure and existence of oxide dispersion)
4. new aluminium alloys for extrusion with extraordinary properties (higher content of alloying elements than solubility equilibrium, e.g. Fe, Cr, Zr, etc.)
5. Efficient ways of scrap recycling powder material (sustainable and circular with very little energy need)

6. Low density (use of Al can result in ~300 kg weight savings for middle size car 1400 kg - ~20%)
7. Excellent corrosion resistance
8. High strength (energy absorption performance)
9. Technological advantages (better handling, castability, extrudability)
10. Excellent recyclability (95% of Al is recycled, about 50% of recycled Al is again used in cars)
11. Cost of part from recycled Al ~ 26% of cost of the same part from primary Al
12. Easy way to prepare composites (novelty properties, functionality)

The introduction of the so-called powder metallurgy, where extrusion of powder billets belong is increasing into the Automotive segment thanks to the general properties advantages that were mentioned above. However, there are also unique characteristics that can be achieved in the field of aluminium powders. A good example described below, on how noise reduction is achieved of a specific components produced with these inputs.

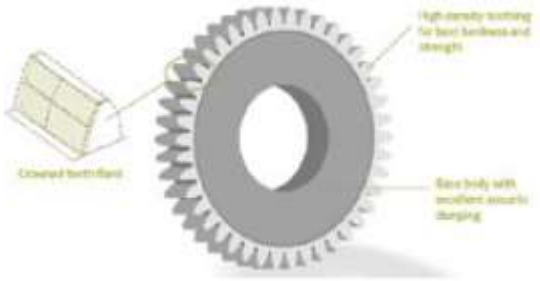


Figure 22: Gear with noise reduction capability (Powder Metallurgy Review, vol11, No 2, 2022)

A German manufacturer, The Shunk Group, producing gears for the automotive industry, has lately introduced gears that achieve much lower noises levels, specially designed for the application in e-mobility, which by default expects noise reduction in every aspect. The combination of a structurally robust and hard toothing of the gear, that reduces wearing, and the main body with superior capability of damping, achieves

a result that was previously not achievable with regular materials. The company is presenting that the structure of the used material (having certain porosity) is engaged to achieve the reduction of noise, without affecting the parameters of strength, getting to levels of materials that are normally forged. The consumption of electric energy has decreased by this solution by 60%, so also there is the positive achievement in the sustainability area. **(Inovar Communications Ltd, 2022, vol.11 No.2)**

The portfolio of all possible applications is described on below pictures

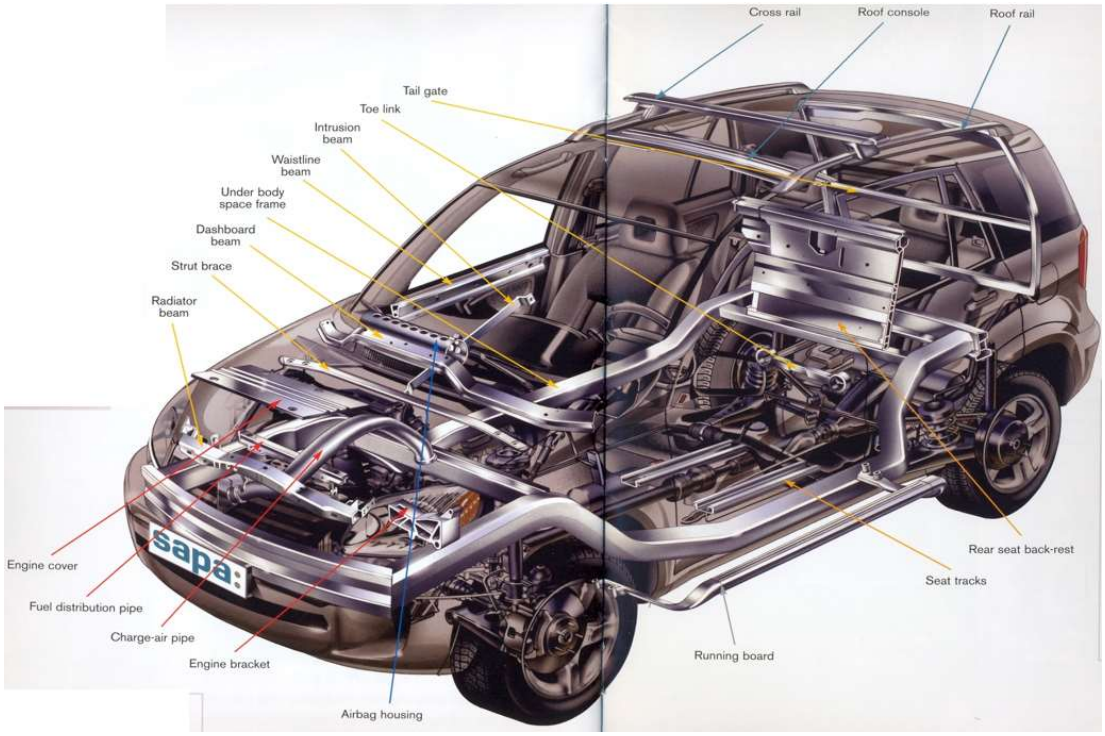


Figure 23: Potential applications for extruded Al composites (Sapa Aluminium A.S internal material, 2018)

2.3. Local research and development

The novelty of a material often requires technological background for the execution of the hypothesis brought in by the scientific work. In the case of the real life, the author is working together with the local branch of Institute of Materials and Machine Mechanics, The Slovak Academy of Sciences (Ústav materiálov a mechaniky strojov Slovenskej akadémie vied, UMMS SAV) and acting as the testing environment for the Al powder developed materials. HESK (previously Sapa Profily, a.s.) has been a solid

partner providing extrusion, machining and surface treatment by anodic oxidation, for the common projects together with UMMS SAV.

In the case of this collaboration, the utilized method to create the materials is the Cold Isostatic Compactation (refer to sub-chapter 2.1) or also called Cold Isostatic Pressing (CIP)

Figure 24: CIP technology and CIP microstructure (right) (own picture)

Figure 25: CIP extrusion billets (own picture)

Once the CIP-ed billets are available, these are before the extrusion process pre-heated in an electric furnace (natural gas would not be used due to the possibility of explosion of powder Aluminium). After heated to a level of approximately 450°C X-470°C, the billets are moved to the existing direct extrusion press, and extruded almost as any regular extrusion. **(Alumunium guide, 2022)**

The main process is indicated below

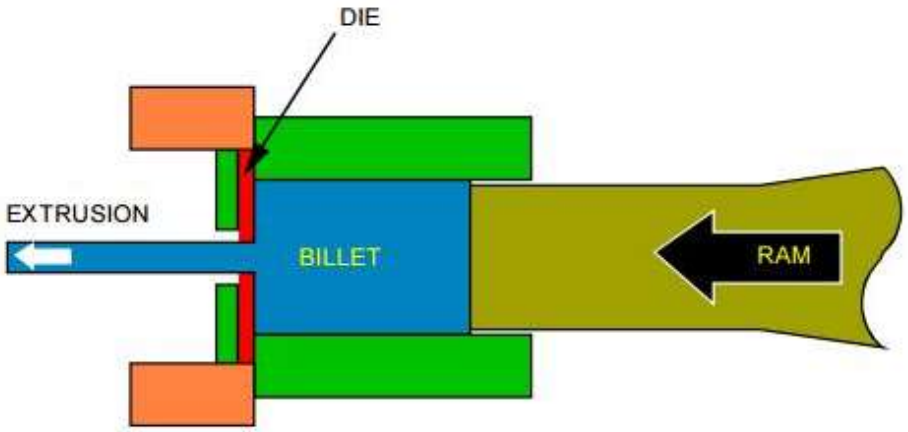


Figure 26: Direct extrusion process (Internal presentation Sapa Technology, 2018)

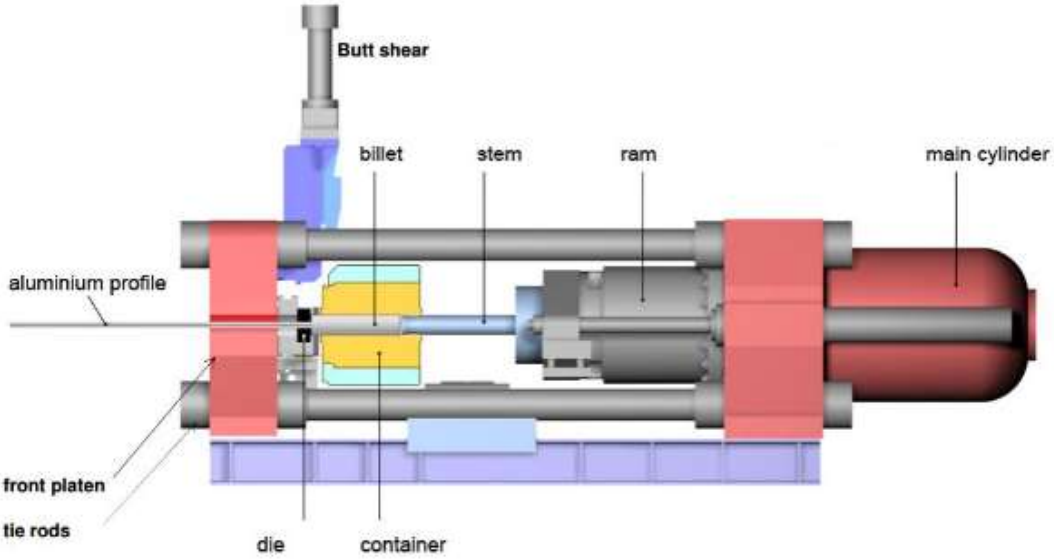


Figure 27: Example of a press for direct extrusion of aluminum alloys and certain aluminium powders (Internal presentation Sapa Technology, 2018)

Throughout the recent year, the company has extruded different type of aluminium powder compositions, into products for different application, hence for different market segments.

One that should be definitely mentioned, was the extrusion of stator profiles (subsequently cut on Fabrication department into smaller parts), for the final customer BMW, who was using these ones in the production of 3.0 diesel engines for BMW 5 series.

Figure 28: BMW 5 series diesel engine stator component (left) (own picture)

Experience from the field – confirmation case Nuclear Energy Application

The author of this thesis, aside of executing this scientific work, is in the real life confronted with a material substitution case that is worth to be mentioned. Although due to non-disclosure agreements details cannot be revealed, there is a real business case for the delivery of aluminium powder extrusions to a customer operating within the scope of Energy segment of Industry. The part of industry, that will be in the following year well on the top of the agenda, given the needs of energetic independence of Europe as a continent. The customer, experienced in the field of deliveries of products used for storage of used nuclear power inputs (i.e. waste storage management), approached the Slovak Academy of Science, to develop together a novelty material, that could be used for this application, with certain technological advantage on the product, that would imply no utilization of water in the storage process, and therefore no contamination of the mentioned water (improvement for the environment)

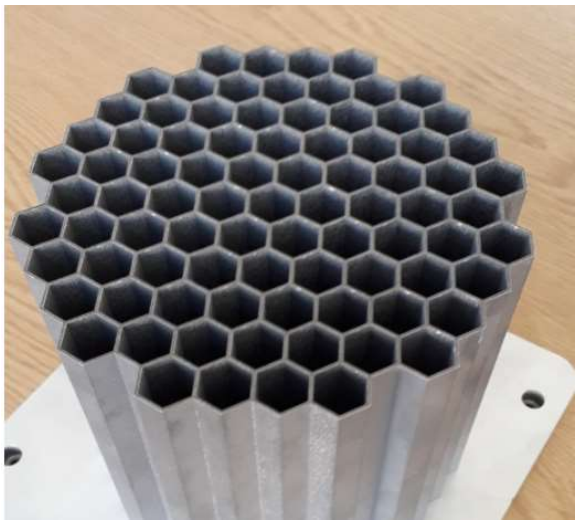


Figure 29 Miniature model of storage container for nuclear waste (own picture)

The solution that was proposed to the customer by the SAV, was to produce a prototype series of a profile shape, that could be welded by Friction Steer Welding to be able to compose a final product.

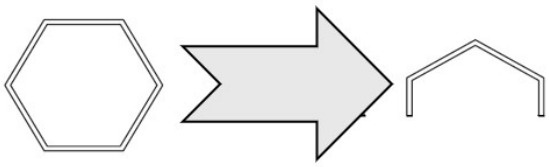


Figure 30 Proposed product shape before FSW welding (own drawing)

The extrusion took place on the existing extrusion press in HESK, utilizing AL powder billets of specific composition (according to the needs of the customer, to achieve unique shielding capabilities against radiation) that have been compacted by CIP.
The extruded profiles are consequently cut to a required length, followed by a rigorous quality check on the mechanical requirements of the customer. Also, the chemical composition is guaranteed, yet in the state of aluminium billet, as the compliance will assure the functionality of the product.

The overall experience of such projects is that this kind of developments needs resources. Not only financial coverage for purchasing special materials, but also technological changes for the equipment, as well as time resources (capacities) for technology, but mainly to the people, that posses the know how about these materials. The journey for the last 2 year has concluded with deliveries of prototypes that are to be validated in final real-world conditions. After a successful release, the door to a business that would require a similar volume but in a month, continuously for the next seven to ten years, will be opened.

New areas of the applications – foamable aluminium powders

When looking back into chapter 2.1, there is the explanation of the process of producing powder metallurgy, making reference also to the materials that after extruded can be grown into 3D shape elements thru further heat treatment. This new approach opens a completely new area of product development, as it permits the application of extruded solutions towards segments that have been provided with elements from castings. Obviously, when looking at the light weighting requirement, foamed profiles are much more favoured as they are having less density than casted solution.

A prototype of a laser beam projector housing is shown below, to demonstrate, how extruded profiles that are consequently foamed into 3D shapes, can look like

Figure 31: Laser beam projector housing from foamable AL extrusions (own picture)

It is with these above-mentioned examples that the author wants to emphasise how important the material substitution together with being sustainable is. At the end of the day, the creation of a niche segment can differentiate a company from the rest of the peers of the industry.

3. EMPIRICAL RESEARCH

3.1. Goal for the survey

For a better understanding of the possible acceptance of a new product and its parameters, the companies generally go to the market researching within targeted groups. The investigation consists in discussions with business partners from a customer's point of view, considering aspects of the product (physical requirements, quality requirements) as well as the impact from these within the whole supply chain (logistics, finance, sustainability). There are cases, where an implementation of a new product might require major change in the final product approach (production setup, application feasibility), mindset (substitution and its impact on other processes), as well as processes in different areas of the organization.

The output of the research will materialize in:

- Real time input from business partners giving the possibility of a good overview (feasibility) before the applications is applied in serial production
- Real time feedback from the final customers of the business partners, thru understanding the main drivers of possible implementation of a new next generation material

3.2. Construction of Survey

The author has constructed the Survey based on 24 questions in different areas connected to the topic of material substitution and sustainability. These areas of the questionnaire are explained more in detail in the next sections. The survey was conducted in an anonymous way and distributed thru email with a hyperlink to be able to perform it digitally, both via a mobile device or via web browser on any kind of hardware platform. For architecting of the survey in a form with the consequent data collection, the Qualtrics platform was chosen and used. The survey was initiated in mid-June 2022 and was distributed to various representatives of the customer portfolio of Hydro Group Customer, as well as members of the Automotive platform of Hydro Group (representatives from ales, project managers), being all of these related to the geographical area of Europe.

3.2.1. Survey areas

A – Customer / Business partner segmentation

In this section a general overview of the participant is gathered, focusing on questions that define the size of his mother company, its geographical location, size from the perspective of number of employees as well as the annual sales revenues. The last question completes the overall position of the customer by defining the type or area of industry within which is operating.

Q1 - What is the company annual revenue?

Q2 - What is the company size from number of employees perspective?

Q3 - What is the geographical scope of your operations?

Q4 - What is the geographical scope of your sales?

Q5 - What is the main area of your industry?

B - Sourcing segmentation

In this section, questions around the type of sourcing where asked, with aim to understand the scope of sourcing, both from the perspective of magnitude, as well as from the perspective of the main input material. There are specific questions around the current utilization of aluminium derived products.

Q6 - How many suppliers is your company using?

Q7 - What is the geographical scope of your sourcing origin?

Q8 - What is the material that you are using mostly, from the following ones?

Q9 - Are there any aluminium components used for your final product?

Q10 - If yes, what kind of aluminium components?

Q11 - What is the area of application of your aluminium components?

C – Product segmentation

The main idea behind this section is to investigate within the organization, who are the ignitors of a possible product change from a perspective of design or its material composition. Also, the individual approach or feeling of each participant is requested by questioning the feasibility of such change.

Q12 - Who is responsible for the final product design?

Q13 - Who is responsible for the final product material composition?

Q14 - Is there a possibility of material substitution in your product range?

D – Material substitution

Once speaking about the area of material substitution, various points must be taken into consideration. The internal process of acceptance or rejection of the substitution of the substitution depends for example on characteristics of the material it self in relation with the production process, on the requirements fields of the final product of final customers, on the financial feasibility, on the risk mitigation strategies on sourcing or on areas covering the sustainability aspects (like integration into the circular economy, e.g. recycling).

Q15 - What would be the triggering point for material substitution?

Q16 - What would be the main obstacle for material substitution?

Q17 - If a material is to be substituted, within what time you expect that change to materialize?

Q18 - Are you ready to "invest" into the development of a novelty material?

Q19 - If "probably yes" or "definitely yes", what would be the range of your investment compared to your revenues?

E – Sustainability

The last section is dedicated to topics around the sustainability agenda in the companies that the participants work for, what is their opinion on their own products, what are the key drivers that enable the focus on this agenda, if there is a strong demand from their customer side on the sustainability, or if the company also applies the same optics when sourcing inputs for their production.

Q20 - How you perceive your product from point of view of sustainability?

Q21 - What is the main sustainability driver for your company?

Q22 - Is the sustainability a requirement from your customers?

Q23 - Is the sustainability a requirement applied to your suppliers?

Q24 - When offering a new solution (novelty) from a sustainability point of view, what is your expectation to the price increase to your customer?

3.3. Research Analysis

3.3.1. Participants categorization

The first set of question determines that two thirds from the participants of the questionnaire were from small and mid-size companies, which was also parallelly confirmed by the size of the company from the perspective of the size thru the number of employees (61%)

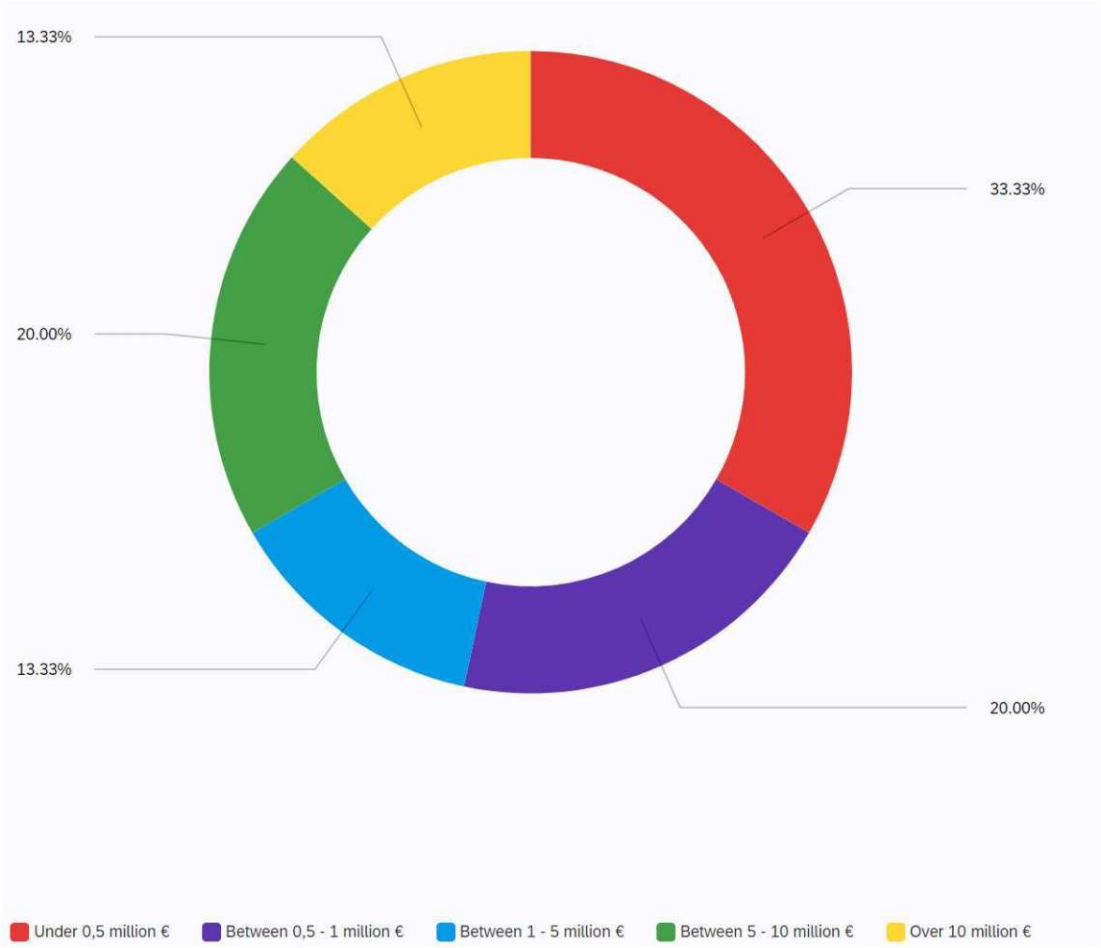


Figure 32: Distribution among participants from the Company´s Annual turnover parameter

Figure 33: Distribution among participants from the Company´s number of employees parameter

The participants were representing the different areas of their facilities location in a quite uniform distribution as shown in the picture below,

Figure 34: Where are the participants coming from (geographically)

with sales performance that is present in main areas quite uniformly, with a somewhat stronger presence in the Europe and South America

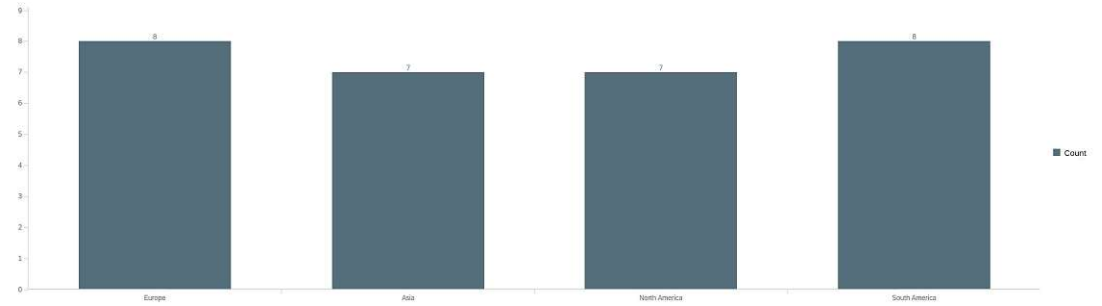
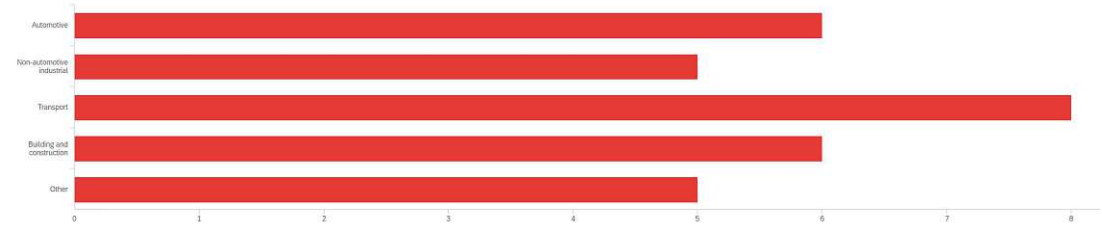


Figure 35: Main areas of sales

The last, but not least, was the segment of the industry, that the participants companies are belonging to. According to the data, we can see that the participation of automotive and transport segments top almost 50% of the participants, which is of importance for further analysis.



In general, the outcome of the first section defines an interesting group of participants and is facilitating our view on the topics of the survey, as the answers of these are related to the automotive sector from Europe, specially from small and mid-size companies.

3.3.2. Participants categorization

The answers to the question from this section shows, again, that mainly small and mid-size companies are being focused on, as almost two thirds of the participants are from companies that deal to up to one hundred suppliers, which are uniformly spread between all regions, confirming the global approach on the sourcing strategies

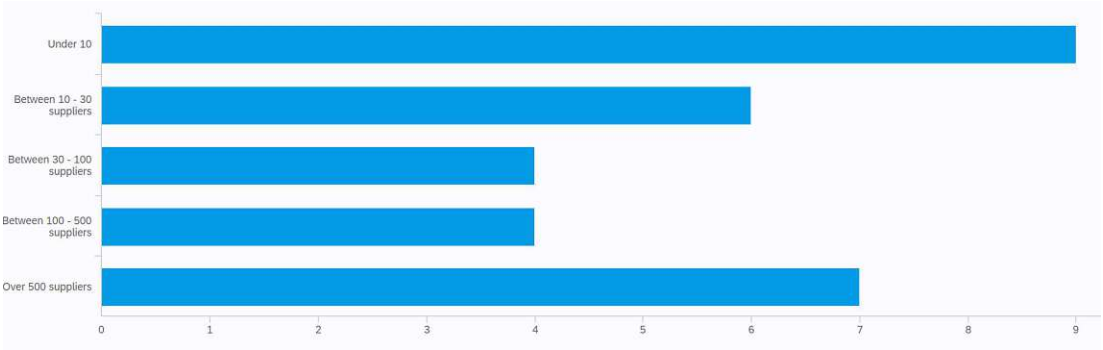


Figure 36: Number of suppliers being used

When it comes to the usage of the aluminium as an input material, and comparing it to steel, there was an even ratio. When digging into the aluminium group then, the uniform distribution was also accounted on the types of components (long length parts, machined components and welded parts). The following question has answered on what the main applications from Automotive and Transport was, that were targeted by the products of these customers. Not surprisingly, the top products comprehended Side Trims and Battery Solutions representing together every 7th product.

A closer look in the relation between the company from Automotive and Transport and the type of material that is used shows a relatively strong focus from small companies on aluminium

	Q9: What is...owing o...	
Q6: What is the main area of your industry?	Steel	Aluminium
Automotive	13,3%	26,7%
Non-automotive industrial	26,7%	6,7%
Transport	20,0%	33,3%
Building and construction	26,7%	13,3%
Other	13,3%	20,0%
Total	100,0%	100,0%

Furthermore, a link between Automotive and Transport, to the machined parts, confirms the focus of producer on Value Added components, that are often used as modules in this industry.

	Q6: What is the main area of your industry?				
Q11: If yes, w...um components?	Automotive	Non-automotive indust...	Transport	Building and construct...	Other
Machined parts	66,7%	0,0%	50,0%	16,7%	20,0%
Long lenght parts	0,0%	20,0%	37,5%	50,0%	60,0%
Various parts welded toghether	33,3%	80,0%	12,5%	33,3%	20,0%
Total	100,0%	100,0%	100,0%	100,0%	100,0%

Long length products (regular profiles) are the domain of Building and Construction segment.

Figure 37: Typical long length extrusions (own picture)

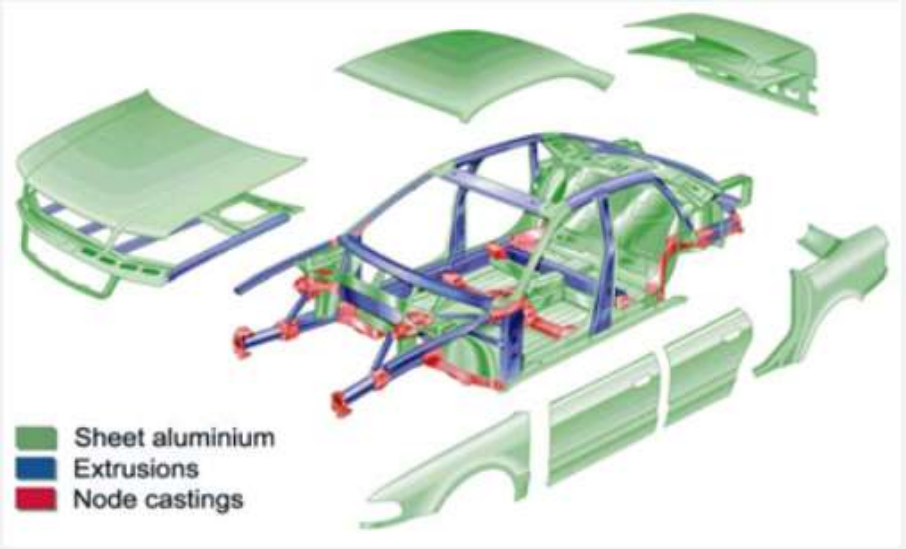


Figure 38: Typical parts from aluminium extruded components (blue) Internal materials of Slovak Academy of Science, 2020)

3.3.3. Product segmentation and behaviour

The possibility of being able to change design of an existing product or its material composition, is one of the key elements contributing to a successful material substitution case. It does not depend solely on the willingness of the supplier or customer, but more on the collaboration of both parties on the case. There can be different triggers that can enable the process of change, and there can be obstacles as well. As described below, generally smaller companies rigorously follow the specifications provided by customer, while bigger companies tend to achieve competitive advantage thru qualitative agreements that can include clauses on product design development.

	Q1: What is the company annual revenue?				
Q12: Who is...duct design?	Under 0,5 million €	Between 0,5 - 1 m...	Between 1 - 5 mill...	Between 5 - 10 mi...	Over 10 million €
Our customer (we are not allowe...	40,0%	50,0%	0,0%	33,3%	25,0%
Our customer (but we are able to...	20,0%	33,3%	75,0%	0,0%	75,0%
The design is completelyinourres...	40,0%	16,7%	25,0%	66,7%	0,0%
Total	100,0%	100,0%	100,0%	100,0%	100,0%

And even if there is not a relatively important correlation between the possibility of substitution and the ownership (responsibility) of the material composition

There is no statistically significant relationship between **Q13: Who is responsible for the final product material composition?** and **Q14: Is there a possibility of material substitution in your product range?**

Show statistical test results

Reorder/Recode | Bucketing

Q13: Who is re...l composition?	Count	Average	Median	% N
Customer is strictly demanding	9	3,11	3,00	
Customer allows materials alternatives	7	2,29	2,00	
Customer defines properties of the produc...	14	3,21	3,00	
Total (3)	30	2,97	3,00	1 2 3 4 5

There is a clear understanding that the 70% of participants are able to influence the customer in promoting a material (composition) alternative or even the responsibility of the material choice lies on the final performance requirements on the product (i.e. technical and functional properties).

Q13: Who is re...l composition?		Count	Percent	Cumu...tive
Customer is strictly demanding		9	30,0%	30,0%
Customer allows materials alternatives		7	23,3%	53,3%
Customer defines properties of the produc...		14	46,7%	100,0%
Total	0,0% 20,0% 40,0% 60,0%	30	100,0%	

3.3.4. Material substitution

Material substitution serves to assure your products' competitive advantage. Keeping the products ahead of the continuously changing demands of the clients may need material substitutes. This process of transformation demands a methodical approach. Dr. Mahmoud M. Farag, an authority in the subject of material selection, identifies the most prevalent causes of material substitution:

- Utilizing innovative materials or methods
- Improving service performance, including increased durability and dependability (reliable products)
- Complying with new legal requirements
- Consideration of fluctuating operating circumstances
- Reduction of costs and increasing product competitiveness

In general, two quantitative substitution approaches are generally presented. The first strategy, “performance/cost”, allows the designer to search for a material with comparable performance at a lower cost, or one with superior performance at a higher price. The other strategy, called “compound goal function”, allows the author to create many substitution possibilities based on the composition of different factors with various intensity scales, relating it to the prerequisite of the application need. **(M.M.Farag, 2008)**

Looking now back to the survey, this first strategy is clearly visible in the answers that appoint on the cost position advantages at almost half of the answers. Together with material properties advantages (these bringing also possibilities in cost effectiveness), these constitute cumulatively two out of three answers, meaning that the there is a strong requirement on the return of such change, once is executed.

Summary of **Q15: What would be the triggering point for material substitution?**

Sample Size	Number of Distinct Categories
30	4

Reorder/Recode | Bucketing

Q15: What w...bstitution?		Count	Percent	Cumu...tive
Material properties advantages (t...		5	16,7%	16,7%
Cost position advantages (compe...		14	46,7%	63,3%
Multi - sourcing advantage (suppl...		8	26,7%	90,0%
Recyclability advantage		3	10,0%	100,0%
Total	0,0% 20,0% 40,0% 60,0%	30	100,0%	

Interestingly, when asking about the obstacles in the material substitution, the opposites of the above-mentioned ones, i.e. material disadvantages (technical / properties related requiring for example significant process changes) or cost position disadvantage like higher price from TCO perspective, cumulate roughly 43%. It is then the additional complexity of multi sourcing together with higher administrative efforts that gets to cumulate the 75%.

Once the substitution is of interest, it is then the topic of the cost or investment that is of importance. Although the customers are tending to expect that the substitution should bring competitive advantage to their product and/or processes, it is only four out of ten that are ready to materialize the investment into a “novelty products”. This bring an interesting point of view, that a completely new product can be perceived as a rather critical element in the integration of the business activities. The existing or explored alternatives can often represent a more risk averse strategy, assuring the company of not jeopardizing with its operations and business profitability.

Summary of **Q18: Are you ready to "invest" into the development of a novelty material?**

Sample Size	Average	Median	Number of Distinct Categories
30	3,0	3	5

Reorder/Recode | Bucketing

Recode	Q18: Ar...terial?		Count	Percent	Cumu...tive
5	Definitely not		6	20,0%	20,0%
4	Probably not		7	23,3%	43,3%
3	Might or might not		5	16,7%	60,0%
2	Probably yes		6	20,0%	80,0%
1	Definitely yes		6	20,0%	100,0%
	Total	0,0% 10,0% 20,0% 30,0% 40,0%	30	100,0%	

Another perspective on the material substitution is the response time to the change requirement. Mainly in the area of “novelty” products, the speed of implementation can guarantee a major competitive advantage, that is often parallelly secured by the preservation of the title of the solution. Intellectual property rights (IPR) are considered on of the most valued assets of a company, and therefore must be protected (in different cases there are different was of solution, e.g. by patents or licences)

Summary of **Q17: If a material is to be substituted, within what time you expect that change to materialize?**

Sample Size	Number of Distinct Categories
30	4

Reorder/Recode | Bucketing

Q17: If...rialize?	Count	Percent	Cumu...tive
Under 6 months	12	40,0%	40,0%
From 6 to 12 months	6	20,0%	60,0%
From 12 to 24 months	6	20,0%	80,0%
Over 24 months	6	20,0%	100,0%
Total	30	100,0%	

It is well understandable, that the companies once successful in the process of substitution, want to materialize the return on the investment as soon as they can, preferably below two years time since the start of such change.

The overall willingness for trying out new material and/or processes also depends on the nature of the materials the companies are working mainly with. In our case, based on the years of experience, we always compare aluminium with the steel.

When thinking about the future of the material that are used from the substitution point of view together with the sustainability, it is interesting to observe that the participants that are using steel are tending more to go into a “novelty” material, which can be perceived as a switch to aluminium, as this can offer multiple advantages described in the section 1.5

Steel tends to have much higher values for **Q18: Are you ready to "invest" into the development of a novelty material?** than **Aluminium**

Hide statistical test results

Ranked T-Test (Recommended)

P-Value	0,00226
Effect Size (Cohen's d)	1,28

Show unranked T-Test results

Reorder/Recode | Bucketing

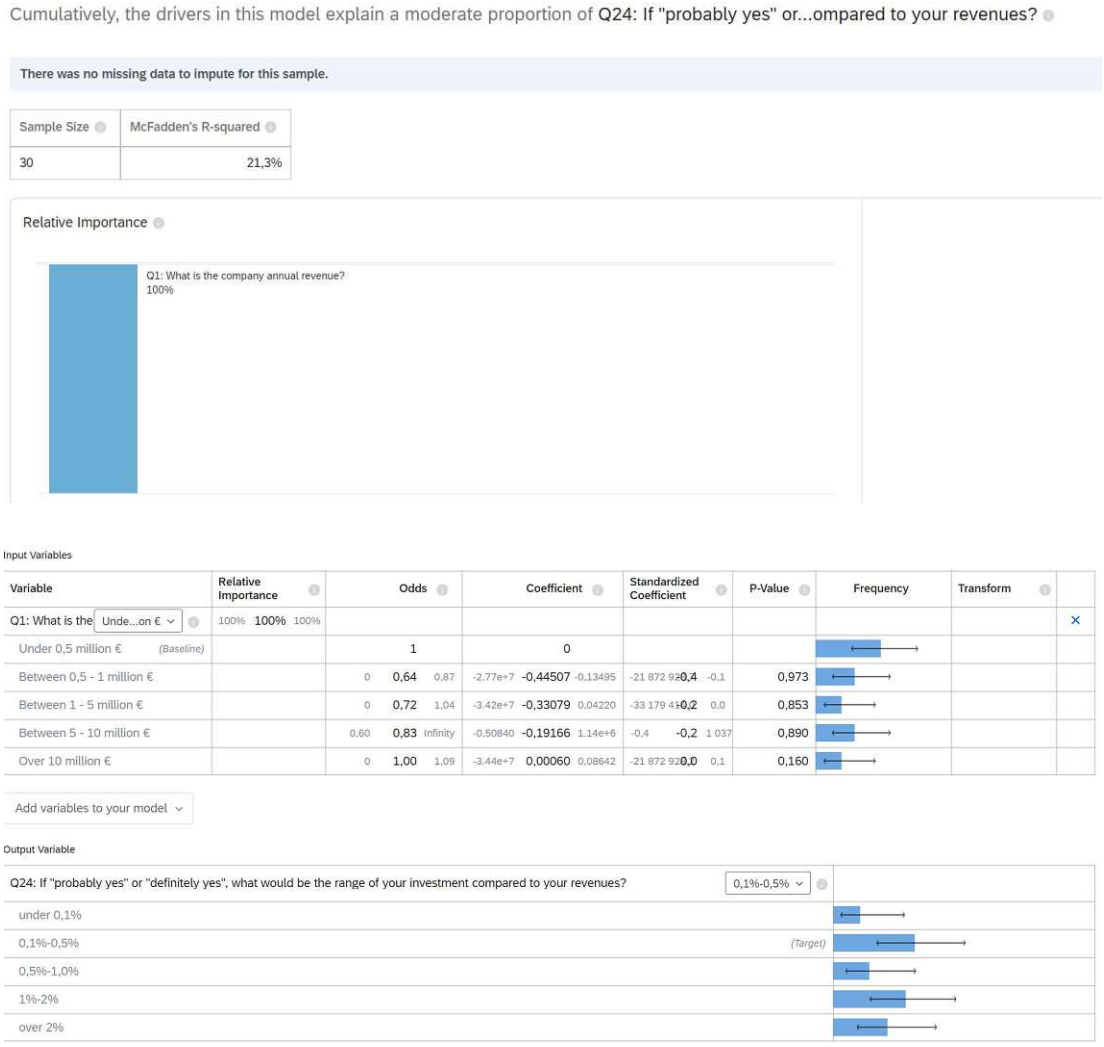
Q9:...nes?	Count	Average	Median	% | N
Steel	15	3,80	4,00	
Aluminium	15	2,27	2,00	
Total (2)	30	3,03	3,00	

The last point to be taken form the survey´s section on material substitution is the expected investment magnitude, that the companies are able to commit while seeking the already mentioned competitive advantage. As nominal values are offering a rather static and isolated information, it is always good to measure thru a dynamic value, like for instance in relation to overall sales turnover.

	Q24: If "probably yes" or "def...ent compared to your revenues?					
Q1: What is...ual revenue?	under 0,1%	0,1%-0,5%	0,5%-1,0%	1%-2%	over 2%	Total
Under 0,5 million €	33,3%	33,3%	75,0%	0,0%	50,0%	
Between 0,5 - 1 million €	33,3%	0,0%	0,0%	37,5%	33,3%	
Between 1 - 5 million €	0,0%	11,1%	25,0%	12,5%	16,7%	
Between 5 - 10 million €	33,3%	22,2%	0,0%	37,5%	0,0%	
Over 10 million €	0,0%	33,3%	0,0%	12,5%	0,0%	
Total	100,0%	100,0%	100,0%	100,0%	100,0%	

It is then clear, that the big companies rather limit themselves under the 2%, whilst in the smallest companies these strike on the opposite side of the chart.

The correlation is according to the model of a moderate strength



3.3.5. Sustainability

Definition of a product or a solution being sustainable, is, according to the Merriam-Webster Dictionary a “relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged”, or “relating to a lifestyle involving the use of sustainable methods” **(Merriam-Webster, 2022)**

As described previously in this thesis, the sustainability is addressed highly in the present business models, as the requirements are deriving from the final customer awareness and demands.

Once companies are working with aluminium, it is generally less expected that the material change would bounce back to steel solutions. It is of basic knowledge for the people of the industry, that the steel might have an initial lower requirement for energy consumption while being produced as a primary product, while compared to the energy needs of aluminium. This first plan perception however needs to be enriched by the further lifetime cycle, meaning that the aspect of recycling needs to be added. It is for the aluminium that speaks a full 100% recyclability with an extraordinary low requirement for energy consumption. It is only the 5% of the initial need of energy while producing the primary aluminium, that is needed to remelt aluminium scrap and generate a new recycled raw material. Furthermore, this process can be repeated endlessly, without literally losing any material in the process.

Looking on the replies of the participants, by the first question there was the intention to understand the perception of product sustainability or the sustainability of the production process end to end. It is very positive to observe, that only one third of the participants are lacking awareness in this field, which is a good starting point for further development.

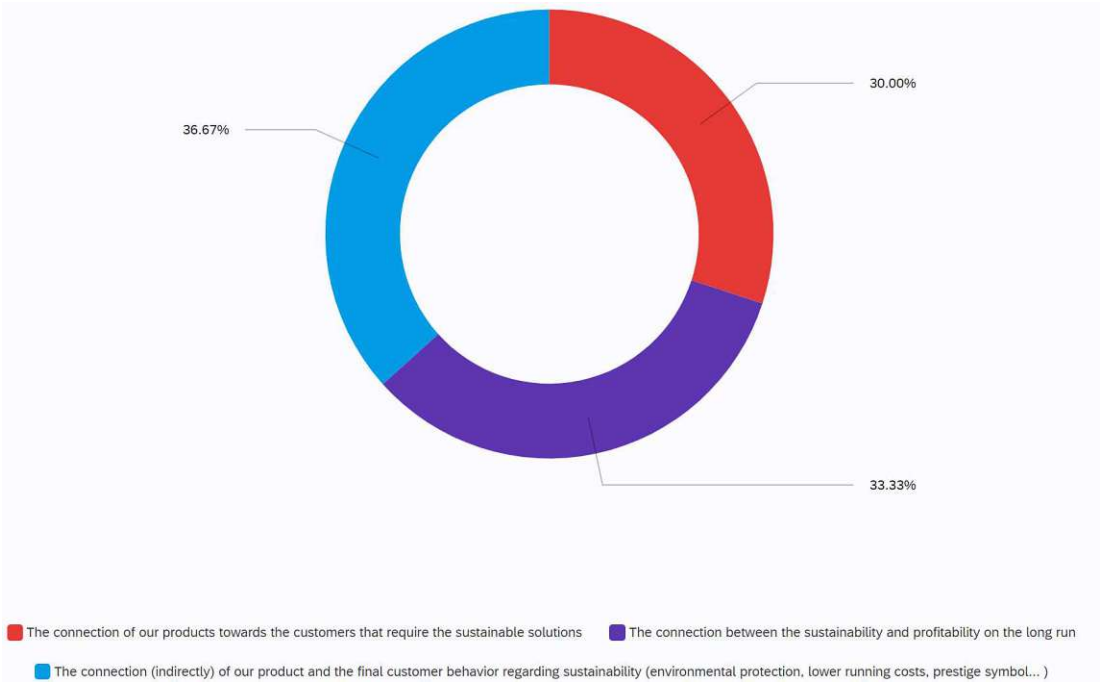
Summary of **Q17: How you perceive your product from point of view of sustainability?**

Sample Size	Number of Distinct Categories
30	3

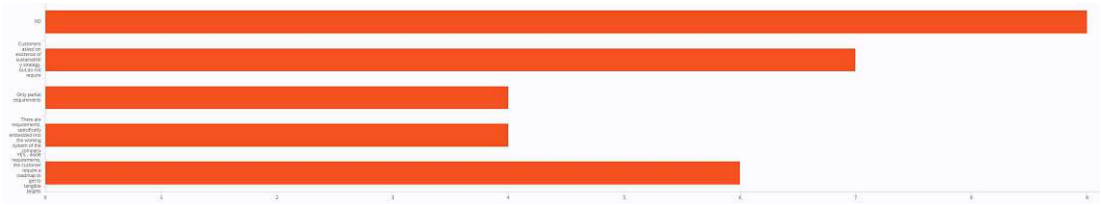
Reorder/Recode | Bucketing

Q17: How yo...ainability?		Count	Percent	Cumu...tive
Our product is produced in a sust...		12	40,0%	40,0%
Our product could be produced i...		8	26,7%	66,7%
Not sure		10	33,3%	100,0%
Total	0,0% 20,0% 40,0% 60,0%	30	100,0%	

Following to the next question, the aim was to understand the key driver of sustainability implementation I the organization. Although the answers are in quite homogeny spread, there is a slightly stronger reference to the relation between the final customer requirements and the offering of the sustainable solutions.

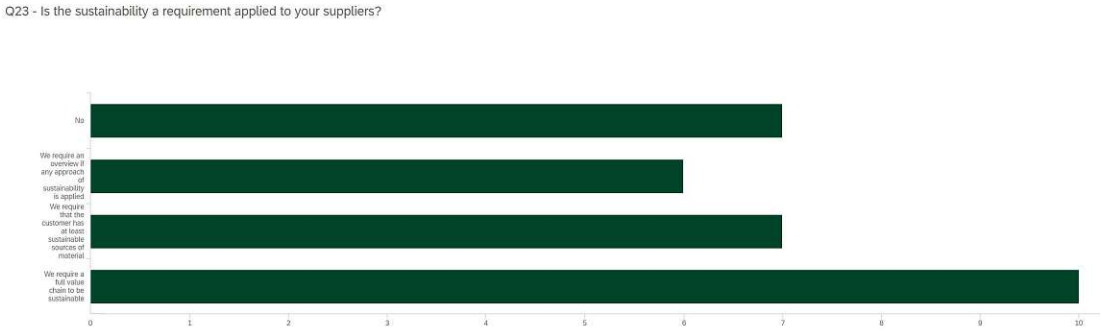


This fact is also confirmed in the field of business customers (compared to the previously mentioned final end customers), where only a third of the participants (nine out of thirty) state, that there are no requirements towards them placed by their clients.



This indeed proves, that the sustainability requirement is flowing from the final end customers, thru the whole chain of supplier (producers) up to the initial sourcing of all input resources that are needed for the entire value chain processes.

And that can be also observed on the next set of answers when replying to the inquiry of sustainability being a integrated requirement towards the supplier, and even in a stronger position, as only seven out of thirty has no requirement at all towards the supply chain. It is often one of the easiest ways how to start the sustainability journey, i.e. by choosing the market alternatives where this topic is already on the agenda and embedded in the daily processes. This, at the same time, also provides security, as sustainability is also there to mitigate risks that derive from material scarcity.



Last but not least, is the expected impact on the bottom line of each business case. The expectations on the profitability of project, product positioning within pricing strategies, taking into consideration the competitive advantage are the most focused areas, when speaking about financial feasibility of a material substitution (even if triggered by the sustainability requirements). These requirements in certain cases will influence changes in the production or sourcing activities, that can require capital expenditures, or additional running costs.

As seen below, more than two thirds of the responses show an expected level of more than 10% increase of price, or, almost a half expects an increase of more than 20%.

When assuming that the new input material would be able to oscillate in the same area of costs as the original material, then we are speaking about a substantial swift in the profitability of such business case, outperforming the average profit levels of regular aluminium extrusions (from casted materials)

4. FINDINGS, PRACTICAL IMPLICATIONS, CONCLUSION

4.1. Findings

The main objective of the presented Master Thesis was to investigate and research the possible application of new “progressive materials” in the segment of the automotive industry. For that reason, a survey was conducted within the group of the customers of the Company where the author is employed, as well as colleagues from the Group that are experienced in the area, or directly working for the Automotive Sales Segment.
Examples of novelty material from both automotive and non-automotive segments have been presented, to confirm feasibility of this new segment in production of Al extrusions.
By using the available sources of literature (theoretical knowledge) in combination with the output from the survey indicates, that there is a significant potential on the development and consequent application of the mentioned progressive materials, both from the perspective of the substitution of the materials as well as from the point of view of a novelty approach.

The awareness of sustainability in the customers behaviour shows a correlation towards the willingness of the suppliers to execute activities and change management in order to capitalize on the explorations of the new methods and product approaches.

The participants expect, that there are costs related to the implementation as well as obstacles in the deployment of material substitution with relation to the sustainability, but they also expect that such deployment in the real life will turn into a business case that is rather significantly more profitable than regular standard business.

One of the findings is, that for a well-functioning business model, a methodology of “same optics” needs to be applied throughout the whole value chain. In other words, it means that the same requirements (or same level of requirements) that are demanded from the End Customer thru our customer, must be applied to us as an organization internally (internal process, even internal customer-supplier approach within a company), and consequently to our supplier. Only such approach can guarantee a solid, customer-oriented flow, that can differentiate the case,

4.2. Practical Implications

With the outputs of this document the author wanted to introduce to understanding of the relationship between the material substitution (including novelty) and the perception of the customers from different points of perspective. The behaviour of the customers show that an implementation of a new material goes way beyond the first plan pricing topic. The combination of the theoretical knowledge from different sources of literature, years of experience in the field and the conduct empirical research thru the survey, point to different aspects that are described in the following sections of this subchapter.

Material substitution approach

This area of the study shows that, based on this statistic, companies are more capable to involve them into them when they are smaller sized, more independent in the process of design, and if they are working with less progressive materials. It is not of surprise, that the companies should use a methodology to educate their own managers and the customers on what are the possibilities of the new materials. Within the HE group this kind of activity is already in place, however there is potential to strengthen this type of education also in the area of Automotive Platform.

The big size companies often are better equipped resource wise to execute changes, however if the substitution is not a top priority for them the result might be jeopardized. A proper strategy on the development of the material substitution should be created or in place, that will draw a road map on how to bring it to life, with the definition of all the resources as well as expected outputs, including the profitability

The sustainability approach

In this area, the outcome of the survey shows, that even the agenda is already in place in many companies, there is space for improvement, especially in the area of the knowledge development of the employees. It is thru them that the company can exercise ideas transfer to the customers and educate them about the solutions that can bring benefit to both sides of the business.

A recommendation for creating a roadmap for the sustainability is based on the author's professional experience in this industry (HE group), where specially in the

last decade, the road to sustainable future has been designed and put in the daily agenda with step-by-step activities that assure the completion of this goal.

And even that at the beginning it was perceived as a rather administrative exercise with no tangible outcome, after some two years the first customers initiated the discussions about the next step of material sustainability in the aluminium extrusions. In such cases, a company has either the possibility of being the first on the market to obtain a solid part of the market share (means speed to the market) or needs to be offering a unique product with unparallel properties that are not matched by the competition (novelty to the market)

Hydro Extruded Solutions has realized this concept in early stage and therefore in these days has the advantage of market share in the segment of low-carbon solutions, which was delivering to the customers as one of the first supplier from this field.

4.3. Conclusion

In the last few years, massive disruptions are occurring in the global macroeconomic situation, the pandemic throughout the whole planet, the chip shortage across all sectors of industry, the material shortage in specific areas, war in the Old Continent, Energy crisis. Aside of these, also the Climate Crisis is a highest critical one. The generally presented trends shows worsening of the situation year on year, with appellation on drastic changes that must be executed in order to reverse the negative development. Therefore, the sustainability is today becoming the topic that is moving fast towards the highest priority point of the business agenda of companies. On one side, countries, unions, global economic structures, as well as other non-governmental organizations (NGOs) are pushing on the governments to impose legislation that prevents the further industrial development would cause more damage thru its processes and products.

On the other side, individuals, acquaint knowledge and perception about the situation, as well as their own impact on the environment, thru their own consumption behaviour. Consumers, equipped with their “power of change” that indeed allows the option of choosing a more sustainable future. It is the above-mentioned combination of legal framework and consumer behaviour that is speeding up the process of implementation of sustainable solutions. Every company, every leader of any organization realizes that this change is not to happen, but we are already living it in real life.
The companies, and specially in automotive sector, do realize that the roadmap to sustainability is key on the long term run in the business.

The author of this Master Thesis investigated within the existent portfolio of business cases as well as on a group of business partners how material novelty, i.e. substitution of material, and sustainability are related, and what is the importance of these for the customers. The clear connection between the light weighting of the vehicles in the Automotive segment, and the exploration of utilization of new material was confirmed.

The hypothesis defined at the beginning of the work has been confirmed as follows:

- Overall, the material substitution contributes to the sustainability of solutions

Indeed, willingness into investigation of material parameters and capabilities unveil new opportunities and potentials, that go hand in hand with the more sustainable solutions, both form customer and supplier point of view. Novelty of materials is the next step, or better said step higher, in the material substitution approach.

- The key stakeholders in the process influence are the ignition of the change, that drives the companies to sustainable solutions

In every process, it is fundamental to identify the stakeholders, as these are crucial for the process to be executed. In the case of this study, there are various types of stakeholders that influence the change of the materials, as well as the choices made when referring to the internal processed of the companies. There is a strong orientation towards the final end customer behaviour, and his purchasing preferences.

- The cost perspective of a change in materials is perceived as rather less important comparing to the competitive advantage of the solution, that can achieve profitability on the long run

Although many of the participants indicated that the cost perspective is of importance, they have also indicated that they would be willing to perform investments into the activities that are related to sustainability agenda.
This because the competitive advantage generated by novelty that is at the same time covered within the guidelines of sustainability, is perceived as valuable as the profits that should be generated, and which are expected to materialize rather in a short to midterm period.

Many examples of companies show that even that the introduction of the sustainability agenda needs to perform the “extra mile” in order to embed it into the strategies and the whole working environment of an organization, the commitment pays off on the long term. Understanding the customers, their customer behaviour and needs or desires that are related to sustainability solutions, leads towards the adaptation of the organization, which on the same page grants the long-term existence of the companies in a sustainable way. Explaining and onboarding the people of an organization into the sustainability agenda is fundamental.

The author, being a managing director of an aluminium extrusion company, after the study of the topic, the execution of the research among customers, and after reviewing the ongoing business cases can conclude, that the sustainability is actually the driver to the business continuity and development of such company. The increasing demands of the customers push the boundaries on the properties of the materials, that often lead to seeking of new methods and opportunities that would satisfy those demands. The outcome of the work shows that there are certain concerns regarding investment costs related to technology adaptations, however these are not of great materiality once compared to overall business cases values of revenues and/or profitability. These desired values can be only achieved by higher Value Added products, which would be accepted by the customer by providing novelty materials that offer properties that go beyond the regular aluminium extrusions.

On one side, the legal framework together with the macroeconomic situation create pressure on sustainable solutions with low demand on material sources and energy inputs, on other side the cost awareness of OEMs make European manufacturers find themselves in competition with Asian solution that are not fulfilling the sustainability (environmental) demands.

A solution to this dilemma is the utilization of the powder materials in aluminium extrusions (material substitution) that allow new properties (novelty) as well as reduction of usage of natural resources including energy, assurance of the recycling requirements of a circular economy, to satisfy the demand of sustainability, and therefore guarantee long term prosperity for the environment we work and live in.

List of Abbreviations

MBA	– Master of Business Administrations
HESK	– Hydro Extrusion Slovakia
HE	– Hydro Extrusions group
UTS	- ultimate tensile strength
YTS	- Yield tensile stress
NGO	– Nongovernment organization
IPR	– intellectual property rights
AMC	- aluminium matrix composites
FSW	– Friction steer welding
UMMS SAV	- Institute of Materials and Machine Mechanics, The Slovak Academy of Sciences (Ústav materiálov a mechaniky strojov Slovenskej akadémie vied, UMMS SAV
TCO	- total cost of ownership

List of figures

Bibliography

Alumunium guide. (2022). *Alumunium guide.com*. Retrieved from aluminium-guide: https://aluminium-guide.com/en/pressovannye-alyuminievye-profili-klassifikaciya/ visited on 17/05/2022

Amirkhanlou, S., & Ji, S. (2020). A review on high stiffnes aluminum-based composites and bimetallics. *Critical Reviews in Solid State and Materials Sciences* , Volume 45, pages 1-21.

BMW Group. (2020). *www.bmwgroup.com*. Retrieved from https://www.bmwgroup.com/content/dam/grpw/websites/bmwgroup_com/responsibility/downloads/en/2020/2020-BMW-Group-SVR-2019-Englisch.pdf visited on 20/06/2022

Bombac D., C. P. (2020, 11). In-Depth Comparison of an Industrially Extruded. *MDPI Metals*.

Bonnell Aluminium. (2022, 6 16). *https://www.bonnellaluminum.com/tech-info-resources/aluminum-extrusion-process/*. Retrieved from https://www.bonnellaluminum.com/tech-info-resources/aluminum-extrusion-process/ visited on 18/05/2022

DruckerFrontier. (2022, 06 14). *Aluminium Content in European Passenger Cars 2019*. Retrieved from DuckerFrontier/European aluminium 2019

European Aluminium Association. (2022, 06). *European Aluminium Driving change*. Retrieved from https://european-aluminium.eu/activity-report-2021-2022/market-overview/ visited on 25/08/2022

Hydro A.S. (2022). *https://www.hydro.com/en/about-hydro/*. Retrieved from https://www.hydro.com/en/about-hydro/ visited on 18/05/2022

Hydro Annual Report 2021. (2022). Retrieved from https://www.hydro.com/globalassets/06-investors/reports-and-presentations/annual-report/rdmar21/annual-report-2021-eng.pdf, visited on 18/05/2022

Chelladurai, S., Kumar, S., Venugopal, N., Ray, A., Manjunath, T., & Gnanasekaran. (2020). A review on mechanical properties and wear behaviour of aluminium based metal matrix composites. *Materials Today: Proceedings*, Volume 68 part 3.

Inovar Communications Ltd. (2022, vol.11 No.2). Powder metallurgy review. *Powder metallurgy review*.

JLR. (2020). *media.jaguarlandrover.com*. Retrieved from media.jaguarlandrover.com: https://media.jaguarlandrover.com/news/2020/08/jaguar-land-rover-upcycles-aluminium-cut-carbon-emissions-quarter, visited on 20/03/2022

LMC AUTO. (2022, 06). *Global Light vehicle sales*. Retrieved from https://lmc-auto.com/news-and-insights/public-data/ visited on 25/08/2022

M.M.Farag. (2008). Quantitative methods of materials substitution: Application to automotive components. *Materials & Design*, 374-380.

MatalCo Inc. (2022, 6 14). *www.mataluminum.com*., visited on 18/05/2022

Merriam-Webster. (2022, 9 21). *Merriam-Webster.com Dictionary, Merriam-Webster,* . Retrieved from https://www.merriam-webster.com/dictionary/sustainable, visited on 10/10/2022

Norsk Hydro. (2020). Hydro REDUXA 4.0., (p. 3).

Norsk Hydro AS. (2022, 10). *Hydro CIRCAL recycled aluminium*. Retrieved from https://www.hydro.com/en/aluminium/products/recycled-aluminium/hydro-circal/ visited on 18/05/2022

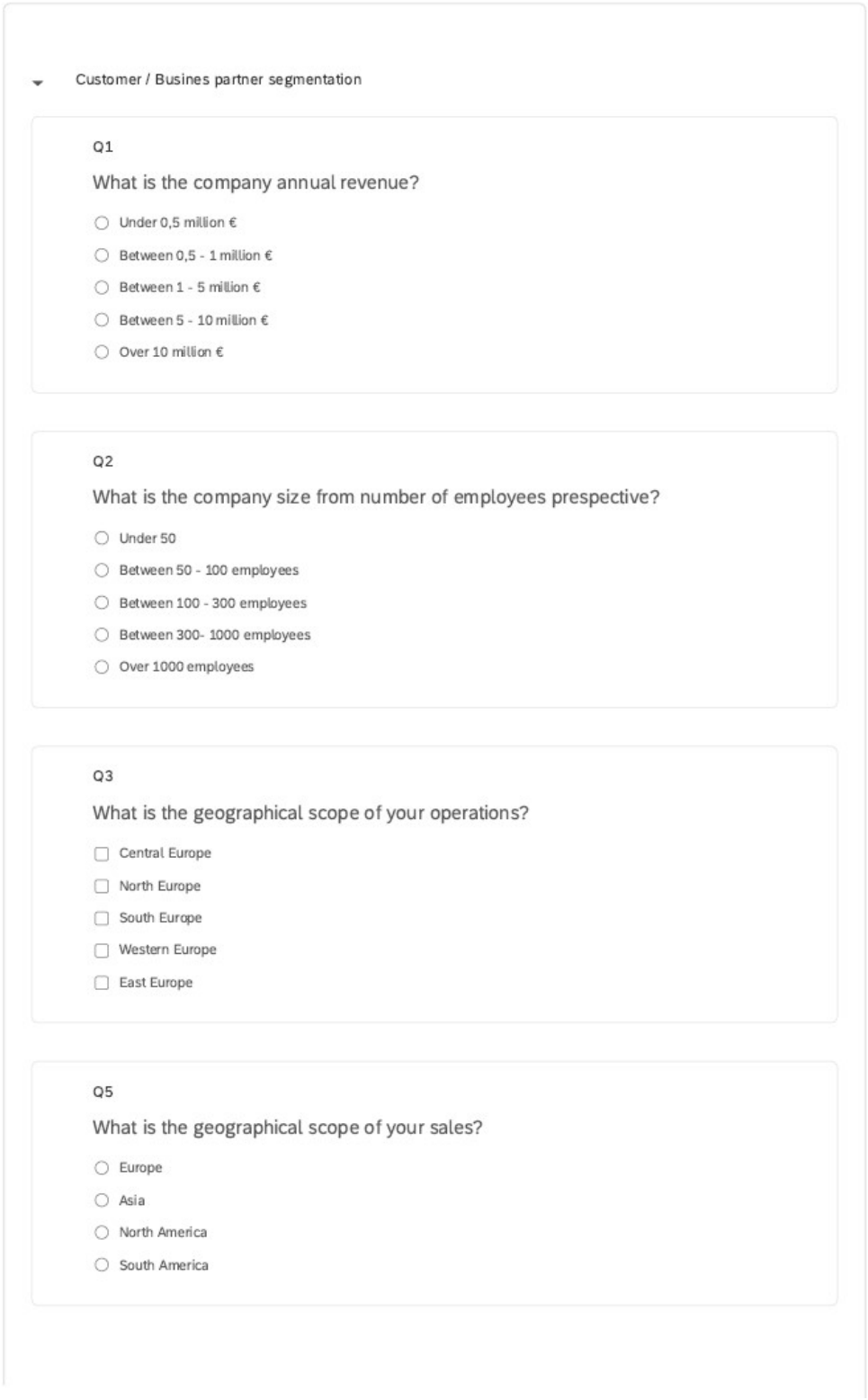
Reuters. (2022, 10 28). *EU approves effective ban on new fossil fuel cars from 2035*. Retrieved from https://www.reuters.com/markets/europe/eu-approves-effective-ban-new-fossil-fuel-cars-2035-2022-10-27/ , visited on 30/10/2022

SAPA. (2018). *Extrusion Design Manual.* Stockholm: SAPA AS.

Volvo Cars. (2020). *www.media.volvocars.com*. Retrieved from https://www.media.volvocars.com/no/nb-no/media/pressreleases/259147/volvo-cars-lanserer-ny-klimaplan-skal-gjore-store-reduksjoner-i-selskapets-co2-utslipp, visited on 20/03/2022

Appendix

Survey form used in the MT



Customer / Busines partner segmentation

Q1

What is the company annual revenue?

- ○ Under 0,5 million €
- ○ Between 0,5 - 1 million €
- ○ Between 1 - 5 million €
- ○ Between 5 - 10 million €
- ○ Over 10 million €

Q2

What is the company size from number of employees prespective?

- ○ Under 50
- ○ Between 50 - 100 employees
- ○ Between 100 - 300 employees
- ○ Between 300- 1000 employees
- ○ Over 1000 employees

Q3

What is the geographical scope of your operations?

- ☐ Central Europe
- ☐ North Europe
- ☐ South Europe
- ☐ Western Europe
- ☐ East Europe

Q5

What is the geographical scope of your sales?

- ○ Europe
- ○ Asia
- ○ North America
- ○ South America

Q6

What is the main area of your industry?

- ○ Automotive
- ○ Non-automotive industrial
- ○ Transport
- ○ Building and construction
- ○ Other

Sourcing segmentation

Q6

How many suppliers is your company using?

- ○ Under 10
- ○ Between 10 - 30 suppliers
- ○ Between 30 - 100 suppliers
- ○ Between 100 - 500 suppliers
- ○ Over 500 suppliers

Q7

What is the geographical scope of your sourcing origin?

- ☐ Europe
- ☐ Asia
- ☐ North America
- ☐ South America
- ☐ Africa

Q8

What is the material that you are using mostly, fromt the following ones?

- ○ Steel
- ○ Aluminium

Q9

Are there any aluminium components used for your final product?

- ○ YES
- ○ NO

Q10

If yes, what kind of aluminium components?

- ○ Machined parts
- ○ Long lenght parts
- ○ Various parts welded toghether

Q11

What is the area of application of your aluminium components?

- ☐ Antivibration
- ☐ ABS / Brakes
- ☐ Subframes
- ☐ Body-In-White
- ☐ Doors / Hoods
- ☐ Crash Management System
- ☐ Sunroof
- ☐ Luggage Cover
- ☐ IP Beam
- ☐ Roof Rails
- ☐ Side Trims
- ☐ Decorative Parts
- ☐ Heat Exchangers
- ☐ Engine Parts
- ☐ Wheels
- ☐ Battery Solutions
- ☐ Engine Housings
- ☐ Power Electronics

Product segmentation

Q12

Who is responsible for the final product design?

- ○ Our customer (we are not allowed to design the parts)
- ○ Our customer (but we are able to influence changes into the design)
- ○ The design is completelyinourresponsability

Q13

Who is responsible for the final product material composition?

- ○ Customer is strictly demanding
- ○ Customer allows materials alternatives
- ○ Customer defines properties of the product, and leaves the composition to the discretion of the supplier

Q14

Is there a possibility of material substitution in your product range?

- ○ Definitely not
- ○ Probably not
- ○ Might or might not
- ○ Probably yes
- ○ Definitely yes

Material substitution

Q15

What would be the triggering point for material substitution?

- ○ Material properties advantages (technical/process related)
- ○ Cost position advantages (competitive price)
- ○ Multi - sourcing advantage (supply risk mitigation)
- ○ Recyclability advantage

Q16

What would be the main obstacle for material substitution?

- ○ Material properties disadvantages (technical/process related)
- ○ Cost position disadvantages (higher price, TCO perspective)
- ○ Multi - sourcing advantages (more administrative)
- ○ Recyclability advantage

Q17

If a material is to be substituted, within what time you expect that change to materialize?

- ○ Under 6 months
- ○ From 6 to 12 months
- ○ From 12 to 24 months
- ○ Over 24 months

Q18

Are you ready to "invest" into the development of a novelty material?

- ○ Definitely not
- ○ Probably not
- ○ Might or might not
- ○ Probably yes
- ○ Definitely yes

Q19

If "probably yes" or "definitely yes", what would be the range of your investment compared to your revenues?

- ○ under 0,1%
- ○ 0,1%-0,5%
- ○ 0,5%-1,0%
- ○ 1%-2%
- ○ over 2%

▾ Sustainability

Q20

How you perceive your product from point of view of sustainability?

- ○ Our product is produced in a sustainable way
- ○ Our product could be produced in a more sustainable way
- ○ Not sure

Q21

What is the main sustainability driver for your company?

- ○ The connection of our products towards the customers that require the sustainable solutions
- ○ The connection between the sustainability and profitability on the long run
- ○ The connection (indirectly) of our product and the final customer behavior regarding sustainability (environmental protection, lower running costs, prestige symbol...)

Q22

Is the sustainability a requirement from your customers?

- ○ NO
- ○ Customers asked on existence of sustainability strategy, but do not require
- ○ Only partial requirements
- ○ There are requirements, specifically embedded into the working system of the company
- ○ YES - aside requirements, the customer require a roadmap to get to tangible targets

Q23

Is the sustainability a requirement applied to your suppliers?

- ○ No
- ○ We require an overview if any approach of sustainability is applied
- ○ We require that the customer has at least sustainable sources of material
- ○ We require a full value chain to be sustainable

Q24

When offering a new solution (novelty) from a sustainability point of view, what is your expectation to the price increase to your customer?

- ○ 0-5%
- ○ 5-10%
- ○ 10-15%
- ○ 15-20%
- ○ 20-25%
- ○ over 25%

End of Survey

We thank you for your time spent taking this survey.

Your response has been recorded.