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# High Density Die Casting (HDDC): new frontiers in the manufacturing of heat sinks

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**Abstract.** Finding a good solution for thermal management problems is every day more complex, due to the power density and the required performances. When a solution suitable for high volumes is needed, die-casting and extrusion are the most convenient technologies. However designers have to face the well-known limitations for those processes. High Density Die Casting (HDDC) is a process under advanced development, in order to overcome the extrusion and traditional die casting limits by working with alloys having much better thermal performances than the traditional die-casting process, while keeping the advantages of a flexible 3D design and a low cost for high volumes. HDDC offers the opportunity to design combining different materials (aluminium and copper, aluminium and stainless steel) obtaining a structure with zero porosity and overcoming some of die-casting limits, as shown in this paper. A dedicated process involving embedded heat pipes is currently under development in order to offer the possibility to dramatically improve the heat spreading.

## 1. Introduction

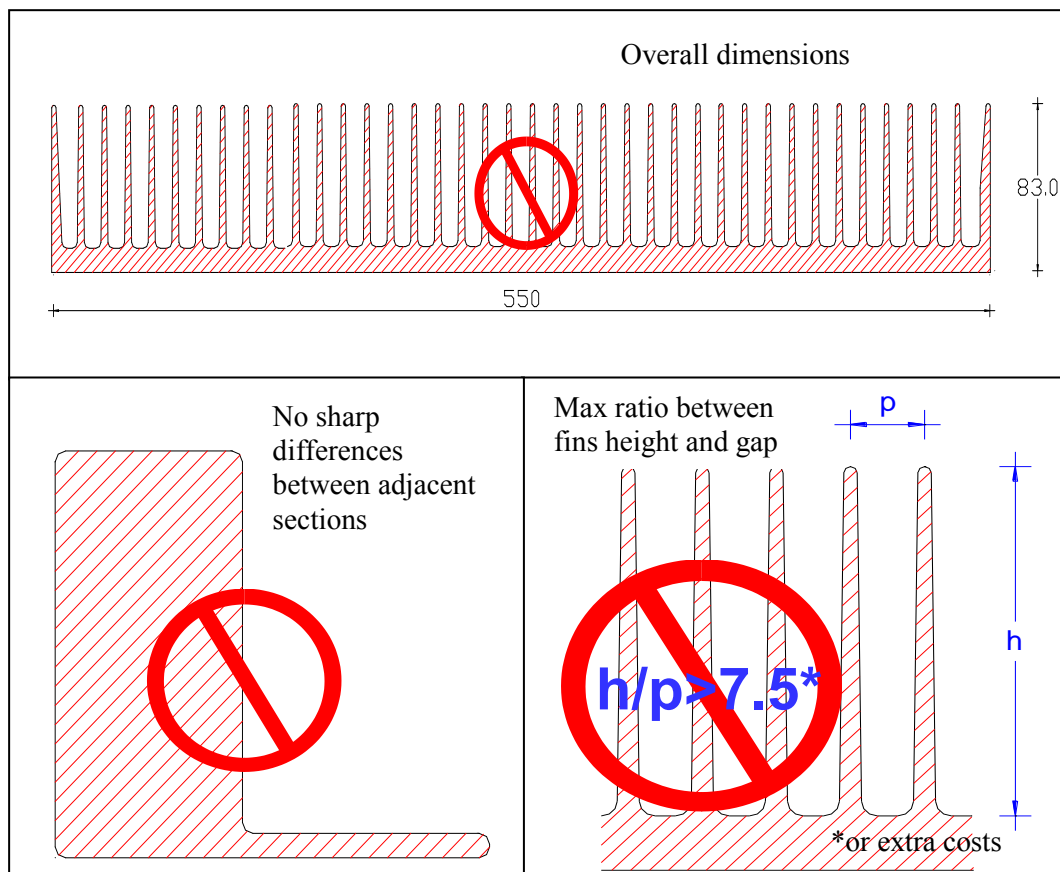
Thermal management problems are becoming more and more challenging: power density is constantly growing in order to overcome the limits and develop a powerful application in a reduced space (or giving a more compact final product). Furthermore, power sources often require improved performances in order to ensure them a longer lifetime.

Thermal engineers try to find suitable solutions by using the most common technology, by respecting all the customer's requirements (including the target cost). There are many technologies available for manufacturing; however, when high volumes are involved for mass production, extrusion and die-casting are the most common alternatives; however, during the design phase it is necessary to remember their well-known limitations:

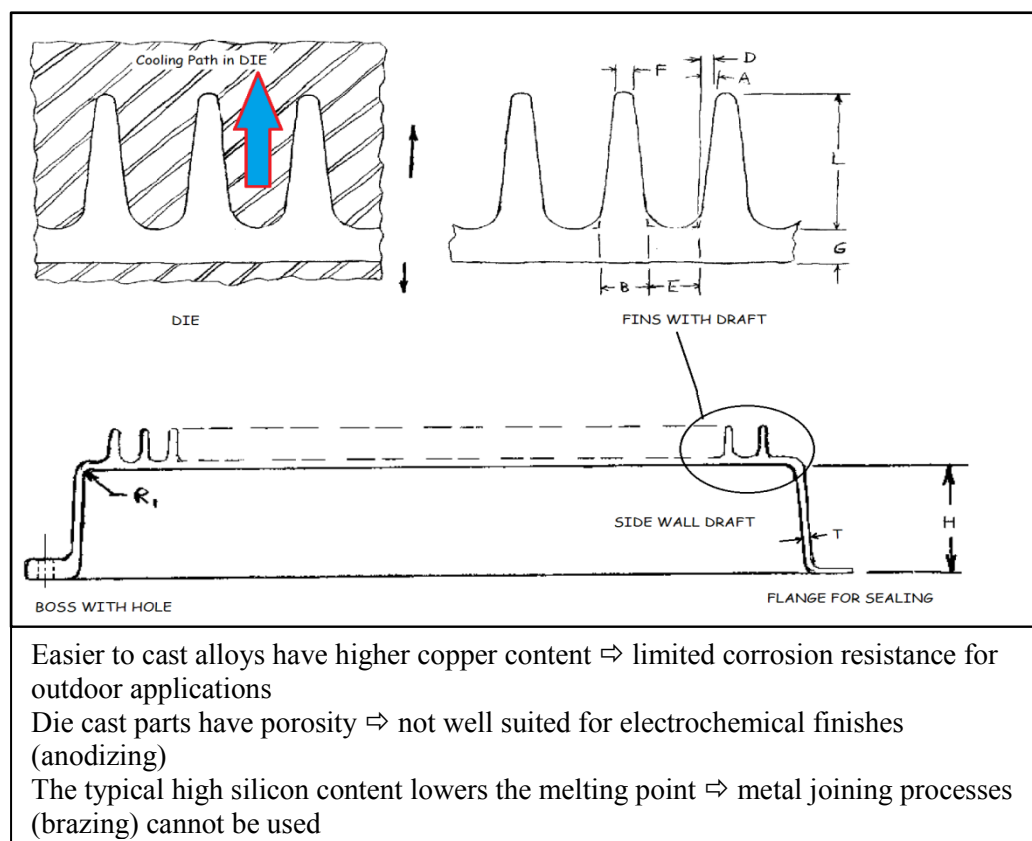
- Extrusion is only a 2D process;
- It can use only 6xxx alloys;
- It has limitations in fin density and geometry (as shown in figure 1);
- It cannot have any different material inserted.

Die-casting can be done only with some kind of aluminum alloys, characterized by a very poor thermal conductivity (normally between 90 and 140 W/m-K): this further constraint could be a bottleneck where thermal performances are difficult to be reached and in all the applications where the heat transfer by conduction has a relevant role in the overall heat transfer phenomena ([1], [3] and [5]). The most common constraints of die-casting (including geometry limits) are summarized in figure 2.





**Figure 1.** Extrusion limits



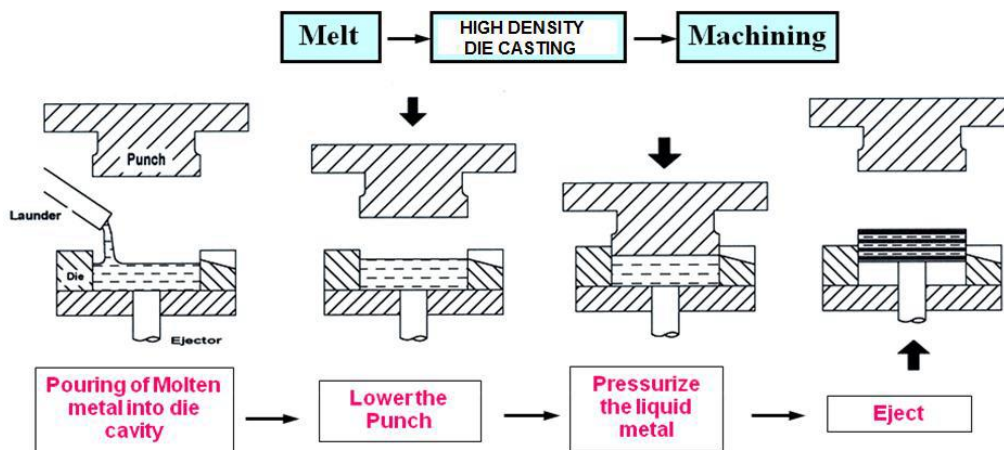
**Figure 2.** Die-casting limits

## 2. High Density Die Casting (HDDC)

### 2.1. General description

High Density Die Casting (HDDC) is a process under advanced development, able to overcome extrusion limits and some of die-casting limits, in addition to the opportunity to work with high thermal conductive aluminum alloys. The process keeps the advantages of a flexible 3D design and a low cost for high volumes due to the manufacturing process. HDDC is a hybrid process that combines elements of casting and hot forging, offers the opportunity for cost effective heat sink manufacturing in near net shapes. This process enables optimized heat sink designs that incorporate cavities, bosses, and thin fins for low weight. In addition, the process is flexible to allow heat sink fins to be forged in place as integral parts of an electronic housing or enclosure.

The HDDC process used to produce aluminum heat sinks from molten aluminum is shown in figure 3. The process involves firstly transferring a pre-fixed amount of molten aluminum from a melt furnace to a mold cavity using a ladling robot. The top section of the die, the punch, is then lowered into the cavity and pressed downwards with high pressure to form the molten metal into the shape of the heat sink. When the molten metal has solidified, the punch is raised, the heat sink is ejected from the cavity and a pick-up robot grabs the heat sink and places it onto an unloading area. The whole cycle is then repeated for continuous production.



**Figure 3.** Steps in the HDDC process

### 2.2. Differences against die-casting

With its capability of utilizing high thermal conductivity wrought aluminum material like Al 6063 or Al1070, HDDC heat sinks can achieve much better heat dissipation efficiencies than aluminum die cast heat sinks. With the application of direct high pressure during the solidification process, porosity free, leak tight products with good mechanical strength can be produced.

Different fin shapes such as flat, oblique, elliptical, round pin arrays and radial plate designs can be made to take full advantage of the three-dimensional geometry capability of the process and to direct the airflow as required. This can greatly reduce back pressure by creating turbulence only where needed. The re-design of the fin arrangement facilitated by the HDDC process can enable reduced flow resistance to incoming air or liquid streams and enhance turbulence between the fins for improved thermal performance.

Advantages and features of HDDC products can be summarized as follows:

- High thermal conductivity Al alloys (200+ W/m-K) as well as normal die-cast Al alloys as needed
- Fine grain structure, zero porosity or shrinkage defects due to robust process control during solidification.
- Thin and high aspect ratio fin features
- Defect free surface with lower roughness values
- Feasible to do all kind of electrochemical surface treatment process
- Embedding of copper, graphite as well as aluminum material within product

- High feasibility of brazing products (application like liquid cold plates and housings)  
Some of these aspects are summarized in table 1.

**Table 1.** Preliminary comparison for heat sink with 40-60mm tall fins between HDDC and die-casting

Description of features	Die-casting	HDDC
Fin Geometry (Plate, pin etc.)	All Types	All Types
Minimum Enclosure wall thickness (mm)	2-4	1.5-3.5
Minimum fin to fin spacing (mm)	5	3-4
Minimum fin tip thickness (mm)	2.5-3	1.0-1.5 plate fin 2.0 pin fin
Minimum fin angel (degree)	1-1.5	0.5-1.0
Porosity (%)	3-7	0
3D near net shape rating (5 is best )	5	4
Surface quality rating (5 is best)	2	4
Leak tight rating (5 is best)	2	5
Aluminium Alloys	ADC 10-12 or 3xxx	1xxx, 6xxx, 3xxx

Some of the characteristic dimensions need a range as the limit is fixed in combination with others: for example, the minimum wall thickness can be variable according to the overall shape and geometry of the part (fins height is very important in order to define the other parameters).

The latest three characteristics have been evaluated through a qualitative evaluation rate, where values are coming from a comparison between the two products (made with two different alloys).

HDDC offers the opportunity to work with different materials (aluminium and copper, aluminium and stainless steel) where the added material is embedded in a high density aluminium “body” made by casting process.

A dedicated process involving embedded heat pipes is currently under evaluation and development in order to offer the possibility to have solutions with heat spreading.

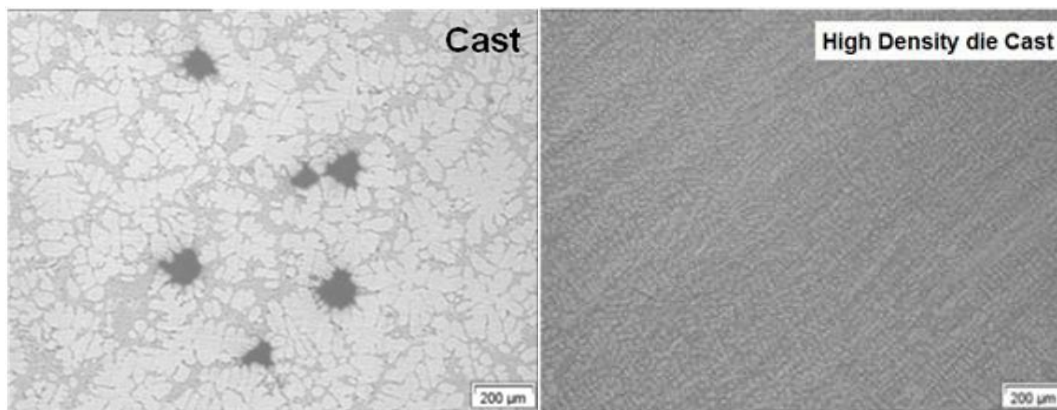
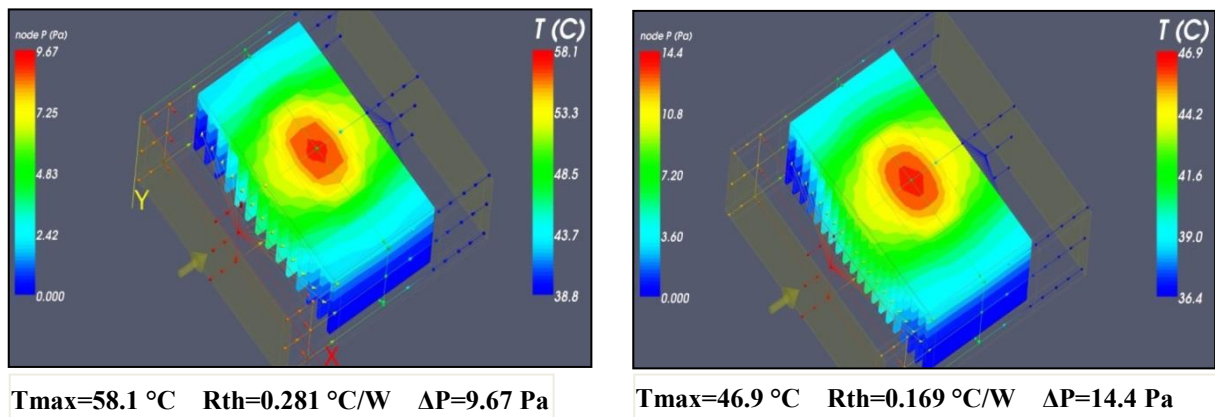
### 2.3. Development process

The development of this technology has started from some thermal simulations (made with different CFD software's such as Icepak and QFin), (as shown in figure 4) for some applications. They have been performed by considering a fully ducted air flow and the same air speed (2 m/s), ambient temperature overall dimensions and power density applied on the base.

The results show an improvement of performances ( $R_{th}$  is about 40% less) due to the increased thermal conductivity of the material (from 120 to 200 W/m K) and the exchange surface (from 14 to 20 fins).

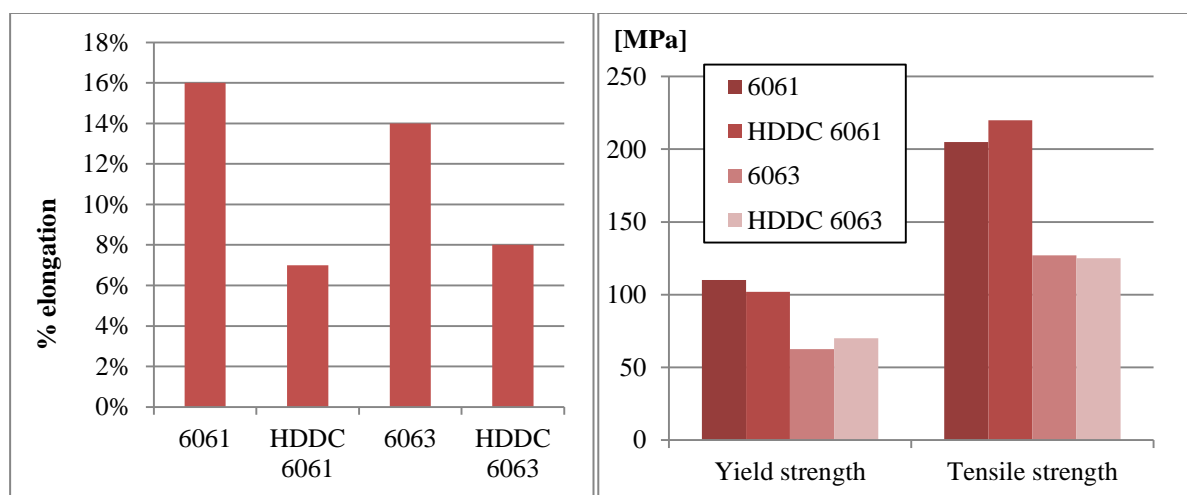
After a first and detailed research phase ([2] and [4]), a pilot plant has been built for the manufacturing of the first prototypes: the aim of these pieces was to conduct a detailed metallographic study in order to understand if through this process it was possible to get the expected good results.

The results (shown in figure 5) have been good: there is no porosity in the final product. The figure shows the difference between the two technologies: while the traditional casting process is characterized by some porosity distributed in the volume (with a relevant impact on the leak prevention of the final product), HDDC products have pore free microstructure. This means that HDDC can be used to make leak tight enclosures, including leak tight liquid cold plates.



**Figure 5.** Metallographic analysis of HDDC structure vs die-casting structure

The pore free microstructure is able to increase also mechanical strength: it has been properly validated as shown in figure 6 (through the classic tensile test). HDDC products are similar or better than extruded ones made with the same alloy and the

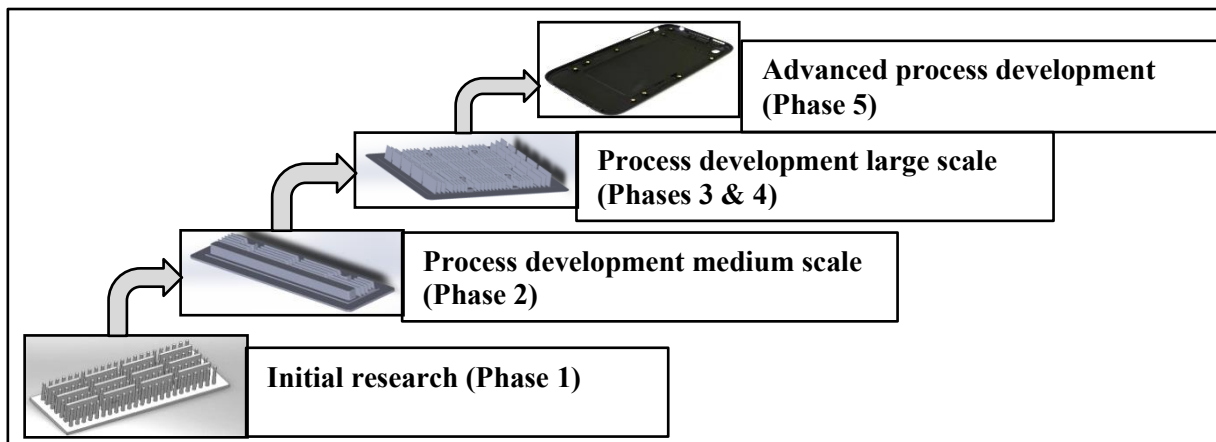


**Figure 6.** Mechanical Properties for Al 6xxx-T4 Series: test results comparison between HDDC and extruded material

Based on the above results and after different manufacturing tries (in order to verify the theoretical limits), scale-up has gone on and a plant for mass production has been built.



Capabilities are still under an improvement process: it is started with simple products and it is oriented to more complex parts, with embedded different materials and heat pipes (as indicated in figure 7).



**Figure 7.** Capabilities development path

After a first step where small parts (up to 80x200 mm for the base) have been studied and manufactured (with a parallel development of the tool manufacturing), efforts have been concentrated on the dimensions of the parts, from medium scale to large scale (up to 500x500 mm for the base). These steps have given a more realistic idea of the dimensional limits and the size of the tools to be developed for future manufacturing.

More complex products (with different materials and heat pipes) still have to be further developed, in order to use in the best way this technology.

### 3. Results and applications

#### 3.1. Products feasible with HDDC

Based on the above tests and analysis, HDDC can be considered as a real improvement of traditional die-casting: it is possible to work with better aluminum alloys (from thermal point of view) and to overcome some of the die-casting limits.

Particularly:

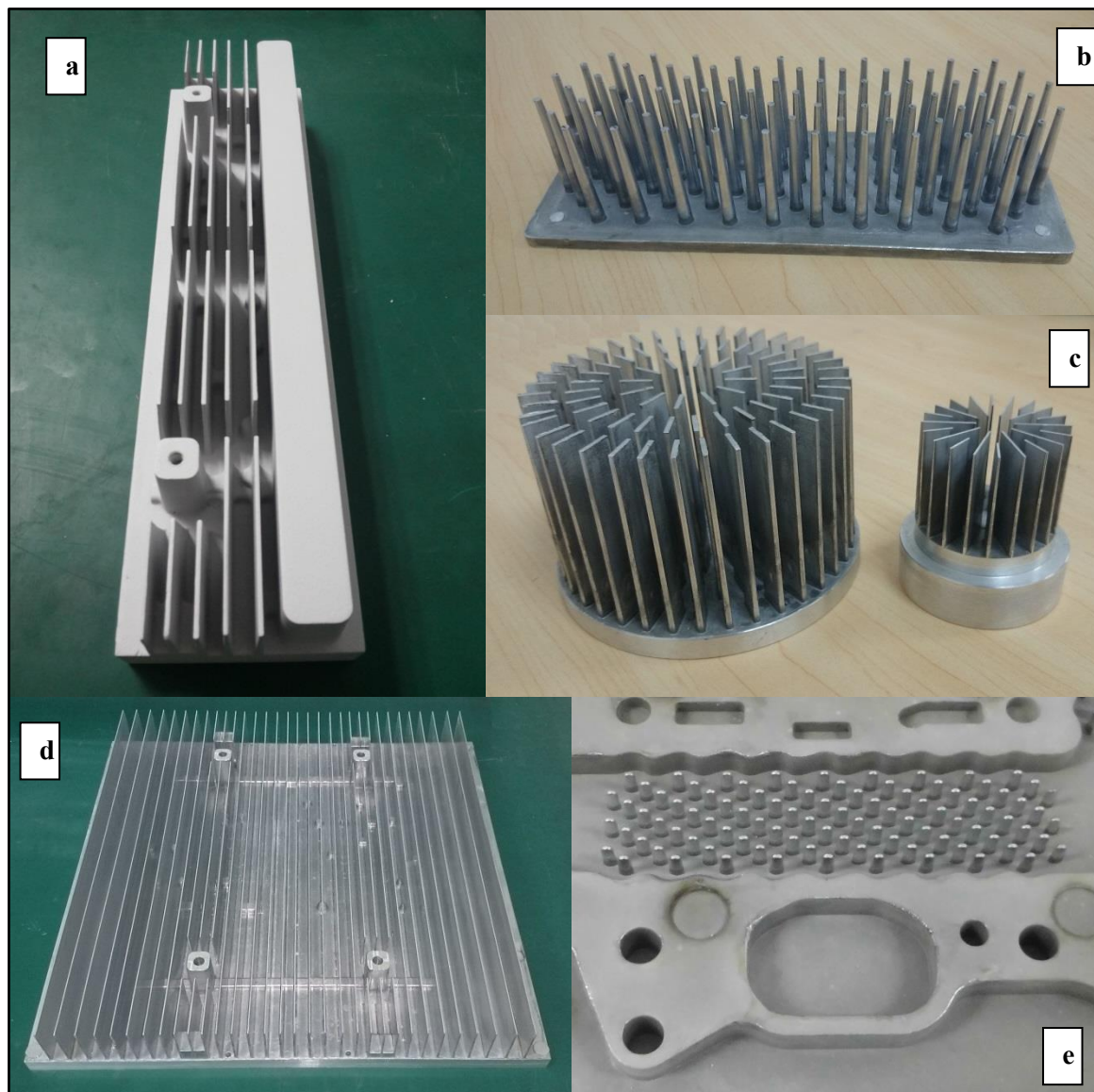
- Successfully formed a full size heat sink 450x450x60 mm with embed continuous extrusion fins in manual mode
- Bonding between fin and base is quite strong, pull strength is 80 N/mm<sup>2</sup>
- Thermal performance is as good as solid extruded heat sink
- Overall mass reduced significantly by using thinner fins/walls with an improvement of cooling performances

HDDC has been already used to made different kind of products (enclosures, pin fin structures, etc.) with good results; some example are in figure 8. Dimensions are variable from 80x200 mm (the first pieces made after the research stage – figure 8a) to 450x450 mm (figure 8d), passing through 150x450 mm (intermediate stage).

Concerning the tolerances level, dimension tolerances are usually positive and are approximately 0.5 % of the dimension. Die closure tolerances are in the direction of opening and closing, and range from 0.1mm to 1.5mm in the vertical direction depending on the precise volume control of the melt from the ladling.

High density die cast wrought Al heat sinks can achieve a surface roughness Ra better than 0.8 microns and they can be treated for aesthetic appearance and surface protection using wet electrochemical processes such as anodizing, nickel plating, e-coating and chromate treatment. In addition, the parts can be finished using finishing processes like electrostatic powder coating and polyurethane coating that are conventionally used for aluminum die castings.

Due to the possibility to use different alloys than traditional die-casting process, HDDC wrought Al heat sinks can be incorporated into more complex or larger assemblies by fusion processes like soldering, CAB and vacuum brazing, and fusion welding as well by non-fusion processes like friction stir welding.



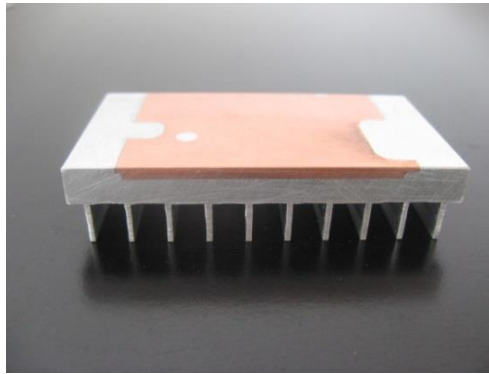
**Figure 8.** Examples of HDDC products

### 3.2. Working with different materials

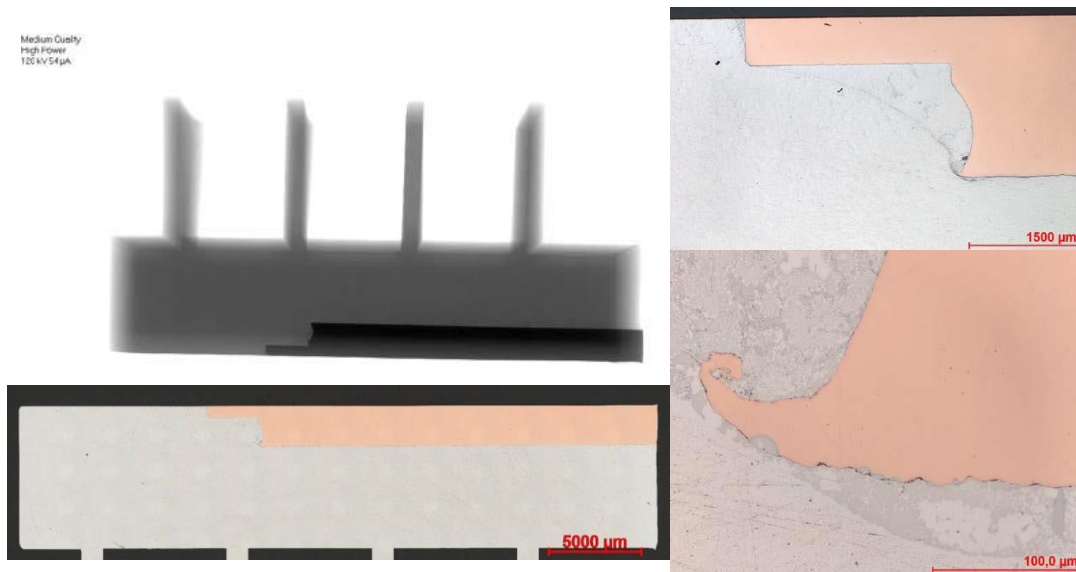
Test and manufacturing processes have been launched by using different materials, such as aluminum and copper

Cuts, microscopic analysis and ultrasonic scans been made and the results are shown in figures 9 and 10.





**Figure 9.** Examples of HDDC products with Al and Cu (cut section – 60x17x40 mm)



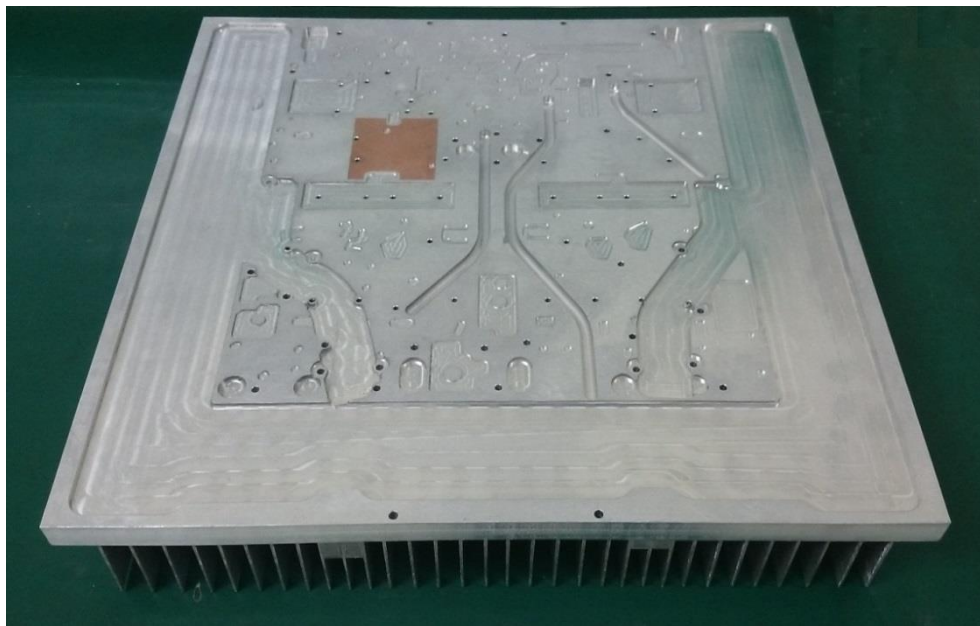
**Figure 10.** Microscopic and ultrasonic scan on HDDC made with Al and Cu

This step has been developed by study and manufacture a small part with aluminum and copper: the theoretical study has been used to fix the geometry and the detail of the shape in the contact area between the two metals. The expected results were to confirm the absence of porosity or micro gap in the mentioned contact area.

Then, the part has been made through HDDC process and a section where the two metals were in contact deeply analyzed in order to verify the results in terms of porosity (in the interface area), strength and behavior of the two materials during the HDDC process itself.

The above results have been used to fix the process and to make bigger parts, like the heat sink shown in figure 11.

Dimensions are much bigger than the part used for the first tests (400x500x60 mm vs 60x40x17 mm) and the results show that the process is moving in the right direction.



**Figure 11.** A big part made by HDDC with Al and Cu

#### 4. Conclusions

High density die casting gives the opportunity to make heat sinks with several important advantages over their die cast and extruded counterparts. The increased thermal performance coupled with the ability to expand the fin configurations and shapes of the heat sinks are unique advantages for example in the design of pin fins, oblique or elliptical fins etc. and radial fin arrays. Some of these features cannot be achieved via extrusion or die casting techniques. Lastly, HDDC allows the harnessing of wrought aluminum alloy in a liquid state to form heat dissipation fins on housings and enclosures with intricate features.

The benefits related to the new limits on shapes and geometry are mainly visible according to the ventilation conditions: a HDDC part optimized for natural convection will be totally different than another one designed for forced convection. Even parts made for forced convection applications will be different according to the boundary conditions (available flow rate, maximum pressure drop, cabinet sizes and shape, etc.).

The application of high direct pressure helps eliminate hot tearing and creates products with superior mechanical properties and pore-free structure with improved thermal performance. The elimination of porosity allows the parts to be finished using wet electrochemical processes like anodizing and the use of wrought alloys enables the parts to be brazed and welded to create more complex assemblies.

#### 5. Next steps

Now it is planned to go some steps ahead during 2014; the plan is:

- Embedded heat pipes
- Thin product development with multi-cavity tooling

The first development is a very interesting application for HDDC as heat pipes are common where a better heat spreading is needed or it is necessary to move the heat from a region to another one where there is space for the finned area.

It is not easy, as heat pipes have to be carefully handled: they have a thin copper wall and the contact surface between them and aluminum base is crucial in order to have a good heat transfer process. At 680 °C (melting temperature of aluminum alloys), the pressure of the vapor inside the tube can reach almost 100 bar, causing the bumping of the tube; in order to prevent this phenomena, a special process has been studied and the theoretical study is finished. First experimental test are currently planned.

The other development is important in order to manage very high volumes: multi-cavity tooling would allow the manufacturing of more pieces in a single shot. Of course, the number of cavities is strictly related to the dimensions of the part we are going to design: efforts will be first concentrated on small parts and according to the results of this step, bigger products could be analyzed too.

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