TITANIUM RAPID CASTING

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INTRODUCTION

CRP Technology

CRP has been instrumental in the success of many winning racing teams. From F1, to MotoGP, WRC (World Rally Championship), American Le Mans Series, Rally Raid (Paris –Dakar) we offer a high level of support throughout the entire project, including the manufacturing process. What makes this company different are the partnerships we have formed with the different teams. CRP is involved at the earliest design and development stages and our innovative approach to the use of new materials and technology is widely recognised by the race car industry.

CRP Technology is therefore considered a unique service point for several different technologies and engineering activities.

The main activities are:

- **HQ & HSM CNC** (high speed and high quality machining with 3, 4 and 5 axis)
- **Rapid Casting** (lost wax casting with RP patterns) in Titanium, Aluminium, Steel alloys or Superalloys
- **New ULTRARapid Casting**, optimized for Aluminium alloys
- **Rapid Manufacturing and Rapid Prototyping** services
- **Rapid Manufacturing & Rapid Prototyping** composite materials production and sales
- **R&D**: continuous research on materials like metallic alloys, plastic materials and new manufacturing processes development
- **Reverse Engineering**

In particular, CRP manages innovative projects, such as high precision titanium alloy castings and hard to work materials machining of complex shapes. The Machining Department is therefore characterized by CNC milling centres, suited in particular to hi-tech materials machining.
WINDFORM® materials, developed by CRP’s internal R&D Department, are commercialized worldwide. Technological patent pendingings and trademarks were done. In Particular, WINDFORM® PRO and PRO B, by now, are covered by US patent and registered trademarks!!

The Procedure

The CRP R&D department is involved in the Rapid Casting technology since 1997.

In 1998 CRP Technology began to work alongside the Minardi F1 team, supplying them the engineering process, the manufacturing process optimization and the manufacturing of front and rear uprights: they began from the study of the **Titanium Rapid Casting process.**
Rapid Casting is based on the combination of Rapid Prototyping technology, to manufacture the disposable pattern, and Investment Casting technology (Investement casting).

The RP disposable pattern is made by a consecutive overlapping of layers, using the Selective Laser Sintering technology. The system doesn’t require any support because the piece is held up by the non sintered powders, therefore giving complete freedom of shape.

The Rapid Casting procedure is composed of a number of steps:
- A disposable pattern is made through RP technique and polystyrene material
The pattern undergoes wax infiltrations (immersion and capillarity) to increase its strength (to avoid handling breaks);
The pattern is immersed in a ceramic bath:
Slurries and stuccoing and exsiccatation;
The lost pattern is evacuated: dewaxing with flash firing or in an autoclave and subsequent sintering of the ceramic shell
Alloy casting with inductor or voltaic arc;
pouring, cooling, reduction of the shell, shot peening, gate cutting, heat treatments

Example of disposable pattern, ceramic shell and casting

The casting structure is formed of an aggregate of grains or polyhedral crystallites which produce isotropy by compensation, while in a solid metal they are anisotropic: it is obvious that isotropy has great advantages, for instance, FEM calculations are very close to the real behavior of the part thanks to the isotropy of the piece.

Micrography in which it’s possible to see the alpha-beta structure in the grain center and the typical annealed alpha structure at the grain border.

Isotropy By Compensation

The casting structure is formed of an aggregate of grains or polyhedral crystallites which produce isotropy compensation. In a solid metal and a CNC-machined part (such as welded part) they are anisotropic. A body is assumed isotropic when it has normal and shear
components of stress on any plane through a point of that solid, and homogeneous when this situation is valid for any point of the solid.

Normally a CNC-machined part from a forged round bar, plate or billet has an anisotropic structure. In fact, as results from the machining process stress, the structure of the forged material is composed by an aggregate of grains or polyhedral crystallites that are oriented in the space toward a unique and preferential way/direction.

On the other hand, in the casting process the structure of the piece is modified and the aggregate of grains or polyhedral crystallites are oriented at random. Therefore, the new structure obtained is definite—"an isotropic structure by compensation."

Isotropy has great advantages, such as stiffness of the parts, reliability and FEM calculations are very close to the real behavior. For that reason, Rapid Casting (since it’s a casting process) allows to produce parts with quality and properties (durability and reliability of the part) very close to a CNC-machine part, but with the advantages of the casting part, given by the isotropy structure, as stiffness and fewer design limitation.

Moreover, Rapid Casting with laser sintered patterns allows complete shape conception freedom: thus reducing undercut and tool path problems during CNC machining. It’s therefore possible to create the product along its mechanical stress axes, and to obtain a perfect reproduction of all details of the RP pattern, with tolerances and surface finishing of a very high quality (such as fully machined parts). It’s what we can call DFFF: Design For Functionality & Fun, thus allowing you to think about what you need and not how to machine it (Design for Functionality instead of Design for Manufacturing).

The Materials

In 1997, CRP began to study laser sintering technology to manufacture disposable patterns using Polycarbonate and Trueform materials. Although these materials were not suitable for titanium alloy pouring—because the high ash content remaining inside the shell reacted with the titanium alloys, producing porosity and scrubs—they proved perfect for steel and aluminium alloys.

Therefore, CRP decided to develop new materials for rapid casting patterns sintering, and partnered with DTM Corp. in 1998 to be the first to use rapid casting for hard to cast shapes such as F1 uprisers and gearboxes, and alloys such as titanium. They were first to optimize a polystyrene material for laser sintered patterns—CastForm®. For many years CRP used Castform®, from DTM Corp. for the sintered disposable patterns.

In an effort to solve issues, the CRP R&D department built on the knowledge and experience in rapid prototyping, casting and machining to become experts in the rapid casting process. This work led to CRP being recognized as a leader in the use of rapid casting for motorsport applications throughout the world. These efforts have now yielded a breakthrough in this arena.

Today the result is Windform® PS.
Windform® PS is a new polystyrene based material, suited to produce complex investment casting patterns. The sintered patterns are enough porous in order to allow the convenient wax infiltration, and therefore becoming easy to handle and to finish.

Improved properties, compared to other polystyrene materials already available on the market, and that make the difference, are:
- Improved surface quality and details reproduction
- Less “curling” effect on the first layers
- Very low ash content, therefore perfect suitable for highly reactive alloys, such as Titanium alloys too, besides aluminium, magnesium, steel and nickel based alloys.

It’s particular suited for the foundry and RP market since the main applications are:
- Complex investment casting patterns
- Casting with highly reactive alloys, in addition to typical cast alloys.

CRP’s goal was to use Rapid Casting for very high performance parts, primarily for F1, therefore having very complicated shapes and geometries, and using the best alloy available for the casting procedure: Ti-6Al4V. Thanks to CRP Method and the continuous R&D on polystyrene based material, the production of ash during the evacuation of the ceramic shell has been reduced: the ash, when in contact with the titanium, produces chemical reactions that damages the casting, and have therefore to be eliminated before pouring the cast metal in the ceramic shell.
Upright disposable model made with Windform PS and Titanium Upright

This allowed CRP Technology to become the first to use rapid casting for very hard-to-cast shapes (such as F1 uprights and gearboxes) and alloys (such as titanium).

The Ti-6Al6V is the most widely used alloy in motorsport and aerospace markets, particularly the one used by CRP. It contains 6% aluminium and 4% vanadium, an excellent combination of stress resistance and toughness, with optimal wear resistance.

Positive aspects of Ti-6Al4V are:
- lightness (density 4.43 g/cm3)
- high specific Ultimate Tensile Strength (225.73 MPa/(g/cm3)) (UTS 1000 Mpa)
- bio-compatibility
- low thermal and electrical conductivity
- corrosion and stress-corrosion resistance (SCC)

Advantages given by heat treatment of the casting are:
- stress reduction
- ductility
- workability
- dimensional and structural stability
Minardi Titanium Rapid Casting gearbox 2001

Titanium casting has a really high reactivity and that’s the reason why it needs in addition:
- Chemical milling, to remove the alpha case created when the metal touches the ceramic shell;
- HIP: Hot Isostatic Pressure applied in an inert atmosphere (argon) to eliminate micro-porosity and shortage of material inside the casting;
- TIG Weld repair in inert atmosphere to fill in porosity or HIP hollows, tested with real time RX inspections;
- Shot peening: under-control shot peening to reduce stress and increase fatigue resistance.

This technology was immediately highly appreciated by customers: it provided durability and reliability of the part (a casting is naturally isotropic for compensation), fewer design limitation to lightener (pockets) and get stiffer (adding ribs) the part during the racing season.

**CRP decided to continue to improve the Rapid Casting process because they know what their customers need: at 300kmh quality isn't optional, it's your life.**

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**THE EXPERIENCE**

**The Minardi uprights and the followers**

The first Titanium parts made for Minardi were the Cast Titanium front and rear uprights. The upright is the connecting part of the wheel where the hub transmits the engine rotational power to the tires. The suspension brackets, the front steering bracket, the rear convergence tie-rod and the brake callipers are connected to the uprights.

Minardi M02 front upright (2000 season)  
Rear suspension, in which the torsion bars are hinged in the higher part
The required properties of the uprights therefore are: lightness (it is a non-suspended mass, therefore need no resonant bumps given by heavy wheels), stiffness (any deformation compromises the kinetics of the suspension and braking) and reliability, (as one of the safety components).

The uprights were usually manufactured through a long and complicated process of forming and cutting steel sheets, which included welding, heat treatment, CNC machining and finally painting to protect against corrosion. This process can’t optimize the mechanical performances of the piece, making the uprights heavier than they should have been. Moreover, being a welded piece, it presents a structural anisotropy that shortens its lifespan, and therefore its reliability and life expectancy.

In the beginning the classic cast alloys were tested, like aluminium ones, but almost immediately CRP decided to make the big jump and study the Titanium Rapid Casting. In 1998 the study began for the **Minardi F1 team, Marc Gené** driving the test car, and the first uprights were produced in **1999**. Titanium Rapid Casting was therefore introduced in F1 by CRP Technology as a world première, in 1999.
Complex geometries were achievable only with this process, saving weight, increasing stiffness and reliability, besides giving cheaper costs than the other solutions.
In **2000 and 2001, Cast Titanium front and rear uprights** were produced for other F1 Teams whose names have to be kept confidential. 

In **2002 and 2003, The Cast Titanium front upright** was studied and produced also for the **Jaguar Racing F1 Team**, driven by **Eddie Irvine**. Later on more or less all F1 teams used Titanium cast uprights, and nowadays it remains one of the best solutions and the safest back-up in case of need.
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Considerable weight saving, high stiffness (specific coefficient of elasticity within the F1 regulations limit). The new bound of composites material.

Complex geometries achievable only with this process, weight saving and stiffness, use of 17-4 PH (steel alloy, with high mechanical characteristics), reliability.
The Minardi gearbox

In 2000, CRP also developed the Minardi Titanium Gearbox.

Titanium gearbox: season 1999 (Magnesium), 2000 and 2001 (Titanium)

After the titanium fabricated g/box (‘97 Ferrari) and the carbon fibre case (‘98 Arrows/ ‘98 Stewart), the Titanium Rapid Casting Gearbox was the latest evolution in this field and is
currently one of the few providing such a high performance, as shown by the significant limitations following its introduction on the 2000 Minardi.

The requirements are the same as those of the uprights, however in this case the complexity of the piece’s design and dimensions increases. From a direct comparison between our solution and a gearbox produced in magnesium, the results are:
- 20-25% of weight saving
- approximately 20% of dimensions saving
- double torsional stiffness
- less wear on the gears and lower power absorption, thus allowing the use of special lubricants, able to run at a higher temperature and with lower viscosity.

General advantages

Rapid Casting technology was immediately highly appreciated by customers because it provided significant advantages.

For example:
- the possibility of maximum post-stress control of the components compared to carbon laminated parts
- durability and reliability of the detail (a casting is naturally isotropic for compensation)
- fewer design limitation
- the possibility to lightener (adding pockets) and get stiffer (adding ribs) the part during the racing season.

Outside F1

After having consolidated with success its innovative transformation technologies, CRP decided in 2002 to begin the first cooperation out of the F1 circuit. The intention was, and is, to introduce into other motor series new hi-tech solutions, in order to increase mechanical performance and reliability.

CRP has cooperated in many different series using Titanium Rapid Casting first, and, being Titanium banned in some series in 2003, Steel special alloys Rapid Casting later.

Mitsubishi Dakar

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In WRC and Rally Raid, CRP Technology strongly cooperated from the first design stage, in order to optimize the part project together with the constructors’ technical staff, and this alliance was finally rewarded.

**2002**

In 2002 Peugeot Cast Titanium front and rear uprights were studied and produced for the Peugeot WRC Official Team and MARCUS GRONHOLM won the World Rally Championship with these Titanium uprights made by CRP. This solution had cheaper costs compared to the other ones made in Titanium alloy.

In 2002 CRP began also to use 17-4 PH, a steel alloy with high mechanical characteristics. “Process and production of mechanical parts through investment casting made by 17-4PH steel alloy did allow us first to gain a weight saving, second to obtain a structural behavior with higher efficiency, as well as much better final quality”, Franco Cevolini, CRP Technology’s Chairman, explains. “The perfect synergy between our partners’ and CRP technical offices has always facilitated co-design of the component, obtaining an excellent mechanical performance, respecting the foundry requirements”.

CRP therefore made the study and production of the Cast 17-4 PH front and rear uprights for the 3GR Cadillac official ALMS Team.

**2004**

In 2004, CRP studied the same kind of uprights for the Mitsubishi official Rally Raid Team (Paris-Dakar). CRP also studied and produced prototypes of the Cast Titanium front and rear uprights for the Citroen Official WRC Team.
2005

In 2005, Mitsubishi Repsol Official Rally Raid Team and with LUC ALPHAND won the Lisbon-Dakar Rally Raid with 17-4PH Steel uprights made by CRP.

2006

In 2006, CRP Technology made the study and production of the Cast Titanium 17-4 PH front and rear uprights for the Mitsubishi Repsol Official Rally Raid Team and the study and production of the Cast Titanium front and rear uprights for an Official Le Mans Team. Once again, it was a great success for Repsol-Mitsubishi in the Dakar 2006.

2007 - The winning synergy: Mitsubishi experience, 2007 Paris-Dakar

The last part that CRP made for Mitsubishi is for the 2007 Mitsubishi Pajero / Montero Evolutions. It is again the racing wheel upright for Rally Raid car, which is the typical part holding the wheel hub bearing and formed with various mountings and brackets for suspension attachment (wishbones and damper), and in addition various analysis sensors.
After validation from Mitsubishi engineers, CRP has begun the productive cycle involving its internal Rapid Prototyping department. After full inspection, these sintered PS lost patterns have been used for the casting process. The CNC (Continuous Numerical Control) service has completed various tests on the parts, including NDT (Non Destructive Test) inspection, allowing the uprights to be fully finished in short time period for car building.

“The opportunity of being able to decide between different manufacturing processes inside the same company is fundamental to guarantee the best result. The flexibility of a highly selected staff assures, moreover, reliability and respect of the total timing” indicates Franco Cevolini. “This is one of the reasons why Mitsubishi has decided to renew the winning synergy with CRP Technology”.

The extreme conditions of an event like the Dakar Rally highlights the talent of those who work for you, leaving no margin of error, and rewarding the best collaborations. As for the '07 event, further optimization will be considered on these mechanical components, following the same process, with similar goals, i.e. further weight saving and increased stiffness.

Upright design trends – Mitsubishi Pajero/Montero Evolutions (2007)

Example - Lower mounting point

New design for the cage to get uniform wall thickness all around in order to improve casting quality and to save weight, together with a new distribution of the ribs for better response to the mechanical requirements caused by stress. The “cap type” structure is a direct response to the structural calculation made on the model, and thanks to this new morphology, the result was a more uniform stress distribution and obvious weight savings. This was especially the case in one of the key areas of the upright.

The collaboration between Epsilon Euskadi and CRP Technology began at the end of 2007 with the aim of optimizing some crucial safety features of the new Epsilon Euskadi ee1 for the Le Mans Series and the 2008 Le Mans 24 Hours: front and rear uprights cast in titanium using the CRP Rapid Casting method.

The key to the success of the project was a close partnership between CRP Technology and Epsilon Euskadi that began from the CAD drawings through the first prototype and into the final construction phase. The ee1 project began in 2004, the year in which Joan Villadelprat, with his 30 years of experience, took over the reins of Epsilon Euskadi (until then only a team in the Renault World Series). 2005 saw the official launch of the ee1 project, under the technical direction of John Travis, previously an engineer with Lola and then with Penske and in F1. At the end of 2007, the technical management of the project was taken over by Sergio Rinland, who in his turn had a past in F1.

The synergy between Epsilon Euskadi and CRP Technology has, therefore, been fully achieved in the development of one of the key components of the suspension system, as well as the core business for CRP: titanium uprights.

In particular, considering the vast experience that CRP has gained in Formula 1 and in WRC (World Rally Championship) in the research and manufacture of the parts mentioned above,
the specialised technicians within the company are devoted to engineering Epsilon uprights with the use of high-precision investment casting, in titanium alloy, with patterns made in Rapid Prototyping.

But to produce a component using this method, the racing team’s partner, in this case CRP, must have exhaustive knowledge of the various materials and excellent command of the different construction processes that are used in succession. Naturally, synergy with the team’s technical project department is essential and, as a consequence, the knowledge of how the part works and therefore the performance required. That is why this method, although extremely effective and efficient, is less widespread than other processes that are more outdated, less functional and often more expensive: the team needs an expert partner that can follow the entire process and bring it to a successful conclusion, with the utmost safety and quality. Therefore, they can no longer be considered simply suppliers of orders and based on a design, but much more. At present, very few in the world have been able to gain the same vast experience as CRP in this method, which indeed was first developed by them: 12 years experience in the motor sector at the highest levels guarantee that clients can be sure that they are getting the very best, with the highest levels of safety and with very few problems.

Epsilon Euskadi upright’s pattern

The stages of the CRP method for this particular experience will be published after the 2008 Le Mans 24H, together with a detailed description of the various phases: that will highlight the need for expert knowledge of plastic materials and metal alloys for making disposable models and finished parts, Rapid Prototyping processes, Reverse Engineering for quality control of all stages, engineering and FEM calculation, casting processes, CNC processing, non-destructive testing both during process phases and at the end of processing, CMM dimensional controls and much more, to guarantee the total and complete traceability of every part, from the certification of the metal alloy used to the certificate of final testing, before being mounted on the vehicle.

Conclusion

All this is possible solely thanks to the very long experience that CRP has made during the last 11 years, what we call the “CRP METHOD”. So many years of study, improvement and optimization, allowed us to reach the highest level worldwide. The necessary know-how of Rapid Prototyping (creation of lost patterns), casting technology, design optimization (being able to adapt the design to the casting technology, with its needs), materials, alloys, and so on. A very high level thanks to a very long and deep experience.
It is very important also to understand the needs of the clients and the parts (loads, work conditions of the part, etc.) thus implying the maximum collaboration between the customer and the supplier (CRP) in order to adapt the part to this technique.

CRP will continue to study new materials and work alongside the racing teams in order to find always the best solution for each partner, helping the teams’ staff on engineering, right materials choices, right design suited for the right material and relative manufacturing process, manufacturing process optimization, quality and short delivery times, as motor sport industry requires and as only a lean and flexible company can do: It boosts production and choice, whilst still remaining a small, managerially agile company.

This is for sure a winning strategy, because racing teams need exactly a "KEY IN HAND" product, immediately ready for the race.