Sport case-study

Rapid Prototyping application: a tennis racket scale 1:1 model made with Windform® materials and SLS Technology

Introduction

Creating a prototype is always a challenge. It involves stepping over the limits of knowledge and experience. The Rapid Prototyping represents the most advanced technique in obtaining, in rapid time, the finished testing model.

CRP Technology is a pioneer in Rapid Prototyping application and SLS technology, having started in 1996 with the RP technology analysis, when it was almost unknown in Italy.

CRP has developed new cutting edge materials, including WINDFORM® materials for laser sintering technology. These materials are suited for wind tunnel applications as well as finished running parts.

Currently the WINDFORM® range consists of WINDFORM® GF, WINDFORM® PRO, WINDFORM® PRO B, WINDFORM® XT, WINDFORM® FX, WINDFORM® PS (suited to produce complex investment casting patterns) and the new WINDFORM® LX.
They can be distinguished by their specific characteristics, thermal and mechanical properties, the surface finish and by the colour of the finished product.

They can assure:

- High performance level and prototype definition
- Maximum adhesion of the project to the prototype
- 100% guaranteed functionality to effect all necessary and useful tests for the final use.
- Extreme reliability and resistance for the adaptation testing.
- The aesthetic verification and immediate ergonomics
- The speed of execution, fundamental for highlighting project errors.

This allows for there to be no limit to the use of WINDFORM® materials: from the Aerospace sector to Design, from Racing to Electronics, from Automotive to Entertainment, from Consumer products to Lighting systems and many others. There is always a WINDFORM® product suitable for every type of application depending on the prototypes' characteristics and planning needs.

Along with WINDFORM® high material quality, CRP Technology has a very rigorous policy of client service and is able to satisfy all the demands of a market which is continually changing.
In addition to quality standards CRP Technology guarantees at all times:

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- Client service assistance from the creation to the finished prototype.
- Client service assistance to guarantee the correct use of the powders and to practice the best sintering.
- Sharing of *CRP Technology's* know how with the end users to promote correct and optimal use.

Moreover, after the introduction of Reverse Engineering CRP can offer digitalization of a physical model and reconstruction of CAD models, carrying out Rapid Prototyping directly from the scanned STL files as well as dimensional control of parts and tooling.

Abstract

In late 2007 CRP Technology, together with its Windform® materials, took part in a major initiative together with **PRINCE SPORTS**.
Prince Sports is a leading company in the sports sector and more specifically in the world of tennis. Its aim is to make technologically innovative products able to cater for the requirements of top-ranking professional players, and at the same time upgrade the playing performance of all those enthusiasts who enjoy this sport. The company controls the Prince brand (tennis, squash, badminton), Ektelon (racquetball) and Viking (platform/paddle tennis) and boasts the introduction, over the last 30 years, of novel solutions that have revolutionised tennis, such as the first "oversize" racket; the first "longbody" racket and O3 technology, the last successful patent to be applied not only to the new collections of distributed brands but, thanks to cooperation with world sports companies, also to other sports equipment. Apart from sports equipment, Prince is also investing in the footwear and clothing trades.

Such cooperation is in fact clear evidence of the versatility of Windform® materials, which are able to cover different types of products and to thus satisfy customer requirements, whether these are of a functional or an aesthetic nature.

Examples of this are the two projects followed by our CRP Technology RP department and begun in September 2007, as exclusive partners of Prince Sports S.r.l. (Italy), located in Gardigiano di Scorzè (VE).

Prince Sports is a group consisting of four specific entities: PRINCE SPORTS INC (USA), main headquarters of the firm, where all the brand management managerial and marketing activities are located, PRINCE SPORTS EUROPE (UK) which deals with all the brand sales in Europe and the Far East, PRINCE SPORTS TAIWAN (TW) in charge of productive sourcing, and finally PRINCE SPORTS srl (ITALY) which presents, looks after and develops research and innovation projects which represent cornerstones for the development of all PRINCE collections throughout the world.

PRINCE SPORTS srl (ITALY), besides presenting and industrialising products, also features an in-house laboratory in which all the products being developed and those currently in production are characterised and tested. The Italian branch of the tennis giant uses innovative design and research tools such as, for example, latest-generation three-dimension CADs, structural analysis software, 3D prototyping equipment, microscope analysis laboratory equipment, high-frequency chamber analysis, etc, etc.

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The projects and the goals

The cooperation begun in the latter months of 2007 can in fact be split into two applications:

1. a first application of a functional nature, concerning the manufacture in Windform of 9 samples of inserts/outer clips surrounding the perimeter of the racket. From the very start, our customer wanted to obtain samples, based on our experience, that could be tested, and therefore used, during the game.

2. a second application of a strictly aesthetic nature, as a direct evolution of the project described above, studied for the launching of the world preview of the new 2008/2009 Prince Sports collection: the production of a prototype tennis racket in scale 1:1 that was as close as possible to the real model to shortly be manufactured.

   At the end of January 2008 in fact, the new technology was presented in world preview in the USA for the 2008/2009 collection, the anticipation of a series of models that will complete the Prince collections for the next 4 years.
   The prototyped model will in fact be the first of a series of rackets inspired by the same technology, different in terms of the string plate, weight characteristics, rigidity, quantity and distribution of the string mesh and performance in general. The collection will be completed with 30 models and these will be developed during the course of the next two-three years.

   The aim then is to obtain an aesthetic sample that represents an element of reference to demonstrate and make tangible the technological innovation of the product and make the design and graphic effect as realistic as possible.

The research and development of the materials used for both the above applications have been completely entrusted to CRP Technology s.r.l, as regards both their study and analysis, and the most suitable choice of materials, considering their weight and mechanical specifications.

Project 1: Windform and SLS technology for functional prototypes

The insert sample project was immediately tackled by our RP department with great enthusiasm and right from the early stages of the project close focus was placed on the goals indicated by the customer, always in a customer-oriented perspective.

Hence the targeted attention in solving problems relating to the choice of material, with special focus on problems relating to their use in the field.
A first problem to be overcome was the need to identify the material best suited to providing a minimum amount of strength in view of the thickness, the required functionality and the various stresses which the clips would have to undergo (even though these were assembled inside the tennis racket and were therefore well supported).

The initial choice fell on our best prototype material **Windform® XT**, charged with carbon fibre, by virtue of its unparalleled dimensional accuracy, definition of detail and maximum breakage load properties, which have made it the Rapid Manufacturing material *par excellence*. Windform XT, carbon fibre filled, allows the creation of high-end functional prototypes and production parts for the F1 world and wind tunnel applications.
WindForm XT is characterized by stiffness and extremely high UTS, excellent surface finish, resistance to extreme wear and an optimal reproduction of detail.

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WindForm XT offers an alluring, black, sparkling look, regarded in many design and aesthetics applications, as our example.

A second obstacle concerned the analysis of the shapes proposed for the clips: of the two geometries initially suggested, one appeared fairly thin and fragile, in view of the very reduced thickness, while the second shape was undoubtedly stronger and therefore permitted making clip prototypes in conformity with the resistance and strength requirements of the customer.
Both shapes were nevertheless considered in the manufacture of the 9 clips and underwent both laboratory and practical tests.

From a first feedback from Prince Sports Italia's R&D staff, it appears that the first of the two sampled prototypes was for absolutely untestable shape and thicknesses. The second on the other hand confirmed excellent results in terms of strength and traction resistance. The insert was fitted on a tennis racket without any particular problem and subsequently characterised with their usual laboratory tests. After testing, the clips underwent practical field tests to stress the component by applying normal-use loads.

During the course of the above practical tests, the XT insert unfortunately gave way. The grommet support stressed by static tension (produced by racket stringing) and then by impulsive loads (produced by the impact of the ball on the string plate) collapsed during the game.
We must however take into account a static load for each single string of around 35 Kg and 70 kg if we consider the geometry of the grommet, calculating the tension of two strings (both as maximum tension recommended by Prince Sports stringing instructions) and a dynamic load (meaning the dynamic load produced by the impact of the tennis ball during the game) of 100 kg (50 kg for each string, therefore 100 kg for each single grommet). We can therefore say that on the single string support element, we can achieve impulsive loads of 170 kg.
Considering such data, however, our customer expressed great satisfaction with the results achieved by the insert and our Windform® XT.

This first test did not however represent an obstacle as regards project development, but rather the departure point that resulted in the customer deciding to boost the work still further and to confirm his desire to also use our Windform® materials for a second project, with different aims. Hence his willingness to examine new materials belonging to the Windform® family.
After careful analysis by our R&D and RP department, the customer was presented with the latest addition to the Windform range: the Windform® FX.
Considering in fact the assessments regarding the load and functionality of the piece supplied by the customer, we thought it might be a good idea to test a new insert, this time made using our new Windform® FX material. In view in fact of the latter's exceptional resistance to repeated bending and torsions stresses, this looked like a valid alternative to the XT insert to better withstand the required dynamic and static loads.

A further step forward in the project was that relating to the updating and implementation of the mathematics of the clip to be developed. The customer elongated and extended the insert along the entire racket perimeter. The design was upgraded and structure-wise, the experience of the first prototypes was exploited to increase the performance durability of the piece.

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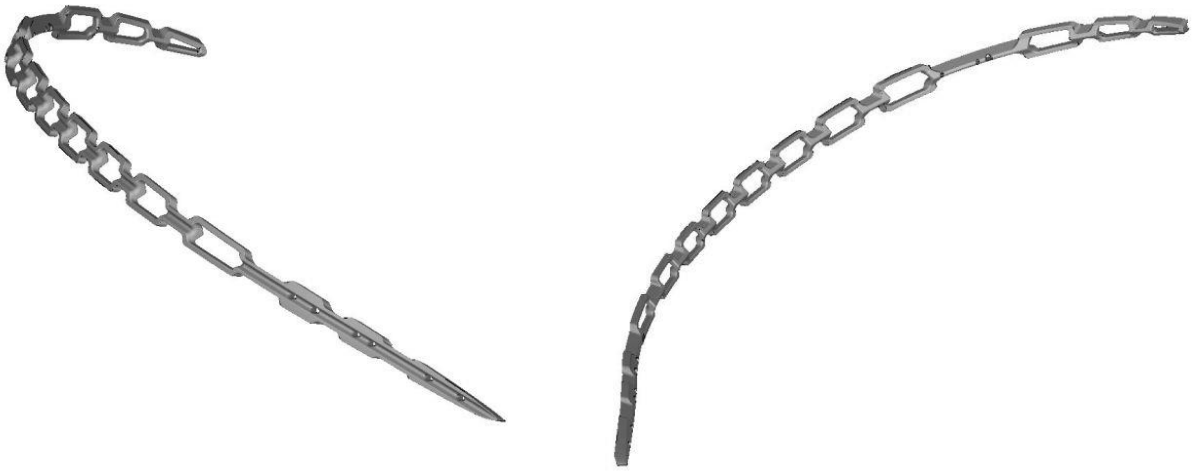

Picture 1: The final geometry of the clips: the customer elongated and extended the insert along the entire racket perimeter.

After studying the updated file and duly verifying feasibility, including from a dimensional viewpoint, our RP department went ahead with the production of the FX clips.

Results

This second solution for the production of the surround inserts achieved the success that had been hoped for. In the customer's opinion too, the samples appeared surprisingly flexible and strong.

Picture 2: Sample of the clips made by Windform FX

Despite the fact that these prototypes were used as demo samples, in any case, the frame stringing procedure resulted in each of the strings tied on the frame undergoing about 15 kg of tension (30 kg per grommet, tensioned by two single strings). Consequently, the prototyped inserts underwent about 200 kg of static load. The considerable flexibility together with the

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tenacity of the materials used enabled the inserts to withstand the load tensions without any resistance problems. And this becomes all the more important if we consider that a major deformation of the inserts makes the frame unstable with consequent stroke imprecision.
The performance of the piece in terms of resistance, in fact, affects the performance of the racket considerably. The loss of energy due to insert deformation or torsion greatly reduces the quantity of useful motion necessary to restore as much energy as possible, and therefore speed, to the ball.

The advantage of using Windform, was therefore clear from the answer to the question: "What are the limits of the previous production method, before cooperation with CRP technology?" to which the customer answered: "The materials generally used in the past for rapid prototyping could not represent a reference for any laboratory test and/or ideal for analysing the stringing procedure. Now, with Windform, this is possible".

The Windform materials permit obtaining all the properties required for assembly tests, wind tunnel tests, display to customers and also for design analyses: SLS technology provides complete freedom of shape and the Windform materials ensure the necessary mechanical performance.

Project 2: Windform and SLS technology for design application

The next step was to fit the tested Windform FX inserts inside the complete racket model, upshot of Prince R&D activities for the new season.
This new request very definitely has a different aim, not related to functional tests, but rather to an application substantially of an aesthetic and design nature, to which the materials of the Windform family in any case adapt well.

The parts making up the model in scale 1:1 and which were made by us are: the frame structure, the relevant inserts or clips surrounding the perimeter of the racket (the only ones to be also tested in terms of function) and a bumper meant to take knocks, positioned on the racket head.

Picture 3: The main parts of the Prince tennis racket, made by Windform FX and GF

All the parts in question were subsequently varnished to make them look more realistic.

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The prototype was in fact essentially used to present a new model and consequently the quest for and the choice of materials used was targeted on making the latter as consistent as possible with reality, maintaining the real overall dimensions and, partially, the weight and mechanical characteristics of a number of component parts.

The dimensional consistency of the different component parts making up the assembly made it possible to cut the dimensional and assembly evaluation times of the different component parts making up the assembly. Last but not least, the prototype underwent stringing procedure. Prototype stringing drastically speeded up the usual technical evaluations as regards the finished product, ensuring the prepared equipment.
From what our customer, Prince Italia srl., says, the tremendous flexibility and strength of the Windform® materials used also allowed excellent resistance of inserts and frame during the stringing phase.

In any case, let us now take a detailed look at three component parts of the model.

The Frame

The choice of material to make the frame certainly took into account:

1.the dimensions of the structure in relation to the sintering volume of our RP machine, equivalent to a maximum of 330 x 380 x 420 mm.
If the frame structure is too big with respect to the work dimensions, it is in fact necessary to cut the model into several parts and then glue the single parts together using a special structural epoxy resin. This does not however affect the effectiveness and functionality of the end model, but does require a careful *a priori* study of the model and of the area in which to make the cuts to avoid affecting the end performance of the prototype.
The dimensions of the considered file did in fact make it necessary to cut the model structure into three parts, then glued and assembled by us, with utmost definition and reducing as much as possible the steps between the three glued parts which, so the customer says, "were almost impossible to notice".

2. the ultimate purpose of the prototype and the ultimate loads this had to withstand.
According to the customer's instructions, the model to be made was "static" including with purposes of an aesthetic and not very functional nature.

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Nevertheless, considering the curiosity of the people taking part in the meeting and the possibility of touching the model, it was thought a good idea to consider a certain sturdiness of the material to make the prototype.

For these two main reasons, the choice fell on our Windform® GF material, the first of the family, a composite material with the addition of aluminium and glass, light grey in colour. This is very definitely suitable for a number of applications, such as in wind tunnels and also design and functional applications, given the upper strength, the excellent surface finish, the resistance to wear, the excellent reproduction of details.

The decision to use a different kind of Windform® material for the racket structure compared to that used to make the bumper and inserts proved to be a winning one for various reasons:

- notwithstanding the dimensions exceeding the sintering volume of our SLS machines, the aesthetic yield of the model fully satisfied the customer and had no negative consequence during demo.
- excellent surface finish and excellent detail reproduction definition.
- cutting of production times
- reduction of costs considering that the GF material is undoubtedly that which, within the Windform family, offers the best value for money.

The Bumper

This last part on the other hand was made from Windform® FX, just like the previously created and tested inserts. In fact, this part also seemed particularly suitable for our new white material, in view of its exceptional resistance to repeated bending and torsion stresses. Naturally, for the ultimate purpose of displaying and launching the racket on the market, it was not necessary for the customer to test this part on the court, but the flexibility of the material chosen to make it well combines with the functionality of the bumpers positioned on the racket head.

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Picture 4: the bumper made in Windform FX

The Inserts

Fitted to the final model presented in America were the same inserts made in FX and previously tested with excellent results.

Results

Once the model was terminated and its three main parts assembled, the racket underwent our usual smoothing process and was then sent to the customer for final varnishing.
For the purpose, the entire frame, made in GF, at our suggestion and considering the customer's requirements, underwent a post-machining surface treatment to polish up the surface of the racket and make it more suitable for varnishing, so that no product imperfections would show.
The Windform® GF material can in fact undergo various treatments, e.g., to better smoothen the surface or make this more resistant to contact with liquids in general.

As regards the final result, let this be summarised by the comments of our customer:
"The prototype racket was appreciated both for its new technological concept and for its geometric and aesthetic accuracy. The aesthetic solution has been considerably upgraded and defined.
From a practical viewpoint, the possibility of stringing a prototype has undoubtedly speeded up the considerations of the stringer and therefore speeded up the industrialisation of the finished product.
The laboratory and practical tests currently being performed will undoubtedly offer us the chance to upgrade and refine the analyses and designs of the component parts so as to be able to also use the prototyped pieces on the tennis court."
In addition to this, in agreement with the customer, we can say that the frame gave no problems as regards resistance, the latter being only a support for the inserts that withstand the load of the strings.
From a technical viewpoint, the tension of the strings certainly forces the inserts to withstand a considerable concentrated static load. The grommets, on which the strings are wound, underwent a uniformly distributed load of around 30 kg, while in the case of the production samples, the static tension on the support bridges reached 70 kg and further increases in dynamic regime (during impact with the ball). As I said however, in this case the prototype was not dynamically tested.

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For this reason, the final rackets are made in laminated carbon.

Picture 5: Final racket

This racket in fact will be made entirely of carbon fibre and will have a weight of 240 g (finished with varnishing, plastic parts, strings etc.). The weight of the raw frame is expected to be around 180 g even though the accessory parts make it heavier of course.

We can therefore end by once more underscoring the effectiveness of RP and SLS technology combined with our Windform materials which, together with SLS technology are able to back and coadjuvate the design phase for the determination of the limits and possible faults affecting the work done, making the manufactured parts "ready to use" and also making it possible to test them and carry out functional tests.
Secondly, the Windform materials have proved able to also satisfy the customer's aesthetic requirements and thus also cater for applications pertinent to the design market, where presentation of the product to the customer is extremely important, to be able to offer the chance to actually experience first hand a model that is completely realistic, which perfectly reproduces the final project in detail and which allows considerably cutting product customisation development times.

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