Development and design of parts for 2K injection molding

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nascannované zadání s. 1

nascannované zadání s. 2

ABSTRACT

Replacement of structural applications with stiff plastic is difficult. Main hurdle is not to achieve the desired stiffness, which we manage though design but to maintain part integrity after severe abuse. Very often, not maintaining part integrity after a crash test is stopping the project.

This is the case for Full Plastic Front end Modules, Plastic Steering Wheel but also Safety Helmets for Police and Fire-fighters.

The goal of our studies is to find the composition of materials which are good at impact test and have good rigidity at different temperatures. We already have materials which are very good in impact but they are not rigid enough. And on the other hand we have super tough materials with poor mechanical properties in impact. So the aim is to have a right combination of these materials such we get compromise of their properties or even to get a synergy effect.

Keywords: Injection molding, 2K molding, DuPont de Nemours, impact test

ABSTRAKT

Tyto projekty a celý výzkum Vývoje a konstrukce dílů pro dvoukomponentní vstřikování jsem dělal během stáže v DuPont de Nemours v Evropském technickém centru v Meyrin, Ženeva, Švýcarsko. Patřil jsem do oddělení Inženýrství polymerů, kde jsem pracoval pod mým vedoucím Guiiloume Doy, který je Technickým produktovým specialistou na materiály Zytel®, Miramid® a Crastin®. Postupně jsem pracoval na různých projektech na vstřikování plastů, testování a vývoje. V DuPontu jsem pracoval rád, především kvůli profesionálnímu přístupu, prestiži, typické pracovní mentalitě, bezpečnosti a možnosti výzkumu.

Systematicky jsem pracoval na mnoha menších projektech, které mě měly připravit na samostatnou činnost ve společnosti pro řešení již mých projektů. Díky tomu jsem měl možnost být trénován na různých testovacích strojích a mohl tak navštívit mnoho laboratoří v DuPontu. Během této doby jsem se naučil mnoho o plastech, marketingu a pracovnímu

systému ve velké mezinárodní společnosti, kde jsem měl možnost bavit se s nejlepšími inženýry a techniky na světě o plastikářských procesech a nových materiálech.

Po dobu zaučování, tedy různých tréninků v ISO laboratořích a pracování na menších projektech jsem si byl schopen udělat přehled o chování plastů a jejich mechanických vlastností. Zaučil jsem se na strojích jako je tahová zkouška, rázový test i Charpyho kladivo, shrinkage zařízení. Mimo mé projekty jsem navštěvoval ostatní laboratoře a oddělení, kde jsem se postupně seznamoval s vytlačováním, výtlačném vyfukováním, výrobu vláken, zkouškou na hořlavost, svařováním plastů různými způsoby, galvanickém pokovování, aplikace s Kevlar® a Nomex® vlákny a další. Především jsem se ale věnoval vstřikování.

Za dobu, co jsem byl na stáži jsem se stal specialistou v oboru vstřikování plastů. Byl jsem trénován na různých vstřikovacích strojích, především na DEMAG 150, ENGEL 150, ENGEL 175, NETSTAL 150, NETSTAL 175 a BILLION. Během zaučování a pracování v Molding shopu jsem viděl spousty různých nápadů a procesů, ke zdokonalení vstřikování. Vážím si této příležitosti, protože Molding shop z DuPontu učí svět vstřikování.

Můj první výzkum v DuPontu nese název této bakalářské práce. Je to Vývoje a konstrukce dílů pro dvoukomponentní vstřikování. Cílem zkoumání je najít takovou kompozici materiálů, které mají dobré předpoklady být odolné při rázové zkoušce za různých teplot. Na výběr jsem měl samozřejmě materiály z DuPontu. Již existují materiály, které jsou velice odolné při rázové zkoušce, ale to jsou elastičtější materiály, které nemají dostatečnou pevnost. Na druhé straně máme materiály, které jsou velice pevné, ale křehké. Proto je cílem této práce zkombinovat tyto dva materiály 2K vstřikováním tak, abychom dostali kompromis jejich vlastností, nebo dokonce synergický efekt.

Hlavní překážkou tedy není dosáhnutí požadované tuhosti, protože tu ovládáme sami, například přidáním plniv. Velkým problémem je tedy udržet výrobek pohromadě i po značném namáhání. Velmi často, díky necelistvosti výrobku po nárazovém testu, následuje zastavení projektu.

Tento nový kompozitní sandwich by mohl najít uplatnění u plastových čelních částí vozidel, plastového volantu, ale také ochranných přileb pro policii a požárníky.

Klíčová slova: vstřikování plastů, 2K vstřikování, DuPont de Nemours, nárazový test

ACKNOWLEDGEMENTS

I would like to express my many thanks to my supervisor in DuPont de Nemours **Guillaume Doy,** product technical specialist I was in contact with and learned lot about company, plastic materials, processing and about lot of others things.

Another person I would like to express my many thanks is to my supervisor in Institut National des Sciences Appliquées de Lyon in Oyonnax **M'hamed Boutaous** and my supervisor in Tomas Bata University director of Faculty of Technology doc. Ing**. Miroslav Maňas**, CSc. for their help and care about my internship and thesis.

And also I would like to express my thanks to all in Molding shop and to all in laboratories at DuPont de Nemours in Meyrin - Switzerland who taught me lot of about plastics.

Motto: Hlupák je nebezpečný teprve ve chvíli, kdy si myslí, že je genius.

Prohlašuji, že jsem na bakalářské práci pracoval samostatně a použitou literaturu jsem citoval. V případě publikace výsledků, je-li to uvedeno na základě licenční smlouvy, budu uveden jako spoluautor.

Ve Zlíně

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Podpis diplomanta

SUMMARY

INTRODUCTION

I belong to DuPont de Nemours in European Technical Centre in Meyrin, Switzerland, department Engineering Polymers, focused on working with Zytel®, Miramid® and Crastin® doing injection molding, testing and investigating new things. It is pleasure work in DuPont because of the prestige, typical working mentality, safety and founding new things.

I was working systematically for many little projects to be able to manage my own big project. Such I was trained at lot of machines and visited many of laboratories of DuPont to see process to better understanding of plastics. Also I could talk to top professional engineers and technicians about plastic around the world. After that time I learned lot of things about plastics, marketing and system of working at the international company.

During making little projects I was learning about utilization of plastics in industry, mechanical properties of plastics, shrinkage - warpage problems, mould deposits of plastic materials, importance of the right melt temperature of plastics, weld lines, welding, coating, Kevlar® application, Nomex® textiles and others.

I got an idea about testing of plastics during many training in ISO laboratory as tensile machine, charpy machine, impact machine, shrinkage machine, flammability machine and I have seen others tests to have a overview.

I became a specialist in injection molding during working at my projects in Molding shop. I was trained on certain injection machines. I have seen lot of new ideas to progress processing of molding. Because of the Molding shop in DuPont teach the world of injection molding.

I found the internship in DuPont as very rewarding due to experiences I got here and due to professional growth I made.

I. THEORETICAL PART

1 INTERNSHIP AT DUPONT DE NEMOURS

1.1 History of Dupont de Nemours

Eleuthère Irénée du Pont (E.I.) (1771-1834) broke ground on July 19, 1802, for the company that bears his name. He had studied advanced explosives production techniques with the famous chemist Antoine Lavoisier. He used this knowledge and his intense interest in scientific exploration – which became the hallmark of his company – to continually enhance product quality and manufacturing sophistication and efficiency. He earned a reputation for high quality, fairness and concern for workers’ safety. [1]

When the company turned 100 in 1902, is was widely respected but also weighed down by tradition. That year, three young du Pont cousins – T. Coleman, Pierre S. and Alfred I. – purchased the company from their older relatives and began to transform it from an explosives manufacturer into a broad, science-based chemical company. The trio modernized company management, built research labs, and marketed new products like paints, plastics and dyes. [1]

DuPont established the Experimental Station in 1903 near Wilmington, Delaware, to conduct and promote scientific research as a major platform for industrial growth. The facility was DuPont's first general scientific laboratory and the site of many of the company's most spectacular research triumphs, including neoprene, nylon and Lycra®. [1]

William Hale Charch (1898-1958) made one of DuPont’s most critical cellulose chemistry innovations and helped guide the company’s development of synthetic fibers. Charch earned a Ph.D. in chemistry from Ohio State University before joining DuPont in 1925. One of his first assignments was to develop a means of moisture proofing cellophane so that the attractive wrap could be used for food packaging. Moisture proof cellophane, marketed by DuPont, quickly transformed food packaging and marketing worldwide. [1]

Like so many miracles of science, the profession of chemical engineering emerged, in essence, from DuPont laboratories. Chemical engineers study processes like distillation, heat transfer and fluid flow common to most chemical reactions, and design the structures in which these reactions occur. The DuPont chemical engineering research group developed the chloride process for making titanium dioxide pigment and the production processes for neoprene, nylon, Dacron® and Orlon®, and systems for plastics recycling. The group's expertise also was instrumental in the design and construction of the first nuclear reactors. [1]

Kevlar® is well known as the material in body armor worn by police officers and soldiers. In 1964 Stephanie Kwolek at DuPont's Pioneering Research Laboratory synthesized an aromatic polymer (one spun with a solvent rather than melt spun) that produced a durable and exceptionally strong fiber. Throughout the 1980s, DuPont introduced new varieties of Kevlar® for such uses as cut-resistant gloves and lighter-weight body armor. More than 2,500 lives have been saved by officers wearing body armor. [1]

Nomex® heat resistant fiber grew out of work done in the late 1950s at DuPont's Pioneering Research Laboratory by Paul Morgan and Stephanie Kwolek. After an unprecedented investment in development – including the establishment of a pilot plant at the Spruance plant in Richmond, Virginia, in 1959 – DuPont introduced Nomex® in both woven and non-woven form in 1967. Offered in paper, felt, fabric and fiber forms, Nomex® serves a variety of industries, but remains best known for its use in fire-fighter's apparel. [1]

As DuPont entered its third major transformation in 1999 – adding biology to chemistry as a core science platform – the firm unveiled its new corporate brand identity. The miracles of science®. It describes the essence of DuPont, including the company's promise for the future. DuPont has a rich history of bringing science to the marketplace in ways that change the way people live. The miracles of science® embodies the company's ability to make leaps that deliver science-based solutions for a better world. [1]

1.2 European Technical Centre, Meyrin, Switzerland

Meyrin, Switzerland, is the site of the DuPont European Technical Centre (ETC), the company's main research, product development and customer support centre on the continent. The ETC was built in 1987 to serve DuPont's rapidly growing European markets. Its Meyrin location places it near Geneva, headquarters of DuPont Europe, formerly DuPont de Nemours International SA. DuPont ETC engineers and technicians provide consultation to manufacturers in the automotive, appliance, electronics, filtration, sporting goods and consumer products industries. In 2001 DuPont completed a major expansion of the ETC, including laboratories for DuPont Advanced Fiber Systems and new blow-moldings processing facilities for DuPont Engineering Polymers. The ETC employs approximately 280 people. [2]

1.3 My noticed to internship

Because of the rich history more than 200 years of DuPont and typical way of thinking it was necessary to lock together with others from DuPont. Such I belong to DuPont group. It was very nice and if I had any problem they were ready to help me in each case, about all problems which could happen; about salary, psychology, doctors, insurance etc. It does not matter if I do not need it but it does when you really need.

But what was really important they helped me in “professionals” questions as are so important for future growth. For all the questions there is someone who can give you an advice.

Before I started my own big project I got a lot smaller ones. I was in contact with people and learn something about the company. Also I made some training at different machines and such I learned more about DuPont mentality and safety and met a new colleagues.

I was talking about safety. Here in DuPont it is very important part of working and thinking. Almost everywhere you have some sign giving you lot advices. Lot of training of safety is obvious. The goal of the DuPont is to have no injury in their site and they do a lot for this. This image gives an idea about philosophy of company and also it helped them to sell the safety products as DuPont is important supplier.

My direct boss was Guillaume Doy. He is working in ETC in Meyrin and he is responsible for Zytel®, Minlon® and Crastin® materials of DuPont. I am his intern and I was in contact with him and learned lot about company, plastic materials, processing and about lot of others things.

2 INJECTION MOLDING

The injection molding of plastic is the most common process by which plastic compounds are converted to useful products. It represents the most important process for manufacturing plastic parts. In most cases finishing operations are not necessary.

An important advantage of injection molding is that with it we can make complex geometries in one production step in an automated process. Typical injection moldings can be found everywhere in daily life; examples include toys, automotive parts, household articles and consumer electronics good etc. [3]

2.1 Components of the Injection Molding Process

For doing injection molding is necessary to have the injection molding machine, the injection mold and tempering system. The injection molding machine composes of injection unit, clamping unit, control system and hydraulic system or electric motor.

2.2 The Injection Molding Process

The central element of the injection molding process is the mold. The mold is made of at least two parts, which are clamped on the injection molding machine. For different molding geometries, different molds are usually necessary. Each mold contains a cavity, into which the plastic material is injected and which forms the final part geometry. [4]

The complete injection molding cycle takes place in several steps. [3]

1) Start of plastication: The screw rotates and transports melt to the screw chamber in front of the screw tip. The screw returns, sliding axially.

2) End of plastication: Screw rotation is switched off. In the screw chamber there is now just enough material to make the molding.

3) Closing the mold: The clamping unit moves forward until the mold halves are in close contact.

4) Start of injection: The screw moves forward axially without rotation and transports the melt into the cavity.

5) End of injection and cooling of the molding: The mold is volumetrically filled with hot melt. As the molded part in the mold cools down from melt temperature, further melt is conveyed into the cavity to compensate for volume contraction – this phase of injection molding is named holding pressure. Subsequently the injection unit starts plasticating and preparing material for the next shot. (repeat of step 1)

6) Ejection of the molding: After the molded part has cooled sufficiently, the mold opens and the finished molded part is ejected. The plasticating procedure is finished (repeat of step 2) and the production of the next molding can start (step 3).

The plastic material coming from the raw material supplier in the form of pellets or powder is put into the hopper. From there the material enters the plasticating unit, where a screw rotates in a barrel and by this rotation transports the melt in front of the screw into the screw chamber, which enlarges (step 1). Because of the increasing melt in volume in front of it, the screw moves axially backward. The plastic material coming from the hopper is heated by friction and by additional heater bands around the plasticating barrel. Thus the material is melted. The screw slides back until the rear limiting switch is actuated and the screw rotation stops. The limiting switch is set in such a manner that precisely the melt quantity that is required for the molding is stored in the screw chamber (step 2). [3]

The next step is closing the mold. The mold consists of at least two halves (parts), which are clamped to the injection side and to the clamping side of the clamping unit, and are closed to form the cavity (step 3). Subsequently the screw is pushed forward with a piston-like action, forcing the melt from the screw chamber through the nozzle into mold cavity (step 4). In this injection step the screw moves only axially, without any rotation. [3]

As the injected melt solidifies because of the cold mold walls, the screw presses additional melt into the mold under holding pressure to compensate for the volume contraction of the material as it cools (step 5). [3]

When the molded part is cool and stiffs enough, the mold opens and the molding is ejected from the cavity with assistance of an ejector system inside the mold (step 6). This completes an injection cycle and the next production cycle can start. [3]

The entire process as described runs fully automatically, monitored and controlled by the control unit of the machine. [3]

3 SPECIAL PROCESSES OF INJECTION MOLDING

3.1 Overmolding

Overmolding is a molding process that can combines two different plastic materials to produce a unique part. That could be made from different reasons. It can be used to combine various colors of the same or different polymers in molding, without supplementary operations like assembly, bonding, or welding. Or it could be used also to have some unique part composes from different materials and it gives needed mechanical properties.

Another example is following. [5] The first material is used to mold a rigid plastic substrate. The second plastic material, usually a rubber-like plastic elastomer, like our Polylastomer compounds, is molded over the substrate. The overmolding process allows designers and engineers to create a strong structural product with excellent ergonomic comfort for the end user. Overmolded parts can add further appeal by being molded in two different colors.

3.1.1 Process of Overmolding

Industrial Processes: There are two basic types of overmolding used in industrial processes today. The first is the insert molding process which "the rigid substrate is molded first and transferred to a second mold, where a thermoplastic elastomer (TPE) is shot around the insert to create the finished part. The process uses standard injection molding machines and relatively simple, low-cost tools. Insert molding is best suited to applications involving relatively low volumes and manufacturing locations where labor costs are low". The second process involves a term called multi-shot molding which basically works off of the same principles that insert molding does but uses many insert molders to shot a compound into a mold. This process is typically used when there is more production being done and manufactures want to be more economically cautious. New processes are being examined in making the overmolding process better. Researchers are using different polymers and trying new temperatures to use when overmolding products in an industrial setting. According to the plastics technology website, new changes are being made in the overmolding process. [6]

Example of high production overmolding [3]: In the first step, a material A is injected. There is no cavity for material B in the bottom part of the mold. In the second step, half the mold is turned by 180°, so that a cavity for material B is opened. In the final step, material B is injected and welds with material A. The final products are shown at the picture 1.

Figure 1.Product made by overmolding [1]

3.2 Multicomponent Injection Molding

In multicomponent injection molding, two (or more) materials are injected into one cavity. The process starts with the injecting of component A. At a certain point in the cavity in the filling process, a second material B follows, completing the filling. The first material, A, cools, at the mold surface and builds up the outer layer of the molding. The second injected material, B, in the core layer is still liquid, pushing the first material to the mold wall and to the end of the flow path. In the finished molding, the skin layer is formed by the material injected first and the core layer is formed by the second material. [3]

This molding process has several advantages. First, a combination of desirable properties of two different materials is possible; for example, fiber-reinforced materials, which may have undesirable surface properties, can be covered by nonreinforced materials. Second, in the core layer an expensive material can be replaced by a cheaper one (such as recycled material). [7]

4 MATERIALS

4.1 Classification of Plastics

Plastic can be divided into two main groups. First is elastomers and thermosets group which are slightly or strongly cross-linked materials. That means there is chemical connection between individual macromolecules, in a chemical reaction. Therefore they can not be reused several times and when trying to melt once made product they degrading. But the advantage is they are more resistant to chemicals. On the other hand there is another group of thermoplastics which are linear chain molecules or branch chain molecules.

The thermoplastics could be divided into another two groups. There are amorphous and crystalline. Amorphous means that the macromolecules are arrange randomly. They can be identified by their transparency, if there is no color pigment added. Crystalline means that macromolecules are arranged regularly, they are not transparent even if color pigment is added.

In the real life there is no clear crystalline plastic, there always is a little part of amorphous part. Such crystalline plastic contents little random arrangements. So we call it semi-crystalline materials. Amorphous and semicrystalline thermoplastics have different properties with regard to processing and they also have different performance characteristics.

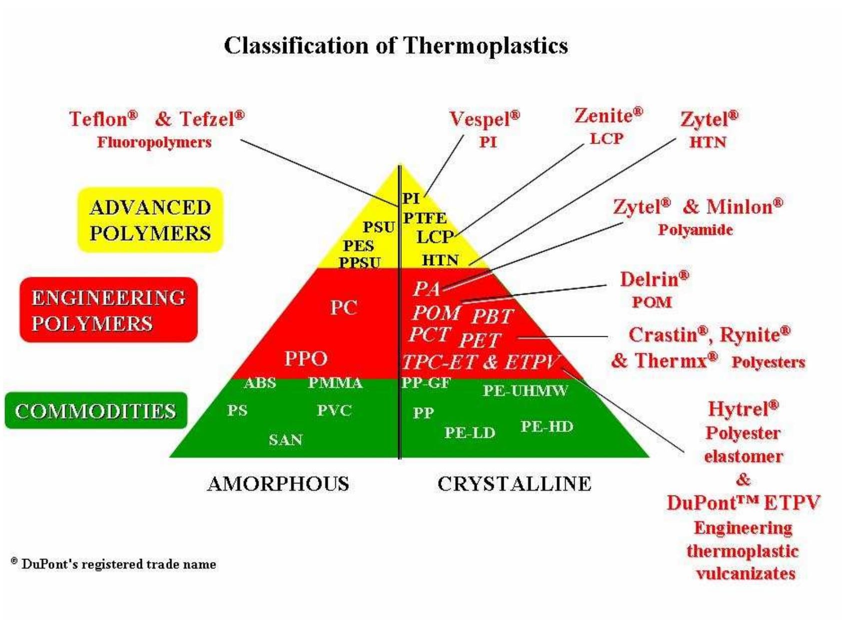

Figure 2.Classification of Thermoplastics [1]

DuPont cares about semicrystalline plastic as shown in figure 2. It was important have an overview on all DuPont materials for my research. So that was my first investigating at DuPont. Zytel/Minlon Product & Properties guide update in collaboration with Marketing Communications. Due to this I was able to learn a lot about plastics and theirs difficulties as are mechanical properties, chemical resistance, electrical properties and thermal properties.

4.2 Zytel®

Zytel® nylon resins are thermoplastic polyamides having properties that place them high on the list of engineering plastics. Zytel® nylon resins are tough and withstand repeated impact. They are highly resistant to abrasion and to most chemicals. Molded articles retain their shape at elevated temperatures, are strong in thin sections and have low coefficients of friction. The principal Zytel® nylon resins may be divided by chemical composition into four basic groups -66 nylon, 612 nylon, 6 nylon and copolymers-all of which may be modified to give special properties. Zytel® nylon resins may be reinforced with glass fibers to increase their tensile strength, stiffness, and dimensional stability. [8]

4.3 Crastin®

Crastin® PBT glass reinforced thermoplastic polyester resins are unique among polyester systems. These products contain uniformly dispersed glass fibers, specially formulated for rapid crystallization during the injection molding process. This offers the possibility of producing high performance parts by conventional injection molding. The Crastin® thermoplastic resin family is known for properties like high strength, stiffness, excellent dimensional stability, outstanding chemical and heat resistance and good electrical properties. Crastin® resins are noted for their excellent melt flow characteristics, close molding tolerances and high productivity from multicavity molding. [9]

4.4 Rynite®

Rynite® PET thermoplastic polyester resins contain uniformly dispersed glass fibers or mineral/glass fiber combinations in polyethylene terephthalate (PET) resin that has been specially formulated for rapid crystallization during the injection molding process. Rynite®

PET thermoplastic polyester resins are among the strongest and stiffest engineering resins available. As an engineering polymer resin family, Rynite® PET thermoplastic polyester resins offer a unique combination of Properties - high strength, stiffness, excellent dimensional stability, outstanding chemical and heat resistance, and good electrical properties. Rynite® PET thermoplastic polyester resins are noted for their excellent flow characteristics in thin wall applications, close molding tolerances, and high productivity from multi-cavity molds. [10]

4.5 Hytrel®

Hytrel® is a block copolymer, consisting of a hard (crystalline) segment of polybutylene terephthalate and a soft (amorphous) segment based on longchain glycols. Properties are determined by the ratio of hard to soft segments and by the make-up of the segments. Most grades of Hytrel® do notcontain or require additives to enhance their properties, except for specific applications. Hytrel® offers a unique combination of mechanical, physical and chemical properties that qualifies it for demanding applications. The various grades of Hytrel® exhibit a wide range of properties and easy process ability. Hytrel® combines many of the most desirable characteristics of high-performance elastomers and flexible plastics. It features: exceptional toughness and resilience; high resistance to creep, impact and flex fatigue; flexibility at low temperatures; and good retention of properties at elevated temperatures. In addition, it resists deterioration from many industrial chemicals, oils and solvents. [11]

5 IMPACT TEST

For better understanding to mechanical properties as is impact I was trained at charpy impact machine (notched and unnotched) and at Impact machine ISO 6603. Description of impact machine is below.

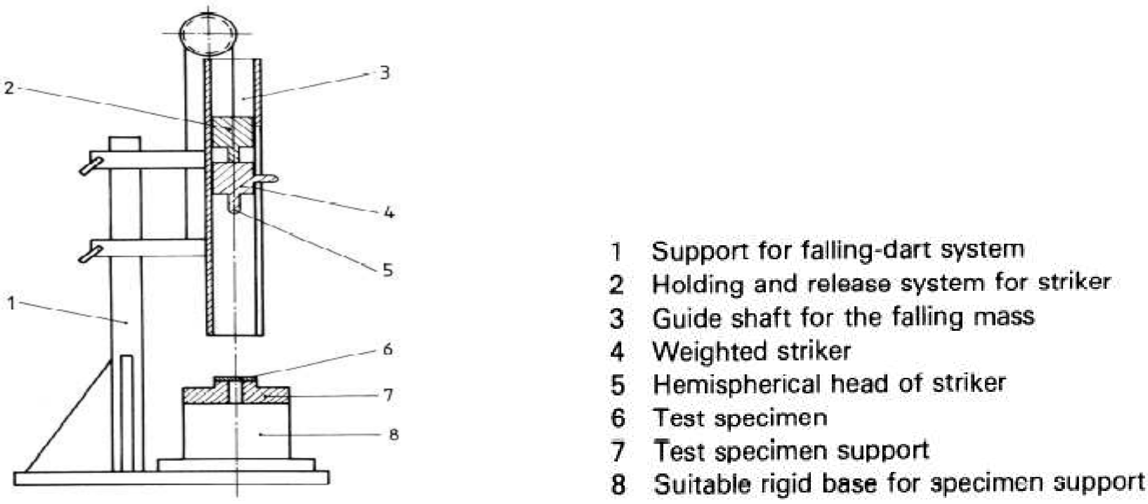

Figure 3.Impact machine [12]

1 Test specimen

2 Hemispherical

3 Load cell

4 Shaft

5 Test specimen support

6 Clamping ring

7 Base

8 Acoustical isolation

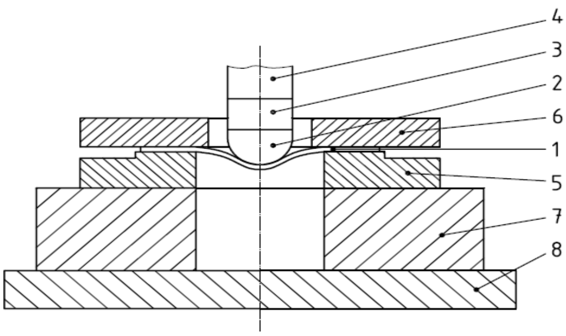

Figure 4.Description of impact support [12]

Calculation of deflection

If the test results are in the form of a force-deflection curve, the maximum force F_M, the deflection at maximum force l_M and the puncture deflection l_P can be read directly from the graph. The energy to maximum force E_M and the puncture energy E_P can be determined by measuring the area under the force-deflection curve, using a planimeter, computer analysis or other suitable means. [12]

$$l(t) = v_0 t - \frac{1}{m_C} \cdot \int_0^t \left[\int_0^{t_1} F(t) \mathrm{d}t_1 \right] \mathrm{d}t + \frac{1}{2} g t^2$$

Where

v_0 is the impact velocity (see 3.1), expressed in meters per second;

t is the time after impact at which the deflection is to be calculated, expressed in seconds;

F(t) is the force measured at any time after the impact, expressed in newtons;

l(t) is the deflection (see 3.3), expressed in meters;

m_C is the falling mass of the energy carrier, expressed in kilograms;

g is the local acceleration due to gravity, expressed in meters per second squared.

Calculation of energy

Once the force and deflection are known for identical times during impact, the energy expended up to specific times shall be calculated by determining the area under the force-deflection curve according to equation (4) (see note 1). [12]

$$E_j = \int_0^{l_j} F(l) \mathrm{d}l$$

Where

F(l) is the force at the deflection l, expressed in newtons;

l is the deflection, expressed in meters;

j is a subscript denoting one of the following points:

M = maximum

P = puncture;

E is the energy, expressed in joules.

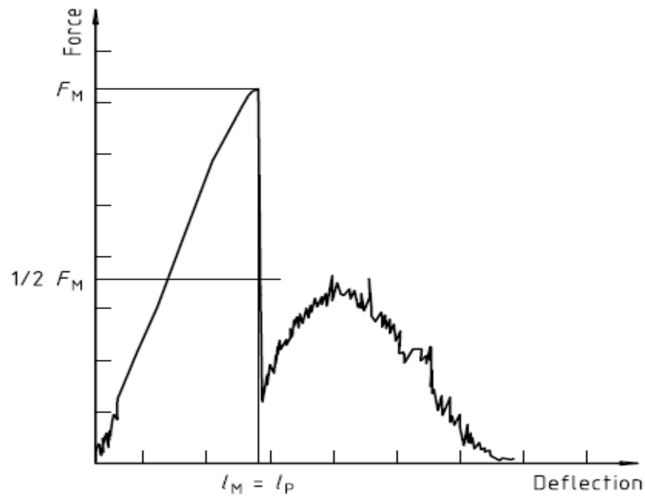

Figure 5.Schematic force-deflection diagram for a brittle or textile-fiber reinforced material [12]

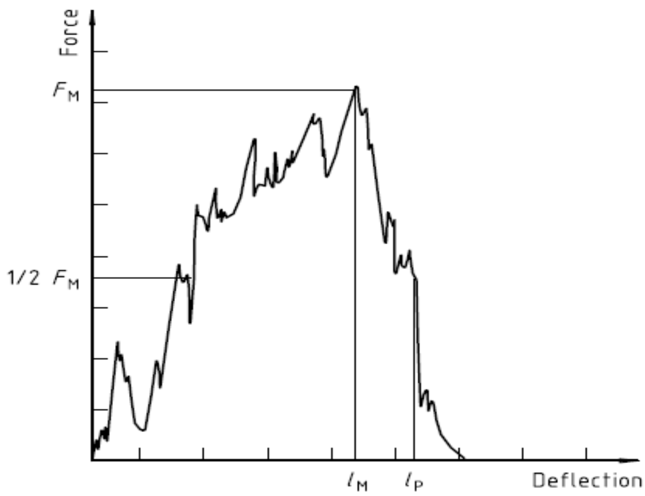

Figure 6.Schematic force-deflection diagram for splintering material, superposed by strong resonance of the test specimen [12]

II. PRACTICAL PART

6 FIRST PROJECTS

By doing my first projects I got an idea about testing of plastics during many training in ISO laboratory as tensile machine, charpy machine, impact machine, shrinkage machine, flammability machine and I have seen others tests to have a overview.

I became a specialist in injection molding during working at my projects in Molding Shop. I was trained on certain injection machines as DEMAG 150, ENGEL 150, ENGEL 175, NETSTAL 150, NETSTAL 175, BILLON and ARBURG. I have seen lot of new ideas to progress processing of molding. Because of the Molding shop in DuPont teach the world of injection molding.

I was working systematically for many little projects to be able to manage my own big project. Such I was trained at lot of machines and visited many of laboratories of DuPont to see process to better understanding of plastics. Also I could talk to one of the top professionals engineers and technicians about plastic around the world. After that time I learned lot of things about plastics, marketing and system of working at the international company.

6.1 Shrinkage project

This is just one of the little projects of shrinkage I made for filling the general DuPont datasheets which are disposable for customers. Sometimes it is made for investigating influence on the different additives on the shrinkage as could be changing the glass fibre, different lubricants and etc. Also it could be necessary to make the shrinkage test if a new factory is opened to check the stable quality of our products. And time to time it is made on request of our customer who had some problem with DuPont materials.

There is an example of the shrinkage test I made. First of all I had to mould the parts. Then it is necessary to wait 24 hours to have specimens stable and start to make a test by shrinkage machine I was trained. There are two kinds of the shrinkage tests. The first one is long bar and the second one is the plaque 60x60x2mm.

The specimens are fixed by clips as shown in figure 8. The number of measured specimens is five at least as says norm ISO 294. The shrinkage machine is shown in figure 7.

Figure 7.Shrinkage machine

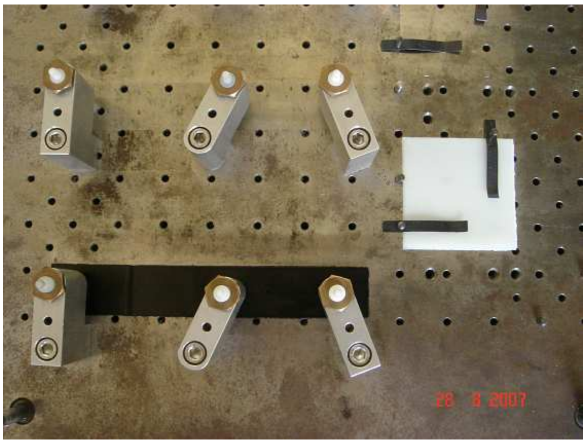

Figure 8. Shrinkage specimens

There are shown pictures of the long bar. There are two measurements on each direction. Than the machine gives me dates and I make results by using excel macro program.

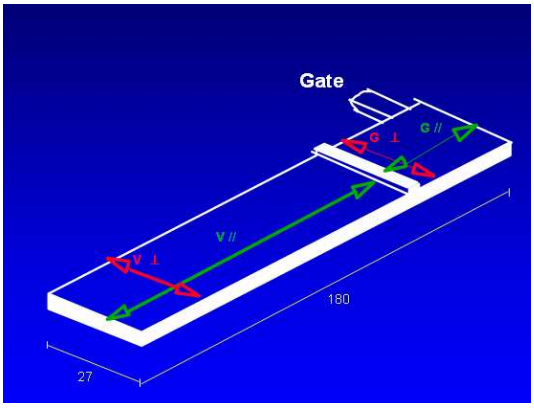

Figure 9.Descriptions of longbar [1]

Figure 10.Shrinkage longbar

Table 1.The example of shrinkage results I made by excel macro program

13225M022			Shrinkage ISO LongBar 2mm							
			Flow direction				Cross-Flow direction			
			close to gate		far from gate		far from gate		Close to gate	
RUN	MATERIAL	LOT	Aver	St.Dv	Aver	StDv	Aver	StDv	Aver	St.Dv
1	CR SK601 NC10	EUYHCMN101	0.94	0.01	0.57	0.01	2.04	0.00	1.89	0.00
2	CR SK605 NC010	EUUHE4D101	0.54	0.01	0.20	0.00	1.80	0.02	1.77	0.02
3	CR SK605 NC010	EUQHE42201	0.56	0.01	0.20	0.01	1.86	0.02	1.83	0.02
4	CR SK605 NC010	EUUHE4D101	0.56	0.00	0.21	0.00	1.81	0.02	1.78	0.00
5	CR SK601 BK851	EMSHB7U101	0.97	0.01	0.60	0.00	2.12	0.00	1.97	0.00
6	CR SK605 BK851	EMJGI6T301	0.55	0.01	0.24	0.01	1.95	0.02	1.84	0.02
7	CR SK601 BK851	EUQHE3T201	0.98	0.02	0.62	0.00	2.12	0.02	1.97	0.00
8	CR SK601 BK851	EMJHE9S301	0.98	0.00	0.62	0.01	2.08	0.00	1.95	0.02

Such it could be compared by engineer or by chemist I was in contact and they decided the best solution for this problem. I could consult the solution which was confidential. In that case it was just filled into general datasheets of DuPont.

Table 2.Composition of tested materials

DuPont materials	
Name of the material	Classification of the materials
Crastin SK601 NC10	PBT 10% of the glass fiber
Crastin SK605 NC010	PBT 30% of the glass fiber
Crastin SK601 BK851	PBT 10% of the glass fiber
Crastin SK605 BK851	PBT 30% of the glass fiber

There are some pictures of plaques 60x60x2mm. They are measured just in two directions. The results are processed the same way as long bar by excel macro program.

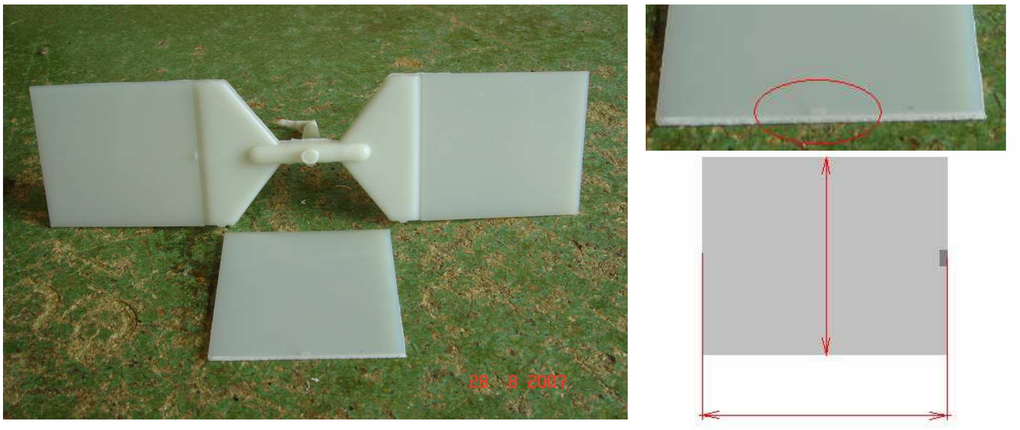

Figure 11.Plaque 60x60x2mm – directions measurements

I made shrinkage test and shrinkage report for many times to get an overview on different types of materials.

6.2 Mold Deposit

The mould deposit can occur in case of technical materials which are performed for some special applications as flame resistance, good ejection, modifiers, etc.

6.2.1 Types of Deposit

Each group of additives produces a specific type of deposit. Flame retardants can react at high temperatures, forming decomposition products which may produce deposits. Impact modifiers are affected not only by excessively high temperatures but also by excessive shear. Modifiers can, under unfavorable conditions, separate from the polymer and form deposits on the cavity surface. Pigments in engineering thermoplastics needing high melt temperatures, can reduce the thermal stability of the molding compound, resulting in deposits consisting of polymer degradation products and decomposed pigments. In parts of the mould which become especially hot (such as cores), modifiers, stabilizers and other additives may stick to the surface and build up deposits. In such cases, steps must be taken to achieve better mould temperature control or use special stabilizers. The table lists the possible causes of mould deposits and ways and means of preventing them. [13]

6.2.2 Care of Moulds

It has been found that deposits on the mould surface can be removed relatively easy in the early stages. Cavities and vents should therefore be cleaned at specified intervals, e.g. at the end of each work shift. Once the deposit has formed a thick layer it is extremely difficult and time-consuming to remove it. Because deposits vary so widely in their chemical composition, trials have to be carried out to find the most suitable solvent which will shift them. [13]

6.2.3 Recommendations on Preventing Deposit

If thermally sensitive compounds are molded using hot runners, it should be remembered that the residence time will be longer, so that the risk of deposits consisting of degradation products will be greater. Shear sensitive materials should always be processed using generously dimensioned runners and gates. Multi-point gating, which reduces flow distances and thus enables molders to reduce injection speeds, have given good results. Generally speaking, efficient mould venting reduces the tendency to form deposits. Adequate venting should therefore be provided at the mould design stage. Self-cleaning vents, or those from which deposits can be easily removed, are to be preferred. Improvements in the venting system have often led to reduced deposits on the tool. In some instances it is possible to apply a special non-stick coating to the cavity surface, which will prevent deposits building up. Tests should be carried out to assess the effectiveness of such coatings. Titanium nitriding has often reduced the rate at which deposits build up on the tool. [13]

Investigation of the mould deposits for these high technical materials Zytel® FR72G25VO GY372, Zytel® FE 230004 GY076E, Zytel® FE230004 GY372.

Table 3.Composition of tested materials

Zytel® FR72G25VO GY372	Flame retardant PA 66/6 25% glass reinforcement
Zytel® FE 230004 GY076E	PA66 a new product. Secret compound
Zytel® FE 230004 GY372	PA66 a new product. Secret compound

Processing:

The mould deposit occur after some time so there is necessary make some number of the cycles and then check if there is some deposit on the mould. Such pictures were taken after certain cycles and compared with others pictures made before testing or during testing.

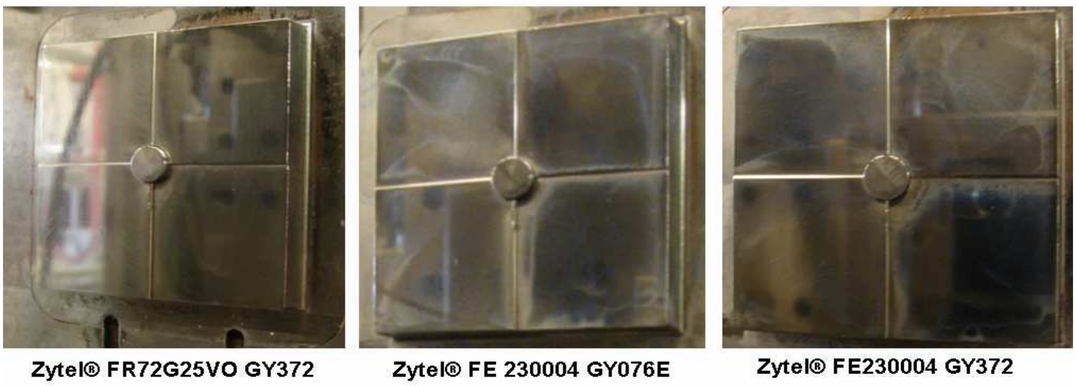

Figure 12.Mold Deposit after 250 shots

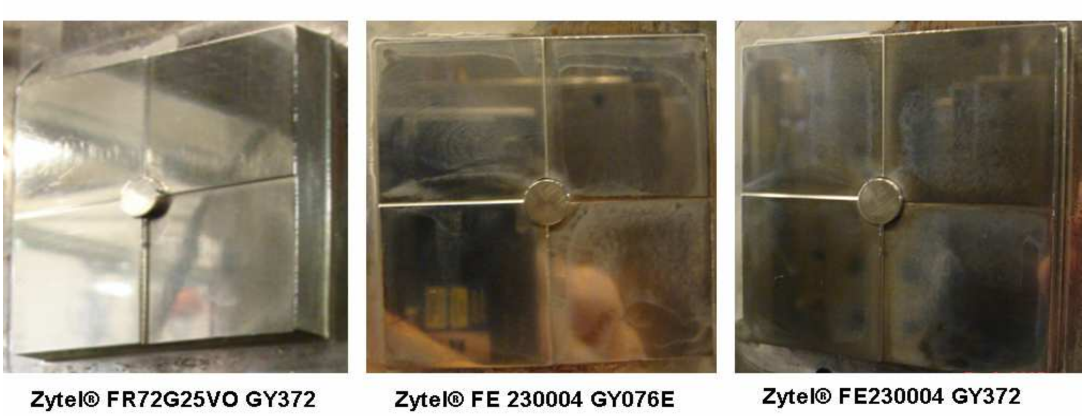

Figure 13.Mold Deposit after 450 shots

Conclusions:

Zytel® FR72G25VO GY372: Deposit on Mould surface **did not** occur

Zytel® FE 230004 GY076E: Deposit on Mould surface occur but not critical

Zytel® FE230004 GY372: Deposit on Mould surface occur but not critical

6.3 Comparison mechanical properties – ISO test and Weld line

The aim of this study was to find influence of the weld line on the mechanical properties. This help to fill the material database for DuPont customer. That is also important study to understand the process of the plastic.

To make this experiment and others I was trained at tensile machine shown in figure 14 and tensile robot machine.

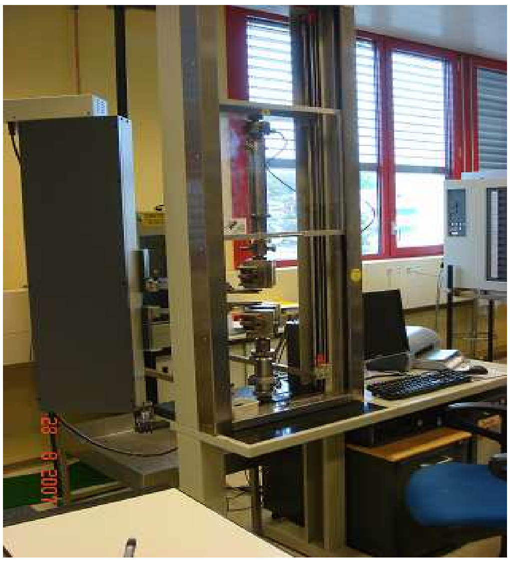

Figure 14.Tensile machine

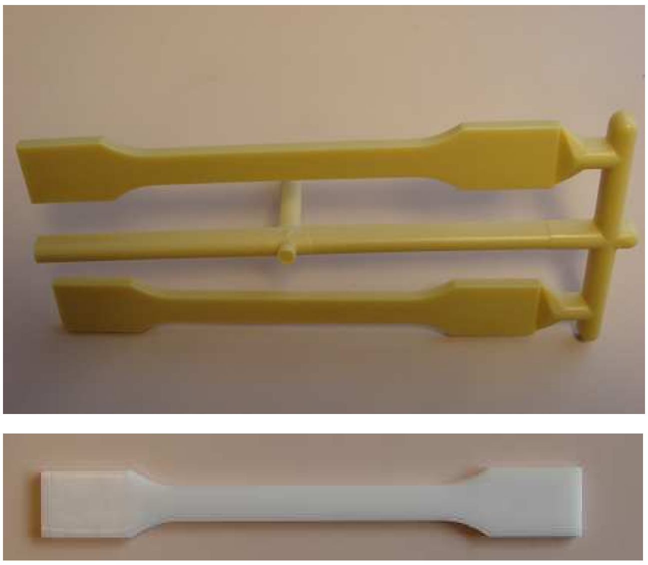

Figure 15.Tensile specimens

All the tests are in norm ISO 527. By this investigating we get E-modulus, Stress at Break and Strain at Break.

In that case I molded testing parts for tensile test with double gate. That means the weld line occurred. Such I measured the mechanical properties at tensile machine and then I made comparison with material data sheet for these materials without any weld line.

Table 4.Composition of tested materials

CR SK605 BK851	PBT with 30% glass fiber
CR HR5330HF BK503	PBT with 30% glass fiber, high flow
CR LW9030FR BK851	PBT with 30% glass fiber, flame retardant

Table 5.Comparison of material without any weld line and material with weld line (WL)

WL/ISO in %	E-Modulus (MPa)	WL	Stress@break (MPa)	WL	Strain@break (%)	WL
CR SK605 BK851	9600	7400	130	55	2,5	0,9
CR HR5330HF BK503	8400	5900	120	40	3,5	1,1
CR LW9030FR BK851	10200	7200	115	25	1,7	0,4

As shown in graphs there are some mechanical lost by weld line. The blue colors are values without weld line and the red colors are values with weld line. Results are most critical for Strain at Break and Stress at Break, for E-modulus there is lost about 30%.

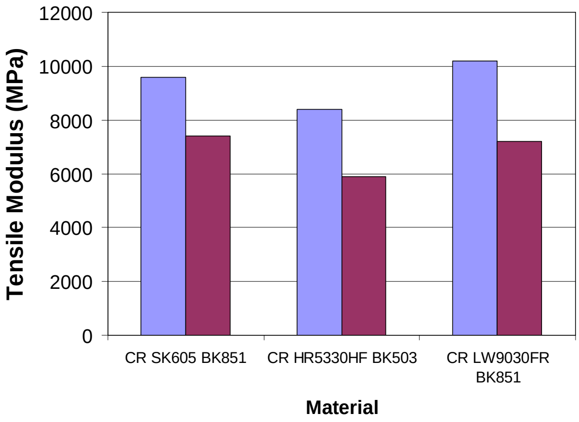

Figure 16.Comparison of Tensile Modulus

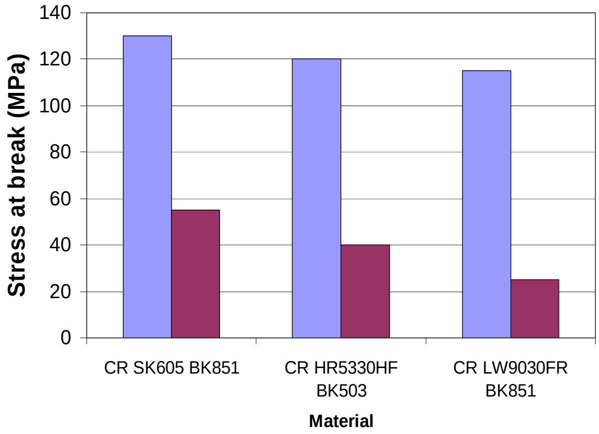

Figure 17.Comparison of Stress at Break

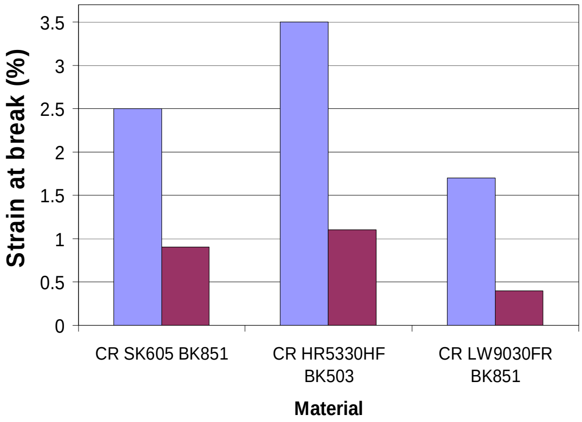

Figure 18.Comparison of Strain at Break

Table 6.Comparison of mechanical properties: Weld line test / ISO test (in %)

WL/ISO in %	E -modulus	Stress @ Break	Strain @ Break
CR SK605 BK851	77	42	36
CR HR5330HF BK503	70	33	31
CR LW9030FR BK851	71	22	24

Conclusion:

The weld lines for glass reinforced materials are critical because of the fiber orientation at the weld line. It affected all of the mechanical properties. The E-modulus that means the rigidity of the material is not so affected (lost about 30%) as others important mechanical properties as Strain at Break and Stress at Break (lost about 60% - 80%). That means it is the best solutions to do not have any weld line if possible. Such I was ready to make similar tests and comparison if needed.

7 DEVELOPMENT AND DESIGN OF PARTS FOR 2K INJECTION MOLDING

Replacement of structural applications with stiff plastic is difficult. Main hurdle is not to achieve the desired stiffness, which we manage though design but to maintain part integrity after severe abuse. Very often, not maintaining part integrity after a crash test is stopping the project.

This is the case for Full Plastic Front end Modules (FEM), Plastic Steering Wheel… but also Safety Helmets for Police and Fire-fighters.

The goal of our studies is to find the composition of materials which are good at impact test and have good rigidity at different temperatures. We already have materials which are very good in impact but they are not rigid enough. And on the other hand we have super tough materials but they have poor mechanical properties in impact. So the aim is to have a compromise of these. That is the reason I divided our materials to two groups. In the first group there are rigid materials and in the second there are soft materials. I tried to combine them depending on their mechanical properties; also on adhesion and shrinkage and war-page by experiments.

7.1 Chosen materials for “sandwich”

With regard on mechanical properties I chose these materials

Table 7.Chosen materials and their mechanical properties

Materials for sandwich		E-modulus	charpy impact 23C (kJ/m2)	
Rigid:	**Soft:**	(Mpa)	unnotched	notched
PA66	**ZY FN718 NC010**	960	NB	123
ZY 75LG40L NC010	PA66 40%LGF	12 500	80	40
ZY 80G33HS1L	PA66 33%GF	8 900	97	20
TPC-ET (PBT+polyether)	**HY 5555HS**	184	NB	84
CR T805	PBT 30%GF	7 300	75	14
TPC-ET (PBT+polyether)	**HY 5556**	180	NB	NB
CR LW9020	PBT 20%GF	7 000	60	9.5
CR LW9030	PBT 30%GF	9 500	60	10
RY 415HP	PET 15%GF	4 700	55	11

LGF - long glass fiber; GF - glass fiber; NB - no break

Here is the table of properties. I chose materials depending on their mechanical properties mainly at tensile modulus and charpy impact tests – notched and unnotched. I paid attention to the E-modulus because this is the parameter which designates the rigidity. The property of charpy impact is also very important because it gives us an idea about absorption of energy and the force which materials can take.

The soft material is great under impact due to its elongation, as it can absorb more energy and more force. On the other hand the rigid material is limited in impact due to its rigidity which means no elongation of the glass fibers and their frangibility.

7.1.1 Description of chosen materials

Zytel® FN718 NC010 is a flexible; plasticizer free modified polyamide 66 resin having good heat aging and chemical resistance. [8]

Zytel® 75LG40L is a 40% long glass reinforced, lubricated polyamide 66 resin for structural applications. [8]

Zytel® 80G33HS1L NC010 is a 33% glass fiber reinforced heat stabilized polyamide 66 resin with outstanding impact resistance developed using DuPont® Super Tough technology. [8]

HY 5555HS is heat-stabilized grade provides an extra measure of strength and service to meet the needs of the most demanding applications in a wide range of hardnesses. [11]

HY 5556 is high-performance resin which provides an extra measure of strength and service to meet the needs of the most demanding applications in a wide range of hardnesses. [11]

Crastin® LW9020 and *Crastin® LW9030*: That is low warp resins reinforced by 20% respective 30% glass fiber. Reinforced PBT alloy for injection molding with improved surface aesthetics has excellent dimensional stability and low warpage characteristics. [9]

CR T805 NC010 contents 30% glass fiber reinforced PBT resin for injection molding with improved impact resistance and good processing characteristics. [9]

Rynite® 415HP is 15% glass-reinforced modified polyethylene terephthalate - improved for easy, fast processing over a broad molding range - excellent balance of strength, stiffness, and temperature resistance. Snap fit applications, encapsulation of sensors, coils, etc. [10]

Table 8.Potential candidates to make "sandwich"

ZY FN718 NC010	ZY 75LG40L	expected great mech. prop.
ZY FN718 NC010	ZY 80G33HS1L	expected good mech. prop.
HY 5555HS	CR LW9020	adhesion 8.6MPa good peeling
HY 5555HS	CR LW9030	good adhesion
RY 415HP	CR T805	19.6MPa good adhesion
HY 5556	CR LW9020	7.8MPa good
HY 5556	CR LW9030	expected good adhesion

7.2 Processing of "sandwich" in three basic steps

1. Injecting of the first material. The mould was a plaque with dimensions of 80mm x 80mm x 1mm.

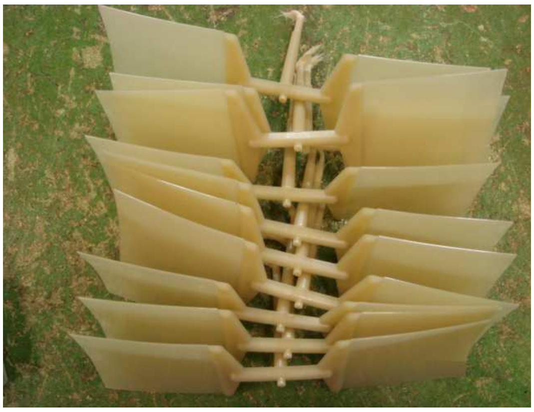

Figure 19.First material injected

Figure 20.Setuping up first layer

It was better to reduce the diameter by filing in order to put it into insert.

2. Then the first plaque (80mm x 80mm x 1mm) could be inserted into another mould at 80mm x 80mm x 3mm

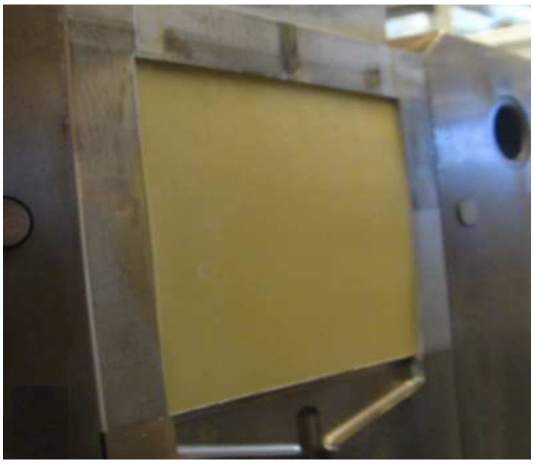

Figure 21.Inserted first layer into mould

Figure 22.Prepared mould for overmolding

Changing injection conditions were needed. All changes were taken for each material from molding guide proposed by DuPont.

3. Overmolded by the second material.

Figure 23.Overmolding

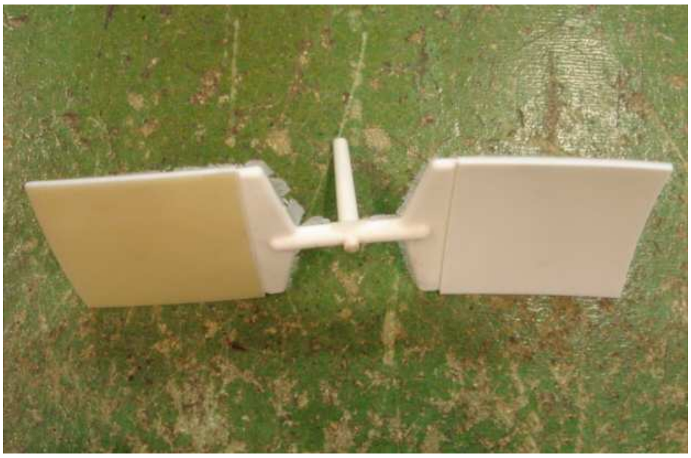

Figure 24.Overmolded by second layer

Sandwich of thickness 3mm composes of two different layers. The first of them is 1mm and the second one is 2mm. The process was repeated with reversion of the materials.

There were also made reference specimens of each material - one layer of thickness 3mm.

7.3 Experiments

Such prepared sandwich was tested on impact machine for having an idea about properties and then it was compared with results of reference specimens. Reference specimens were made by injection molding of the same dimension as sandwich was – thickness of 3mm.

These tests were done for both side and then compared. If there is some interesting results for 23° C another testing in different temperature were made.

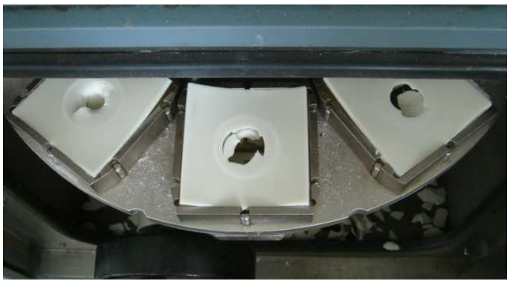

Figure 25.Impact testing

7.3.1 PA66 33% GF and PA66

For this couple of materials great mechanical properties are expected because of their properties. Zytel® 80G33HS1L (PA66 33%GF) has improved properties in impact test and still has big E-modulus because of glass fiber content 33%. Zytel® FN718 NC010 (PA66) is softer material which could add to the sandwich bigger absorption of energy and force.

Investigating:

a) Influence of mechanical properties on sandwich

Table 9.Mechanical properties of materials for sandwich

Materials for sandwich		E-modulus	charpy impact 23ºC (kJ/m2)	
Rigid:	**Soft:**	(Mpa)	unnotched	notched
(PA66) (D)	**ZY FN718 NC010**	960	NB	123
ZY 80G33HS1L (C)	(PA66 33%GF)	8 900	97	20

Process:

The same steps as described above in Processing of "sandwich" in three steps.

Injection condition always was taken from the molding guide:

For ZY 80G33HS1L

Melting point 285° C - 305° C; real 295° C

Temperature of the mould 50ºC - 100ºC; real 80ºC

For ZY FN718 NC010

Melting point 275ºC - 295ºC; real 295ºC

Temperature of the mould 40ºC - 80ºC; real 80ºC

During injection of the first layer of ZY 80G33HS1L there was a problem with warpage so it was necessary to put it under a press to flatten it during certain time.

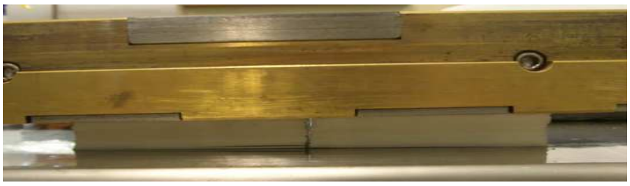

Figure 26.Pressure system

Thereafter it was prepared for overmolding. The process was stable but another problem occur - low adhesion. When trying to twist the sandwich it was easy to separate layers. For getting better adhesion was necessary using the fire lamp to preheat the first layer before overmolding. Then it had much better adhesion and it was not so easy to separate.

Figure 27.Preheating

The new problem of our exotic sandwich was high warpage. Due to this defect was better to reduce the diameter by filing in order to make the impact tests. For comparison with our exotic sandwich I injected pure ZY 80G33HS1L and ZY FN718 NC010 at 80mm x 80mm x 3mm.

Such prepared sandwich could be tested on the impact machine which gives us results of absorption the energy and the force.

Explanation of graphs below: (C) ZY 80G33HS1L and (D) ZY FN718 NC010 are reference materials. The measurement was made of thickness 3mm. The small letter (**c** or **d**) means that the layer is small – 1mm. The big letter (**C** or **D**) means that the layer is big – 2mm. Order of letter is also important (**D+c**; **c+D**): the letter on first place was attacked as first of striker. For this experiment it means that just one type of sandwich were made; 2mm of ZY FN718 and 1mm of ZY 80G33HS1L; this was tested from both sides.

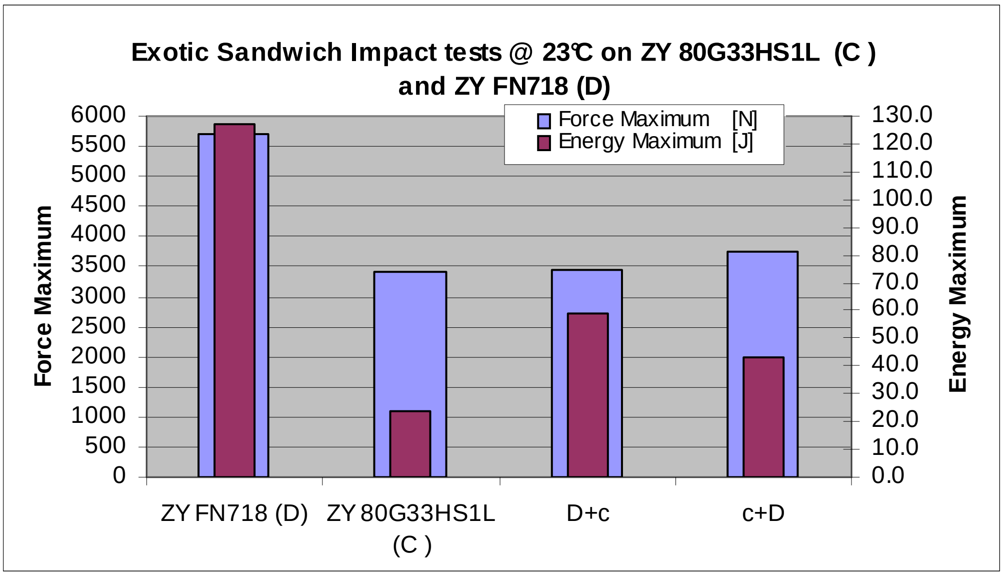

Figure 28.Impact tests at 23°C for reference materials and exotic sandwich

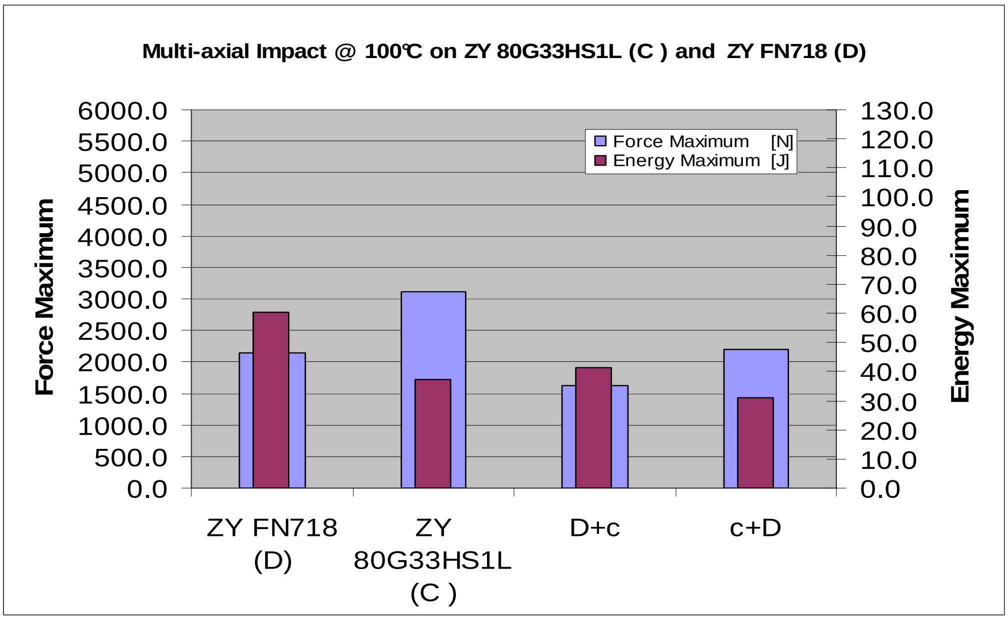

Figure 29.Impact tests at 100°C for reference materials and the exotic sandwich

Figure 30.Sandwich

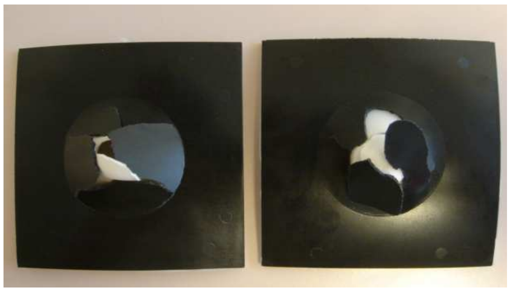

Figure 31. Sandwich

<u>Conclusion:</u>

After using the fire lamp there was good adhesion but high warpage which was limiting utilization of these exotic sandwich structure. Results from impact tests were comparable to the averages of the two composites at both temperatures at 23ºC and 100ºC. Finely it could not by process easily due to its warpage.

7.3.2 PBT 30% GF and PET 15% Glass Fiber

Because of big warpage in last experiment changes were necessary. Now it is aim to our study to know influence of good adhesion on impact resistance. Also we want to investigate if the first experiment were not influenced by preheating first layer. For these reference materials Crastin® T805 (PBT 30% GF) and Rynite® 415HP (PET 15% GF) is good adhesion expected. That was found in Dupont data sheets for two component molding.

Investigating:

a) Influence of adhesion
b) Comparison of influence between preheating first layer and without preheating

Because of the warpage in the above case I tried new materials. I chose the ones which do not need to be preheated. The RY 415HP and CR T805 have the best adhesion (19.6MPa) which was written on the data sheets.

Table 10.Mechanical properties of materials for sandwich

Materials for sandwich		E-modulus	charpy impact 23ºC (kJ/m2)	
Rigid:	**Soft:**	(Mpa)	unnotched	notched
RY 415HP (N)	**(PET 15%GF)**	4 700	55	11
CR T805 (M)	**(PBT 30%GF)**	7 300	75	14

Work Request / Run number:	2668M011/7
Material A: Modification A:	Crastin T805 NC010
Material B: Modification B:	Rynite 415HP BK509
Tensile adhesion strength:	19.6 MPa
Kind of failure:	
Subjective peeling quality:	good adhesion and good peeling and cohesive failure
Insert in mould:	Standard (spark erosion)
Tested on:	25.07.01
Remarks:	

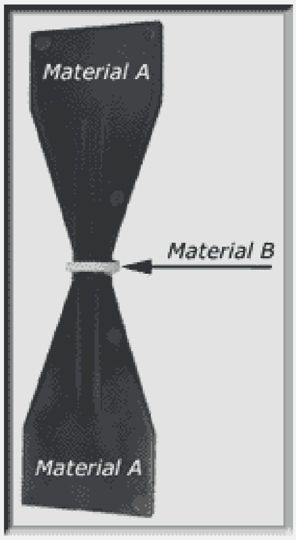

Figure 32.Data sheets for two component molding

Here we expected really good adhesion. On the data sheet (figure 32) was written 19.6MPa – the best of all tests made of DuPont materials. Unfortunately these materials have very similar mechanical properties, as both are quite rigid. So the aim of this experiment was to investigate the influence of good adhesion on mechanical properties.

Condition of injection for CR T805 (M):

Melting point 250^{o}C

Temperature of the mould 80^{o}C

Condition of injection for RY 4185HP (N):

Melting point 280 ^{o}C

Temperature of the mould 110^{o}C

Other dates I kept from the molding guide for each material!

All results are at 23^{o}C.

The RY 415HP (N) and CR T805 (M) are references material. The measurement was made of thickness of 3mm. The injection process is the same as for experiment before. That is injected first smaller layer of 1mm - marked by small letters (**m** or **n**) and overmolded by a bigger layer of 2mm by another material marked bigger letters (**M** or **N**). The symbol **p** means preheating of the first small layer before overmolding to get better adhesion. Order of letter is also important (**M+n**; **m+N; N+m; n+M**): the letter on first place was in front of the striker at impact machine.

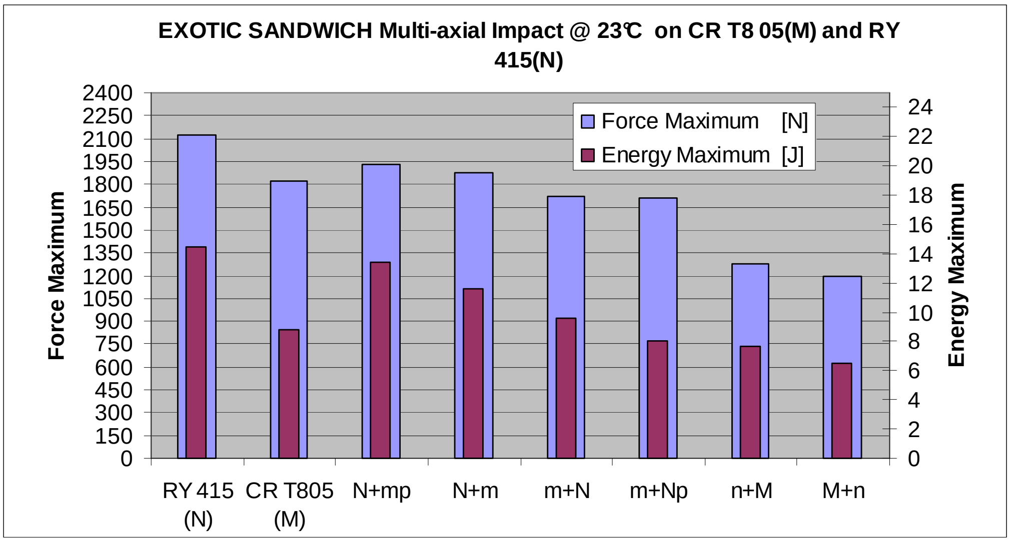

Figure 33.Impact tests at 23ºC for reference materials and exotic sandwiches

As we can see from the graphs below the best results of maximum force and maximum energy at 23ºC are for pure RY 415HP. Then it is quite similar for the sandwich where there is a bigger layer of RY 415HP (N), a smaller layer of CR T805 (m) and for pure CR T805.

We can also see that there are no differences in results if we preheated it before or not.

The worst result we got was for a bigger layer of CR T805 and a smaller layer of RY 415HP. The adhesion was observed better for overmolding RY 415HP at CR T805 due to higher melt temperature of RY 415HP.

<u>Conclusion:</u>

Very good adhesion was observed for overmolding the big layer (2mm) RY 415HP and a small layer (1mm) of CR T805 due to higher melt temperature of RY 415HP. Testing showed that preheating did not have any influence on mechanical properties of our sandwich: but it does for better adhesion. The visible warpage occurred less when the specimens were not preheated. This sandwich is not useful because we did not get better results of maximum force and maximum energy than our reference materials have.

7.3.3 PBT + polyether and PBT 30% Glass Fiber

Because of bad results from last experiments I tried to find another way of composition. I got an idea of mixing two process similar materials in a different ratio. I chose the Hytrel® 5555HS (PBT+polyether) and Crastin® LW9030 (PBT 30% GF) because they have good adhesion relation and they still have different mechanical properties. Hytrel is very good at impact and very rigid Crastin which has excellent dimensional and low warpage characteristics.

Investigating:

a) Influence of mechanical properties on mixing of two materials directly to the hopper

Table 11.Mechanical properties of materials for composites

Materials for sandwich		E-modulus	charpy impact 23ºC (kJ/m2)	
Rigid:	**Soft:**	(Mpa)	unnotched	notched
(TPC-ET$_{PBT+polyether}$)) (O)	**HY 5555HS**	184	NB	84
CR LW9030 (P)	(PBT 30%GF)	9 500	60	10

The process of making an experiment was different. First of all I injected the pure reference materials and then I mixed the material directly into the hopper at a different ratio.

Figure 34.Mixed material in hopper

Condition of injection for CR LW9030 (P) in molding guide:

Melting point 240-260ºC

Temperature of the mould 30ºC -130ºC optimum 80ºC

Condition of injection for HY 5555HS (O) in molding guide:

Melting point ~230ºC

Temperature of the mould 45-55ºC, optimum 45ºC

For making our composite I chose the optimum process conditions with regards on Injection condition for both reference materials:

Melting point 240ºC

Temperature of the mould 50ºC

Other conditions I kept from the molding guide and by experiences.

Materials: CR LW9030 (P) and HY 5555HS (O)

The ratios of our composite were 30% of CR LW9030 and 70% of HY 5555HS, 50% of each and 30% of HY 5555HS and 70% of CR LW9030.

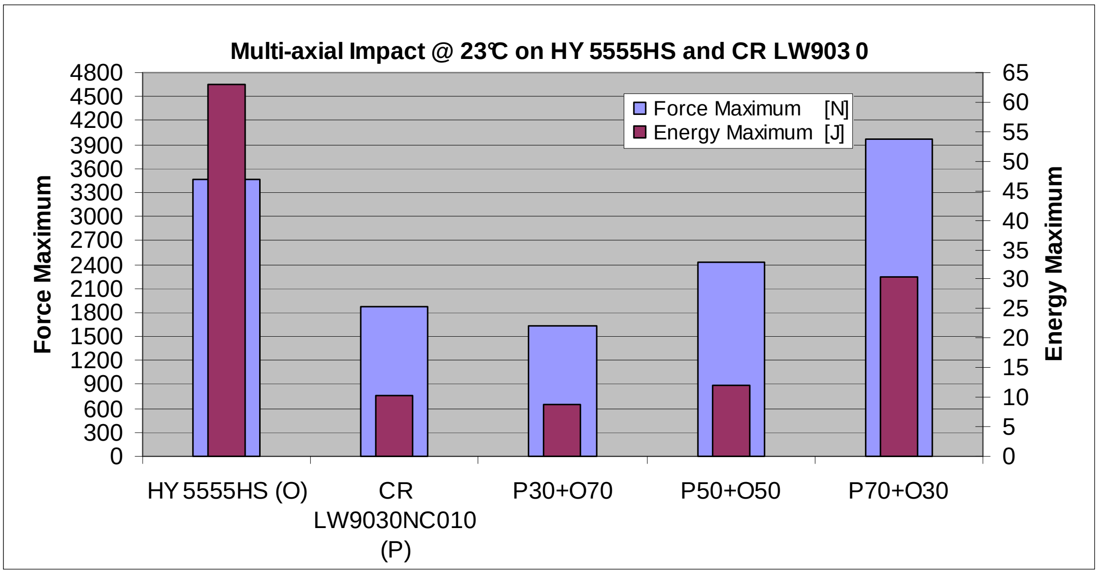

Figure 35.Impact tests at 23ºC for reference materials and composites

The results of 30% of CRLW9030 and 70% of HY5555HS are very interesting. This composite is better than both references material at the force and still good enough in the energy.

<u>Conclusion:</u>

From the graphs we can see that the soft material is much better than the rigid material at maximum force and maximum energy. The larger content of HY 5555HS helped to get better impact properties. A good ratio is 30% of (P) CR LW9030 and 70% of (O) HY 5555HS, which received high maximum force and still has good compromise of maximum energy. The advantage of this composite is good rigidity against pure HY 5555HS which is very soft. Due to the mixing directly into the hopper the composite was homogenized and there were no inconsistencies or warpage of the plaque.

7.3.4 PA66 and PA66 40% Long Glass Fiber

Due to great impact resistance of Zytel® FN718 NC010 (PA66) I wanted to combine that with another material. I chose Zytel® 75LG40L (PA66 40%LGF) which is 40% long glass fiber filled very rigid material. Because both are PA66 good adhesion expected.

Table 12.Mechanical properties of materials for sandwich and composites

Materials for sandwich		**E-modulus**	**charpy impact 23ºC (kJ/m2)**	
Rigid:	**Soft:**	(Mpa)	unnotched	notched
(PA66)	**ZY FN718 NC010**	960	x	123
ZY 75LG40L NC010	**(PA66 40%LGF)**	12 500	80	40

Investigating:

a) Influence of mechanical properties on sandwich
b) Influence of mechanical properties on composite (mixing of materials into hopper)
c) Comparison of these two method

Condition of injection:

For ZY 75LG40:

Melting point 290ºC - 310ºC

Temperature of the mould 70ºC - 120ºC

For ZY FN718 NC010:

Melting point 275ºC - 295ºC

Temperature of the mould 40ºC - 80ºC

Injection conditions for processing of the sandwich composed of 1mm ZY 75LG40L and of the 2mm ZY FN718:

Melt temperature: 294° C

Mould temperature: 120° C

When I used lower temperature of the mould the first layer did not stick in the mould. There was a problem to process the sandwich with layer of 1mm of the ZY 75LG40L due to its warpage. So it was necessary to put it under a press to flatten it.

Sandwich could not be used due to its warpage as is shown in figures 37. This warpage of sandwich is result of two different materials which are overmolded. There is a question of using mechanical way for connection of these two materials instead of making sandwich composition. Because for such warped specimen is not possible to find utilization.

Figures 36.Warped sandwich

The second sandwich which composed of small layer (1mm) of the ZY FN718 and bigger layer (2mm) of the ZY 75LG40L was easier to process due to no warpage. The only problem was to stick the small layer of the ZY FN718 inside the mould. For fixed that was necessary use a water to depositing on the one side of the sandwich. Such it could be inserted into the mould and overmolded.

For processing of the sandwich composed of 2mm ZY 75LG40L and of the 1mm ZY FN718 was the best used these injection conditions:

Melt temperature: 305° C
mould temperature: 55° C
Process of composites of two materials which are mixed directly to the hopper already is described in 7.3.3. For making our composite I chose conditions in taking into account the injection condition of both reference materials:

Melt temperature: 295° C
Mould temperature: 100° C
All the impact results at 23° C and 100° C are shown at figures below.
There were not any problem with processing and warpage.

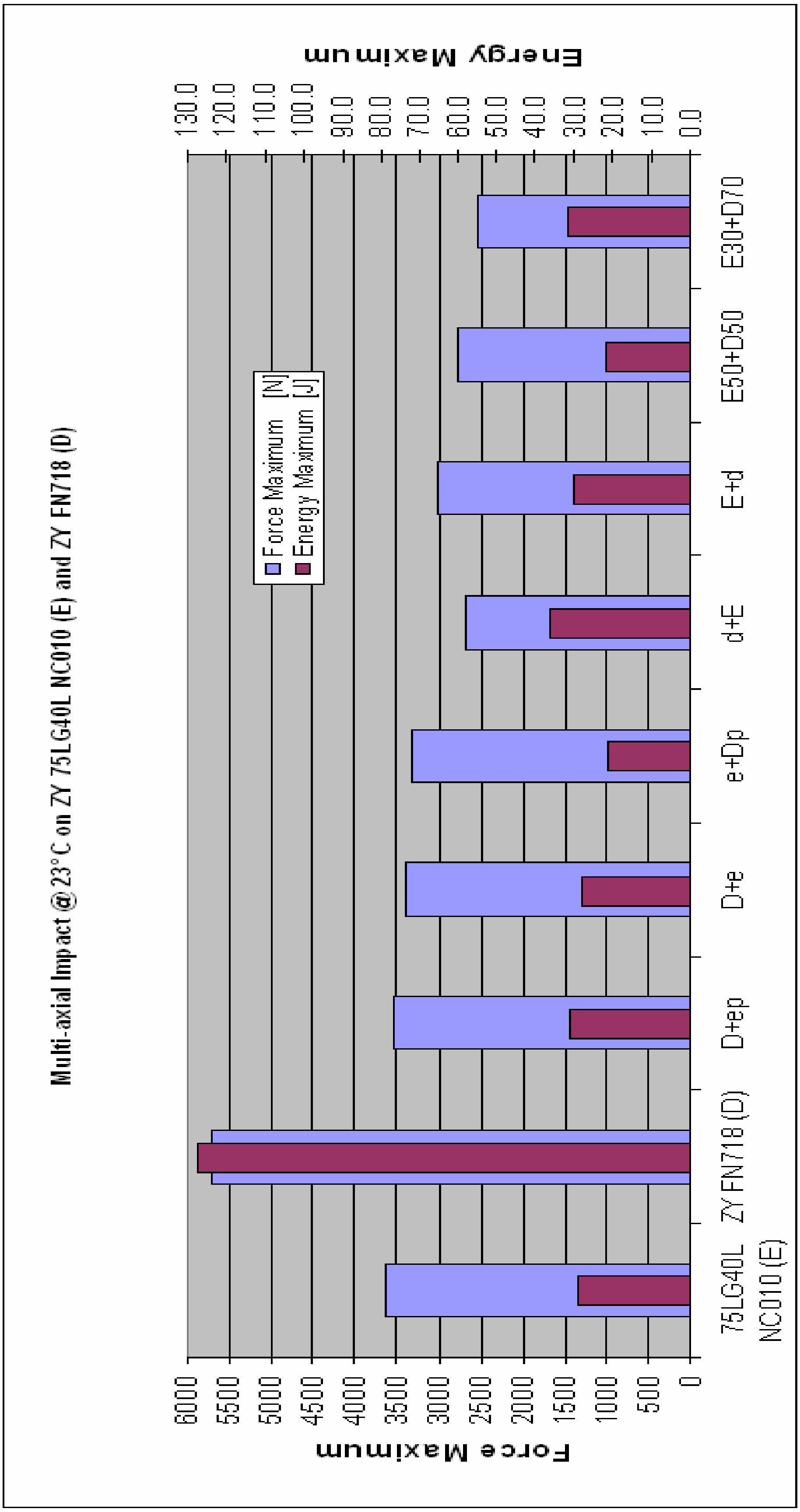

Figure 37.Impact tests at 23º C for reference materials, exotic sandwiches and composites

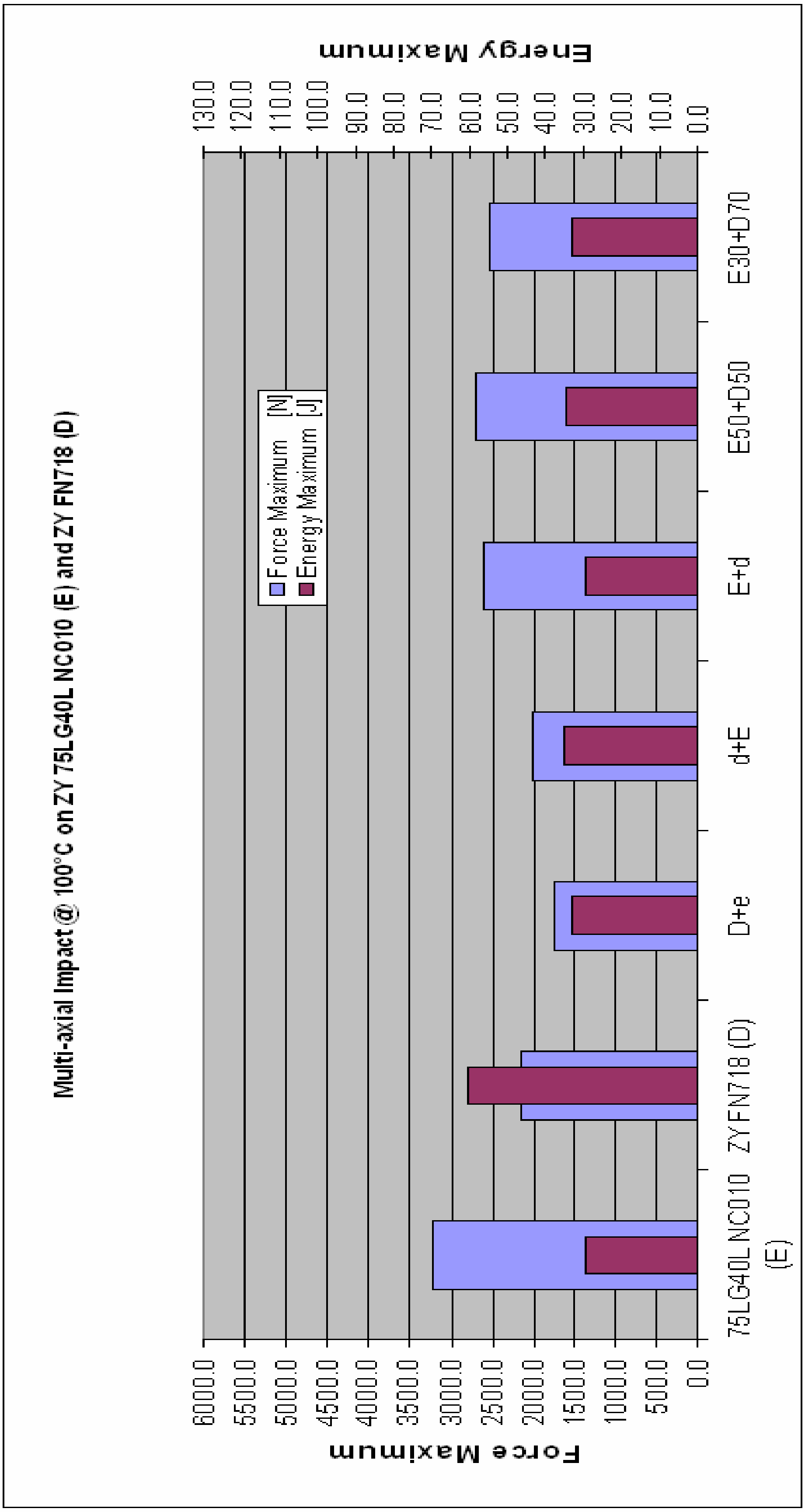

Figure 38.Impact tests at 100º C for reference materials, exotic sandwiches and composites

Conclusion:

If we compare results of sandwich and mixing composites the all advantages are for composites. It is easy to process; there is no warpage and no inconsistencies on the plaque. Another advantage is nice surface.

7.3.5 PBT + polyether and PBT 20% Glass Fiber

Because of no good experiences with sandwiches I decided to focus on making composites. Good results with soft HY 5555HS and the second very rigid CR LW9030 made me sure to choose similar materials; the first soft Hytrel® 5556 (PBT + polyether) and the second rigid Crastin® LW9020 (PBT 20% GF), which has excellent dimensional and low warpage characteristics.

Investigating:

a) influence of mechanical properties on composites (mixing of two materials directly to the hopper)

Table 13.Mechanical properties of materials for composites

Materials for sandwich		E-modulus	charpy impact 23C (kJ/m2)	
Rigid:	**Soft:**	(Mpa)	unnotched	notched
TPC-ET (PBT+polyether)	**HY 5556**	180	NB	NB
CR LW9020	PBT 20%GF	7 000	60	9.5

The process of making the experiment was the same as for experiment in 7.3.3. First of all I injected the pure reference materials and then I mixed the material directly into the hopper at a different ratio. The reference material CR LW9020 (Y) and another reference material HY 5556 (X). The ratios of our composite were 30% of Y and 70% of X; then 50% of each reference materials; and 70% of Y and 30% of X.

Condition of injection for CR LW9020 (Y) in molding guide:

Melting point 240-260ºC

Temperature of the mould 30ºC -130ºC optimum 80º C

HY 5556 (X)

Melting point ~230ºC

Temperature of the mould <55ºC, optimum 45º C

For making our composite I chose conditions in taking into account the injection condition of both reference materials:

Melting point 240º C

Temperature of the mould 50º C

Other conditions I kept from the molding guide and by my experiences.

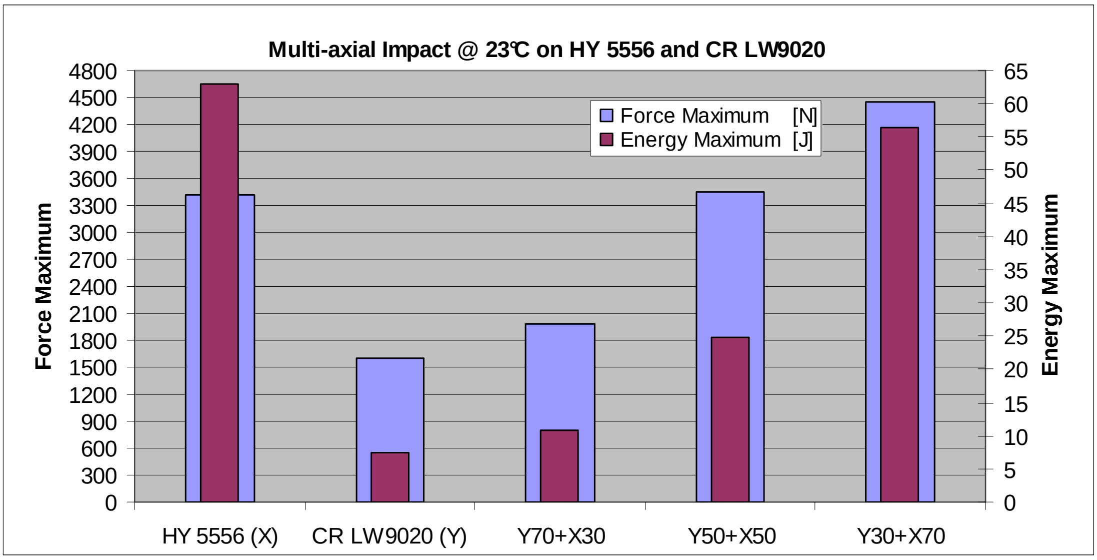

Figure 39.Impact tests at 23ºC for reference materials and composites

<u>Conclusion:</u>

In graphs is shown that composites of 50% of Hytrel 5556 and 50% of Crastin LW9020 is already better in force than both reference materials and his energy is compromise of reference materials. In the case of 30% of Crastin LW9020 and 70% of Hytrel 5556 results are very interesting. The force is better than CR LW9020 and also than HY 5556. His energy result is close to maximum value of the HY 5556.

For this ratio we can say that the material has high energy and force thanks content of soft materials and good compromise of the rigidity thanks rigid reference material. The force is even better than both references.

The advantage of this composite is good rigidity against pure HY 5556 which is very soft. Due to the mixing directly into the hopper the composite was homogenized and there were no inconsistencies or warpage of the plaque.

7.3.6 PBT + polyether and PBT 20% Glass Fiber

Because of the good results of experiments in 7.3.3 and 7.3.5 there is another similar experiment following. The rigid material is Crastin® LW9020 (PBT 20%GF) and soft Hytrel® 5555HS (PBT + polyether).

Investigating:

a) influence of mechanical properties on composites (mixing of two materials directly to the hopper)

Table 14.Mechanical properties of materials for composites

Materials for sandwich		**E-modulus**	**charpy impact 23C (kJ/m2)**	
Rigid:	**Soft:**	(Mpa)	unnotched	notched
TPC-ET (PBT+polyether)	**HY 5555HS**	184	NB	84
CR LW9020	PBT 20%GF	7 000	60	9.5

The process is exactly the same as for experiment in 7.3.3 and 7.3.5.

Condition of injection for CR LW9020 (Y) in molding guide:

Melting point 240-260ºC

Temperature of the mould 30ºC -130ºC optimum 80ºC

Condition of injection for HY 5555HS (O) in molding guide:

Melting point ~230ºC

Temperature of the mould 45-55ºC, optimum 45ºC

For making our composite I chose conditions in taking into account the injection condition of both reference materials:

Melting point 240ºC

Temperature of the mould 50ºC

Other conditions I kept from the molding guide and by experiences

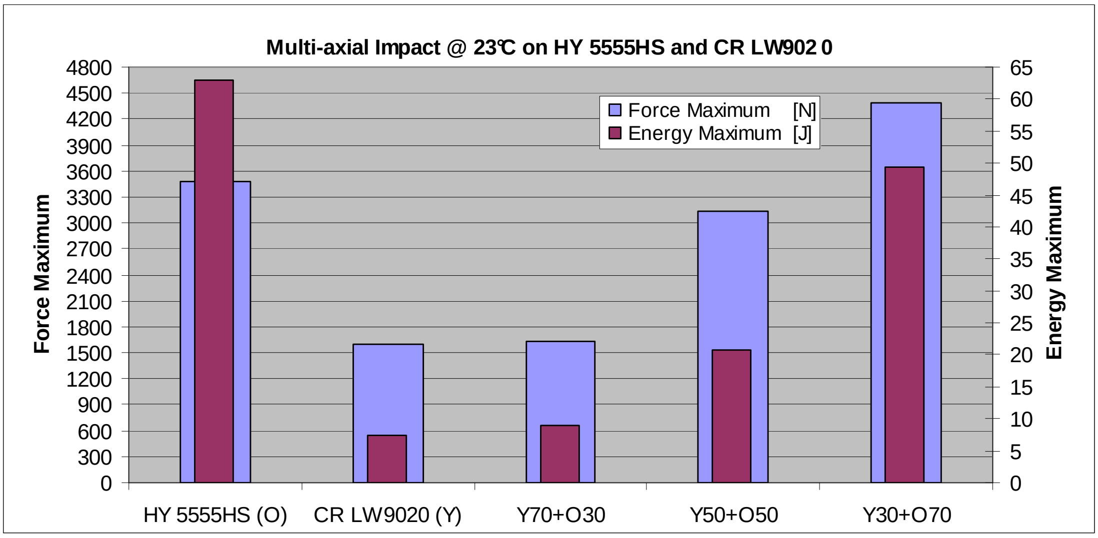

Figure 40.Impact tests at 23°C for reference materials and composites

Conclusion:

In figure 41 is shown that composites of 30% of Hytrel 5555HS and 70% of Crastin LW9020 does not solve anything. The composites of 50% of Hytrel 5555HS and 50% of Crastin LW9020 are already good compromise of the reference materials. In the case of 30% of Crastin LW9020 and 70% of Hytrel 5555HS results are very interesting.

For this ratio we can say that the material has good absorption of energy and force thanks content of soft materials and good compromise of the rigidity thanks rigid reference material. The force is even better than both references. The advantage of this composite is good rigidity compared to soft material and no warpage of the plaque.

7.3.7 PBT + polyether and PBT 30% Glass Fiber

The last experiment is combination of rigid Crastin® LW9030 (PBT 30% GF) and soft Hytrel® 5556 (PBT + polyether).

Investigating:

a) influence of mechanical properties on composites (mixing of two materials directly to the hopper)

Table 15.Mechanical properties of materials for composites

Materials for sandwich		**E-modulus**	**charpy impact 23C (kJ/m2)**	
Rigid:	**Soft:**	(Mpa)	unnotched	notched
TPC-ET (PBT+polyether)	**HY 5556**	180	NB	NB
CR LW9030	PBT 30%GF	9 500	60	10

For making our composite I chose conditions in taking into account the injection condition of both reference materials:

Melting point 240ºC

Temperature of the mould 50ºC

Other conditions I kept from the molding guide and by my experiences.

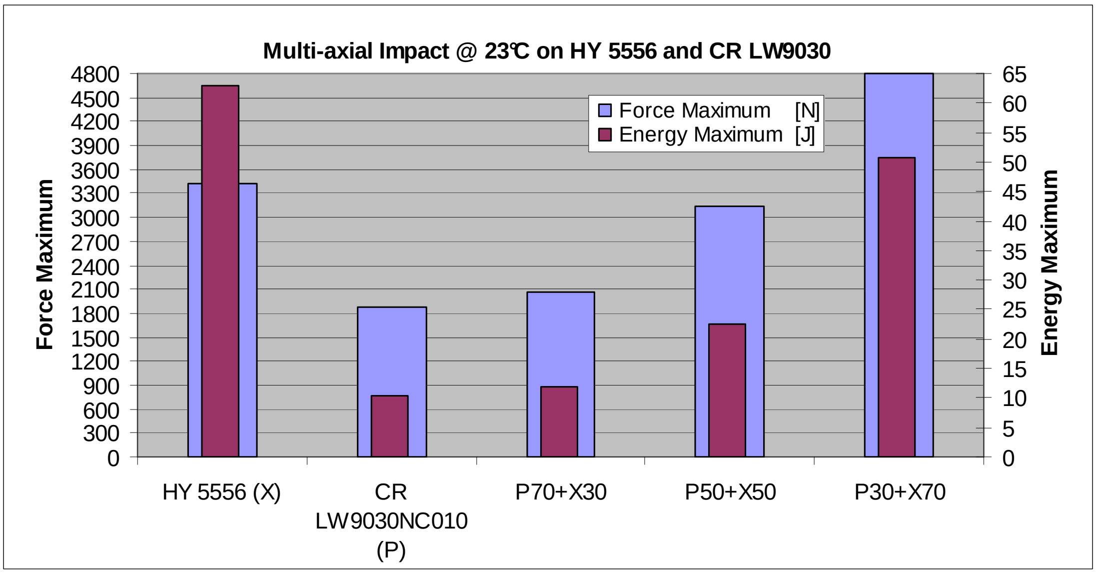

Figure 41.Impact tests at 23ºC for reference materials and composites

Conclusion:

As we expected we got a good results for the ratio of 30% CR LW9030 and 70% of HY 5556. The advantage of this composite is good rigidity against pure HY 5556 which is very soft. Due to the mixing directly into the hopper the composite was homogenized and there were no inconsistencies or warpage of the plaque.

CONCLUSION

We expected a synergy effect that means the phenomenon in which two or more discrete influences or agents acting together create an effect greater than that predicted by knowing only the separate effects of the individual agents. Often the prediction is the sum of the effects each is able to create independently.

Sandwich molding is possible and relatively easy to make in a laboratory. Sandwich molding in the industry is also possible but grade selection must be done with care on warpage, adhesion and mechanical aspects. Testing showed that preheating of the first layer before overmolding did not have any influence on mechanical properties of our sandwich but it has influence on adhesion. There are some limitations due to warpage. Unfortunately we could not get a synergy effect, meaning keeping a very high stiffness and great impact energy.

Although from mechanical stand-point, sandwich is not valuable, there are other tracks to explore like: There could be some advantages of chemistry resistance material which composed of two different materials which one is resistant and noise or vibration resistance.

In the case of mixing materials directly to the hopper the synergy effect occurred. As the best solution I found mixing rigid material CR LW9020 (PBT 20% Glass Fiber) and CR LW9030 (PBT 30% Glass Fiber) with a soft materials of HY 5555HS (TPC-ET (PBT+polyether)) and HY 5556 (TPC-ET (PBT+polyether)). The best ratio of mixing is 30% of rigid material and 70% of soft material. Such we got big values of the force at the deflection, bigger then both reference materials, and still good values of energy. This ratio has also good rigidity to compare with a soft material.

Due to the mixing directly into the hopper the composite was homogenized and no warpage of the plaque which would limit the utilization. There is also a nice surface which could be painted or coated.

There are still some tests of impact at different temperatures needed to know the range of utilization.

ZÁVĚR

Našim cílem bylo vytvořit takovou sendvičovou strukturu DuPont materiálů, která by zaručovala výborné vlastnosti při rázové zkoušce. Tato sendvičová struktura se skládala z pevného materiálu pro tvrdost a z měkkého materiálu pro dobré vlastnosti v nárazových testech. Dále jsme chtěli zjistit, jestli by byl náš výrobní proces lehce proveditelný v laboratoři a potom, zda-li by bylo možno, ho aplikovat v průmyslu.

Od této struktury jsme si slibovali získání synergického efektu, což znamená, že při působení naší sendvičové struktury o dvou vrstvách, bychom dostali větší nebo kvalitativně lepší než prostý součet efektů ze samostatného působení jednotlivých vrstev.

Experimenty ukázaly, že výrobní proces sendvičů je relativně snadno proveditelný v laboratoři. V průmyslu je také možný s ohledem na pečlivý výběr mechanických vlastností, adhezi a zborcení vrstev. Zkoušky nepotvrdily závislost předehřívání první vrstvy před 2K vstřikováním na mechanické vlastnosti, ale potvrdily se na zvýšené adhezi. Takto předehřívané sendvičové struktury byly ale zborcené, takže jejich výroba v průmyslu je tímto značně omezena, to platí pro experiment 7.3.1. Zborcení by se dalo předejít, kdyby se jednotlivé vrstvy předehřívaly rovnoměrně v peci. Pro experiment 7.3.4 jsme nedostali dobré výsledky při rázové zkoušce. Dobrého výsledku, tj. kompromisu malého zakřivení a dobrého výsledku testu rázové zkoušky, jsme dosáhli zkombinováním PBT s 30% skleněných vláken (CR T805) a PET s 15% skleněných vláken (RY 415HP).

Nicméně pro žádnou sendvičovou strukturu synergický efekt nenastal. To znamená, že z mechanického hlediska sendviče nejsou využitelné, ale jsou tam i jiné možnosti využití jako chemické, hlukové či vibrační bariéry.

V případě smíchání dvou materiálů přímo do násypky vstřikovacího stroje jsme dostali velice dobré výsledky. Výrobní proces je velice snadný v laboratoři a stejně tak i v průmyslu. Synergický efekt nastal, protože jsme naměřili vynikající výsledky při rázové zkoušce. Nejlepších výsledků jsme dosáhli smícháním tvrdého materiálů PBT s 20% skleněných vláken (CR LW9020) nebo PBT s 30% skleněných vláken (CR LW9030) a měkkého materiálu PBT+polyether (HY 5555HS) nebo PBT+polyether (HY 5556) v poměru 30% tvrdého a 70% měkkého materiálu. Takový poměr zaručoval výborné výsledky při rázových testech a zároveň, díky podílu pevného materiálu, byl dostatečně pevný v porovnání s měkkým materiálem.

Tímto procesem jsme dosáhli homogenní kompozit s hezkým povrchem, který by mohl být barven nebo pokovován.

Pro vymezení použití tohoto kompozitu za různých podmínek je ještě potřeba udělat rázové zkoušky pro různé teploty.

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