Plastic materials in installation products

Feasibility study

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Matti Töyrylä

Lahti University of Applied Sciences
Faculty of Technology

TÖYRYLÄ, MATTI:

Plastic materials in installation products
Feasibility study

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ABSTRACT

The goal of the study was to examine plastic materials or plastic material combinations for the visual parts of socket outlets and switches and try to find a more profitable choice to replace the present material, in order to make savings in manufacturing costs. Test materials had already been selected when the study began.

The theory part concentrates on the processing method of plastic parts, test materials, colour measuring and the properties of ultraviolet radiation in nature and also its effects on plastic materials. There is also a short presentation of the company that gave the assignment for this study.

In the practical section, materials were compared to each other, to examine the feasibility of changing the material. Materials were compared using the criteria of material price, processability, total manufacturing costs, stability of ultraviolet radiation and finally saving calculations for each material or material combination. Ultraviolet stability tests were only used to measure the yellowing effect because if a material combination is used, the yellowing of both materials should be the same.

Based on the results of the study, with todays's material prices it is not profitable to replace the old material. The results show that one material is above the others with its profitableness and with its characteristics but even so it is not suitable because it does not meet the standard requirements for socket outlets. However, it can be used in switches. A lot of product development is required before the material can be used in socket outlets but it would pay itself back rapidly.

Keywords: ultraviolet radiation, colour measuring, manufacturing costs, plastic materials

Lahden ammattikorkeakoulu
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Muovimateriaalit asennustuotteissa
Kannattavuustutkimus

Muovitekniikan opinnäytetyö, 32 sivua, 11 liitesivua

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TIIVISTELMÄ

Opinnäytetyöni tavoitteena oli tutkia muovimateriaaleja tai muovimateriaalien yhdistelmiä pistorasioiden ja sähkökytkimien visuaaliosiin ja yrittää löytää edullisempi vaihtoehto nykypäivän materiaalille, jolloin olisi mahdollista säästää vuotuisissa materiaalikustannuksissa. Tutkittavat materiaalit oli päätetty ennen tutkimuksen aloittamista.

Työn kirjallisessa osassa on perehdytty muoviosien valmistusmenelmään, vertailtavana oleviin materiaaleihin, värinmittaukseen ja luonnossa esiintyvän ultraviolettisäteilyn olemukseen ja sen vaikutukseen muoveissa. Lisäksi kirjallisessa osuudessa on esitelty sähkötarvikkeita valmistava yritys, Strömfors Electric, jonka toimeksiantona tutkimus on suoritettu.

Työn käytännön osassa on tutkittu materiaalivaihdon kannattavuutta erilaisin vertailuin. Materiaalien vertailuun kuuluivat raaka-aineen hinta, prosessoitavuus, kokonaisvalmistus kustannus, ultraviolettisäteilyn kestävyys ja lopuksi vielä mahdollisien säästöjen laskeminen eri materiaalivaihtoehdoille. Ultraviolettisäteilyn kestävyys on tutkittu vain kellastumisen osalta, koska kunkin materiaalin tulee kellastua samalla tavalla, jotta niitä voidaan käyttää yhdessä.

Tutkimuksen tulosten perusteella materiaalin vaihtaminen ei ole taloudellisesti kannattavaa nykyisillä raaka-ainehinnoilla. Tutkimuksessa yksi materiaali oli ylitse muiden edullisuudellaan ja ominaisuuksillaan, mutta se ei silti täyttänyt tarvittuja vaatimuksia. Materiaalin käyttöön saaminen vaatisi paljon kehitystyötä tuotteelle, mutta saattaisi säästöjen suuruuden vuoksi olla erittäin kannattavaa.

Avainsanat: ultraviolettisäteily, värinmittaus, valmistuskustannus, muovi materiaalit

CONTENTS

1 INTRODUCTION

Today most companies try to find ways to get some savings and therefore be more productive. One of the ways is to find cheaper raw materials. Strömfors Electric is part of the global Schneider Electric concern which is located in Southern Finland in Ruotsinpyhtää. There is a project going on in the department of research and development in Strömfors Electric to find savings in raw material costs.

The main products of Strömfors Electric are socket outlets and switches where smart and glossy visual parts are used to give a good look. The objective of this study was to find a more profitable material for those visual parts and calculate the possible savings per year. The starting point for the study was that I had material used at the moment and three new materials that I started to compare with each other. One of those materials was not suitable for socket outlets because it does not meet standard requirements but it is still right for switches. In this study I compared four materials between each other by manufacturing costs, processability and UV stability, especially concerning discoloration.

Processability for each material is found out by test runs. Test runs are carried out in the Plastics department of Strömfors Electric. All important values are written down in the testing diary and based on it I compared the results by temperatures, times, and pressures. I used the results partly for manufacturing costs estimation which is estimated by using a form from an old book. The machine's hour-rate, which means how much each machine costs per hour in active use, was perhaps a little old data but I compared the results percentually so that way it is a functional form to use.

The property which defines what materials can be used together in socket outlets and switches is ultraviolet stability, which means how much each material endures ultraviolet (UV) exposure without any discoloration or any other effects. If the visual parts of socket outlets and switches begin to discolour they have to discolour in the same way. UV stability is found out for each material by two tests that I carried out in my school and in the Strömfors laboratory. The difference between those two tests was that I used different UV lamps.

After this introduction follows the part of study which gives a theoretical introduction to all methods, products and materials that are used in this study. Theoretical information comes from books and Internet. Book references are the main source because internet includes a lot of unreliable material.

2 STRÖMFORS ELECTRIC

2.1 History

In Finland Strömfors is one of the most famous companies in electric business. In 2007 Strömfors has manufactured electrical installation systems 60 years under the same named factory area. 60 years ago when production of electrical installation products started the factory's name was Ahlström. Factory is located in Ruotsinpyhtää. (Schneider Electric 2008.)

Because of technical development and export activity, internationalization started stongly at Strömfors. In 1995 the company merged with Danish NKT when the Lexel Electric concern was born but after four years, in 1999, Schneider Electric bought the Lexel Electric concern. Nowadays Strömfors is part of the French Schneider Electric concern's Schneider Nordic & Baltic group, which employs about 3600 employees in Scandinavia and the Baltic Countries. (Schneider Electric 2008.)

2.2 Schneider Electric

The workforce of Schneider Electric was 100,000 employees in more than 100 countries in 2009. The turnover was 15.8 billion euros and the European regions accounted for 41%. The operation of markets Schneider Electric is divided into five areas as shown in the list below. (Schneider Electric 2010.)

- Energy & Infrastructure
- Industry
- Data centers & Networks
- Buildings
- Residential

2.3 Products and requirements

Strömfors Electric's main products are electrical installation products, especially socket outlets and switches as shown below in FIGURE 1. In this project the materials of visual parts of those products are studied. For those products there are standard requirements defined by the Finnish Standards Association (SFS) which are based on the stardards of the International Electrotechnical Comission (IEC). There is also Safety Technology Authory (TUKES) which tests and controls the safety of all products. The standards of general requirements for socket outlets and switches are shown below. (SFS-EN 60669-1 2000; SFS 5610 2004; Schneider Electric 2008; TUKES 2010.)

- SFS 5610: 2004 Plugs and socket-outlets for household and similar purposes. Part 1: General requirements (IEC 60884-1:2002)
- SFS-EN 60669-1: 2000 Switches for household and similar fixed electrical installations. Part 1: General requirements (IEC 60669-1:1998)

In this project the important requirement is SFS 5610; 25.2 ball pressure-test. Because one of the test materials does not pass it the visual parts must be divided into two different groups, socket outlet parts and other parts. On the socket outlet centerplates there are two holes for plugs and the ball pressure test is carried out in maximum 2mm away from the edge of the circular hole. (SFS 5610 2004.)

FIGURE 1. Switch and socket outlet (Schneider Electric 2008)

3 INJECTION MOLDING

Injection molding is the first melt processing method and it was introduced in the 18th century. Nowadays, injection molding is the most common processing method for technological plastics processing. The most essential part of injection molding is a well designed and produced mold. Surface quality, form and the materials residual stress can be affected by controlling the injection molding cycle. (Järvinen 2008, 180.)

3.1 Injection molding machine

The injection molding machine (FIGURE 2.) consists of four main parts having their own functions:

- The injection unit melts the plastic and injects it to the mold cavity
- The clamping unit opens and closes the mold and ejects molded part
- The control unit is the machine's "brains" that controls the process
- The hydraulic unit produces pressure for the movements of all components

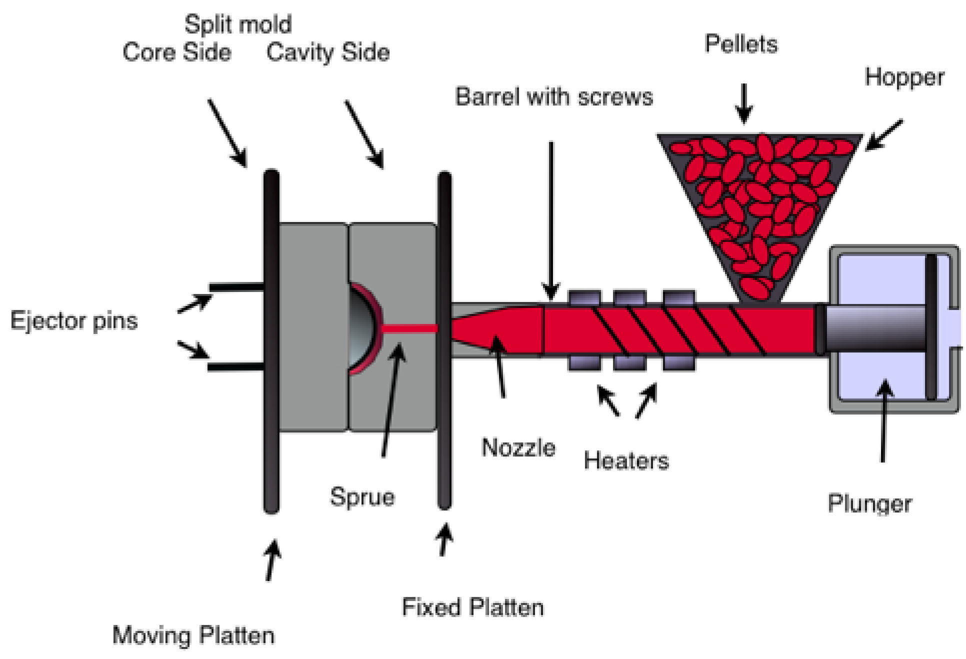


FIGURE 2. Injection molding machine (TLC Plastic Group 2008)

3.2 Injection molding cycle

The modern injection molding machines have many steps in the cycle which are controlled. The most important job of the injection molding machine operator is to optimize all those steps so that the quality of the molded part is best possible. The injection molding cycle is divided up into seven steps. The steps are shown below. (Järvinen 2008, 181 - 182.)

A. Mold closing action
B. Injection
C. Holding pressure
D. Plasticizing
E. Cooling
F. Mold opening action
G. Break time

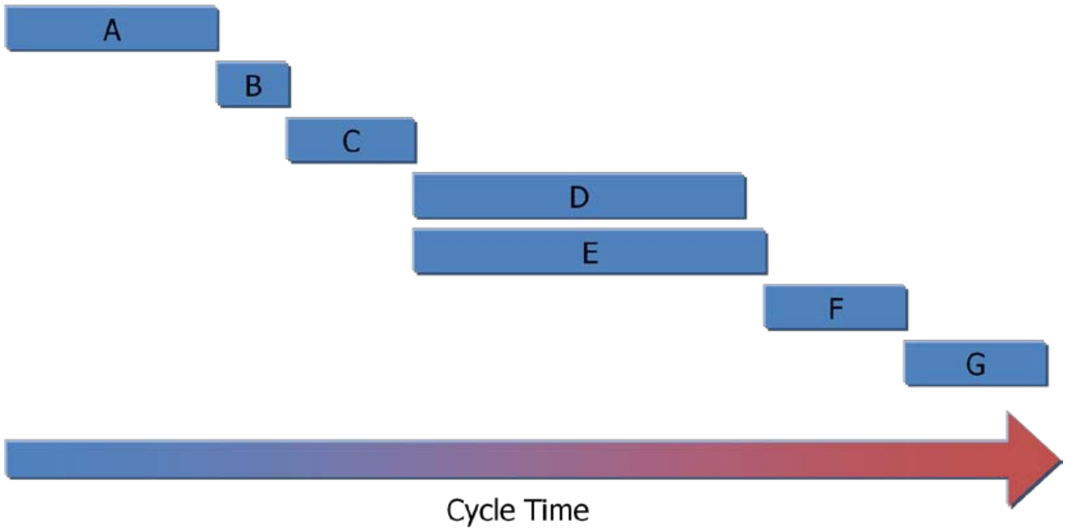


FIGURE 3. The division of injection molding cycle (Järvelä, Syrjälä & Vastela 1999 47)

Following the timelines in FIGURE 3, after the mold closing action the injection unit injects the molten plastic through the sprue to the mold cavity. Injection fills about 95% of the mold cavity and the remaining empty space is filled by holding pressure. After the holding pressure time, the hot plastic part should be cooled before the mold opening action. During the cooling time the injection unit plasticizes the new molten plastic dose for the next cycle. When the mold is opened the cooled plastic part is ready for ejection and after that the injection molding machine is ready to start a new cycle. (Järvelä, Syrjälä & Vastela 1999, 48.)

4 EFFECTS OF ULTRAVIOLET RADIATION ON PLASTICS

4.1 Ultraviolet radiation

Electromagnetic radiation or "light" is the collective name for all forms of energy that move with the speed of light. There are different "types of light" in the spectrum, depending on their energy, which is related to the wavelength of the light: the lower the wavelength, the higher the energy. (UV radiation 2008.)

The UV region covers the wavelength range 100-400 nm (FIGURE 4) and is divided into three bands:

- UVA (315- 400 nm)
- UVB (280- 315 nm)
- UVC (100- 280 nm)

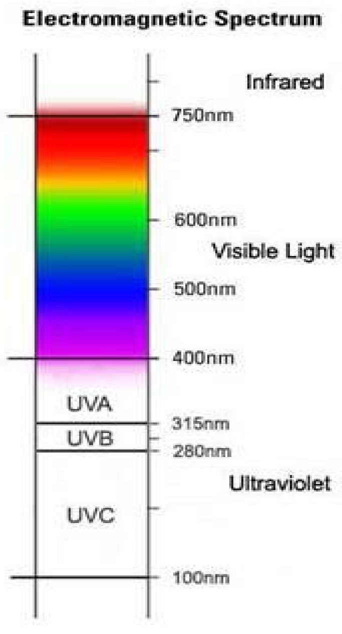


FIGURE 4. Electromagnetic spectrum (Green Facts 2009)

As sunlight passes through the atmosphere, all UVC and approximately 90-95% of UVB radiation is absorbed by ozone, water vapour, oxygen and carbon dioxide. UVA radiation is less affected by the atmosphere. Therefore, the UV radiation reaching the Earth's surface is largely composed of UVA with a small UVB component. (Ultraviolet radiation and health 2010.)

The human eye is sensitive for only the visible light of the spectrum with wavelength between 400 and 750 nm (1 nm = 10^{-9} meter). The wavelength of the light determines the colour: 400 nm is blue, 700 nm is red. (UV radiation 2008)

4.2 Ultraviolet degradation

Exposure to ultraviolet light will degrade many plastics. The results will be discoloration, embrittlement, and finally degradation of physical properties but in this project only discoloration is studied. The basic reason for degradation is a chromophore, a chemical group that absorbs UV light. Such a group may be part of the polymer structure or it may be present because of residual monomer or catalyst, aromatic or other double-bond containments in any of the ingredients, or hydroperoxide or carbonyl groups resulting from thermal oxidation during processing. (Harper & Petrie 2003, 578.)

If the absorbed UV energy is not rapidly dissipated, it will begin to break the chemical bonds in molecular chains. The lower-molecular-weight chain fragments will no longer exhibit the polymer's orginal properties. It also creates free radicals and propagates a chain degradation reaction. (Harper & Petrie 2003, 578.)

The reaction follows this sequence. The UV energy breaks a bond, creating an excited molecule that forms a free radical. The free radical reacts with athmospheric oxygen to form a peroxy radical. This radical then reacts with at another point to form a hydroperoxide and other free radicals, which repeat the sequence. The unstable hydroperoxide can also form new radicals to accelerate the reaction and boost the chain scission. (Harper & Petrie 2003, 578.)

Stabilization inhibits the initiation of this sequence by containing additives to screen UV energy, to preferentially absorb it, or to quench the excited state. Mechanisms also include inhibition of the propagation process by containing additives that will react chemically with the free radicals and hydroperoxides as soon as they are formed to render them harmless. (Harper & Petrie 2003, 578.)

4.3 Ultraviolet Stabilizer

UV stabilizers refer to additives for the protection of plastics from degradation by UV light. The choice of UV stabilizer depends on the application, the polymer's characteristics, the stabilizer's effect on color, and the expected life of the products. There are several types of UV stabilizers. One group develops UV stabilization by screening out the light to restrict UV penetration into polymer, and another group interrupts the chemical chain reactions resulting from free radicals. Several other groups operate with different mechanisms and at different times during the UV degradation process. (Harper & Petrie 2003, 578.)

UV screeners are actually pigments. They render the polymer translucent or opaque and absorb or reflect UV light, thus protecting the polymer. Carbon black, titanium dioxide at relatively high loadings, and other pigments are effective UV screeners. (Harper & Petrie 2003, 578-579.)

UV absorbers are the oldest and largest category of UV stabilizers. They inhibit the initiation of the degradation process. Materials in this class compete with the polymer for UV energy and win because their absorbtivity is orders of magnitude greater than that of the polymer. Benzophenones are used in polyolefins, unsaturated polyesters, PVC, thermoplastic polyesters, and acrylics. Benzotriazoles are used in polystyrene, ABS, polycarbonate, and thermoset polyester. They show good initial color and long-term color stability. They have FDA (Food and Drug Administration) acceptance and show good initial color. Oxanidiles exhibit very low color and low volatility and are suitable for high-temperature processing applications. (Harper & Petrie 2003, 579.)

UV quenchers also inhibit intiation, although they function later than do absorbers. Quenchers are organic nickel compounds and they are typically used in polyolefins. Unlike absorbers, quenchers are effective in thin sections and they are often used along with UV absorbers. Quenchers usually impart color. (Harper & Petrie 2003, 579.)

Scavengers are UV stabilizers that operate later in the UV degradation sequence, inhibiting propagation. Hindered amines function as quenchers or peroxide decomposers and their main function is scavenging and termination of free radicals. Advantages include effectiveness at low concentrations, reduced volatility, and high temperature stability. (Harper & Petrie 2003, 579.)

5 CIE COLOUR SYSTEM

CIE, International Comission on illumination (Comission Internationale de l'Eclairage) released a diagram based on light colours in 1931 where the colors are located premised on light properties to three-dimensional color model. The color system was expanded and updated in 1960 and 1976. In 1976, the CIE recommended the CIELAB color scale for use. (Huttunen 2005, 52.)

CIELAB is intented to provide a standard color scale which could be used by everyone so that color values could be easily compared. In a color scale, the differences between points plotted in the color space correspond to visual differences between the colors plotted. The CIELAB color space is organized in a cylinder form or cube form. The L-axis runs from top to bottom as shown in FIGURE 5. The maximum for L is 100, which represents a perfect reflecting diffuser. The minimum for L is zero, presenting black. The a-axis and b-axis have no specific numerical limits. Positive a value is red and negative a value is green. Positive b value is yellow and negative b value is blue. FIGURE 5 is a diagram representing the CIELAB color space in a cylindrical form. (Adobe systems 2000; Chroma meter 1988.)

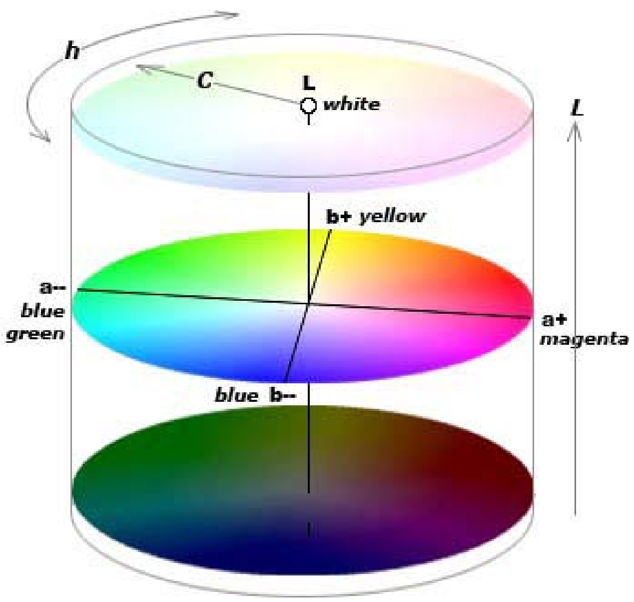


FIGURE 5. CIELAB cylindrical form (Cielab 2008)

It is possible to calculate delta values for each axis. ΔL, Δa and Δb indicate how much a reference and sample differs from one another in L, a and b value. It is also possible to calculate total color difference ΔE. The ΔE is a single value which takes into account the differences between the L, a and b of the sample and the reference. It does not show which single parameters are out of tolerance if ΔE is out of tolerance. It may also be misleading in some cases where a single parameter (ΔL, Δa or Δb) is out of tolerance but ΔE is still within tolerance. Total color difference ΔE is calculated from the equation below. (Adobe systems 2000; Chroma meter 1988.)

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

6 INTRODUCTION OF PLASTIC MATERIALS

6.1 PC/ABS Blend

The most commonly used PC compound is PC/ABS (Polycarbonate/Acrylonitrile butadiene styrene). This blend has been found to be functional on the market. PC/ABS polymer blends are amorphous thermoplastics and they consist of two components which complete each other. PC has good heat resistance and stiffness and ABS is low cost and has good fluidness and stress-cracking stability. The blend has the speciality that it is tougher than both unalloyed PC and unalloyed ABS. PC/ABS is used in electrical applications, for example in covers of mobile phones and laptops and it is also used in socket outlets and switches. (Järvinen 2008, 82-83.)

6.2 ABS

Acrylonitrile butadiene styrene, ABS was developed in the end of the 1940s. ABS is Styrenes copolymer where the material brightness and surface stifness are lost but it has good processability and good surface guality. ABS has a chemical structure where acrylonitrile provides heat resistance, strength, and chemical resistance. The butadiene structure provides impact resistance, toughness, good low-temperature properties and flexibility. The styrene structure imparts rigidity, a glossy surface finish, and easy processing properties. It is possible to modify the material by adjusting the ratio of the three components. ABS is used in the visual parts of cars, for example in control boards and grips for chambers and doors. (Järvinen 2008, 67-68; Harper & Petrie 2003, 10.)

6.3 PC

The production of polycarbonates started in Germany in 1956. Polycarbonates are outstanding in impact strength and have strength several times higher than other engineering thermoplastics. Polycarbonates are tough, rigid, and dimensionally stable and are available as transparent or colored parts. Along with all good characteristics, polycarbonates also have some weaknesses. For example in outdoor use they deteriorate fastly without UV stabilization. Polycarbonate is vulnerable to chemicals and especially their long-term effect when it can cause stress-cracking on the surface of the part. Polycarbonate is used a lot in electronics and electric industries, for example in compact discs, digital versatile discs and electric mounting boxes. The car industry also uses polycarbonates, for example in the lenses of the front lights of cars. (Harper & Petrie 2003, 419-420; Järvinen 2008, 78-80.)

6.4 PC/ASA

The PC/ASA blend consists of two components, polycarbonate and acrylonitrile styrene acrylate. The blend behaves like PC/ABS but it has better UV stability and heat resistance. In general, PC/ASA is used in outdoor applications and unbending and hard products can be manufactured from it. (Järvinen 2008, 83.)

7 TEST METHODS

7.1 Test materials

- PC/ABS
- PC
- PC/ASA
- ABS

7.2 Test runs

I commissioned test runs from the plastic department of Strömfors Electric to find out the processability of each material. The operator of the injection molding machine made test runs and wrote down all important values in the test diary (APPENDIX 6). Based on the test diary I summarized results and made comparisons by temperatures, pressures, times and manufacturing costs.

7.3 UV tests

I conducted three UV tests but I had to discard one of them because after 1000 h exposure time there was not any discolouration on samples. Fluorescent tubes in the discarded test were Philips TL-D 18W/108 x2. The tests that I accepted to this study were carried out in the Strömfors Electrics testing laboratory and in my school's testing laboratory where I also made all colour measurements. Both the UVA and the UVB test are described next.

7.3.1 UVA test

The test where I used UVA light to discolour samples was carried out in the testing laboratory of Lahti University of Applied sciences. In the test cabinet there were four fluorescent tubes Sylvania FT40 / BL350 which exposures ultraviolet radiation in wavelength between 320 – 400 nm, peak 351 nm (APPENDIX 9).

I put a total of 16 samples to the test cabinet, four of each test material and all samples were located about 10 cm away from the fluorescent tubes. I made four colour measurements after exposure times 168 h, 336 h, 504 h and 1000 h by Minolta Chroma Meter CR-200 and wrote L, a and b values in the test diary (APPENDIX 7).

7.3.2 UVB test

In the second UV test I used two Philips TL 20W/ 12RS fluorescent tubes which exposure UVB radiation in wavelength between 280 - 380 nm, peak 313 nm (APPENDIX 10). The test was carried out in the testing laboratory of Strömfors Electric.

I used a total of 12 samples, three of each test material and all samples were located about 20 cm away from the fluorescent tubes. From the cabinet I took out a sample of each material after 90 h, 168 h and 336 h exposure time. Because the color meter was in my school I made color measurements when all samples had been taken out of cabinet. The testing diary is shown in APPENDIX 8.

7.3.3 Estimation for real age

The UVA and UVB tests were not carried out according to any standard method and that is why it was hard to estimate the corresponding real age in outdoor application. 1000 h exposure by Sylvania Ft 40/ BL350 fluorescent tubes corresponds approximately to one year to one and half years of UV radiation that socket outlets and swithes can get outdoors. According to previous UV dose estimation I estimated also the UVB tests corresponding between natural UV dose. All UV dose estimations are based Moran & Sheldon (2000, 1255) view of Ft 40 / BL 350 tubes radiation compared to daily average summertime irrandiance at 30°N latitude.

7.4 Saving calculation

I found out the quantities how many visual plastic parts have been produced in recent years and divided the numbers into two categories, socket outlet parts and other parts. I used those quantities to estimate the production in the near future. Production quantities are divided up into those two categories because ABS does not pass SFS 5610; 25.2 ball pressure test and therefore it is not the right material for center plates of socket outlet. Material consumptions were calculated using those 30 parts from both groups that require most raw materials (APPENDIX 11).

7.5 Total manufacturing costs

I calculated the estimation of processing costs for each material by using the form as shown in APPENDIX 5. I followed the calculation form of Macdermott & Shenoy (1997) partly because for some components, for example maximum injection pressure, which defines the needed clamp force, was already known. Total manufacturing costs tell how much it costs to manufacture 100,000 parts with each material. Because the calculation form has come from too old a source I had to look at it critically so the results were compared percentually. Macdermott & Shenoy (1997) defined machine hour-rate like in the list below.

- 40 ton machine costs 13.30 €/hour
- 60 ton machine costs 13.82 €/hour
- 80 ton machine costs 14.41 €/hour

8 RESULTS

8.1 Material comparison by price

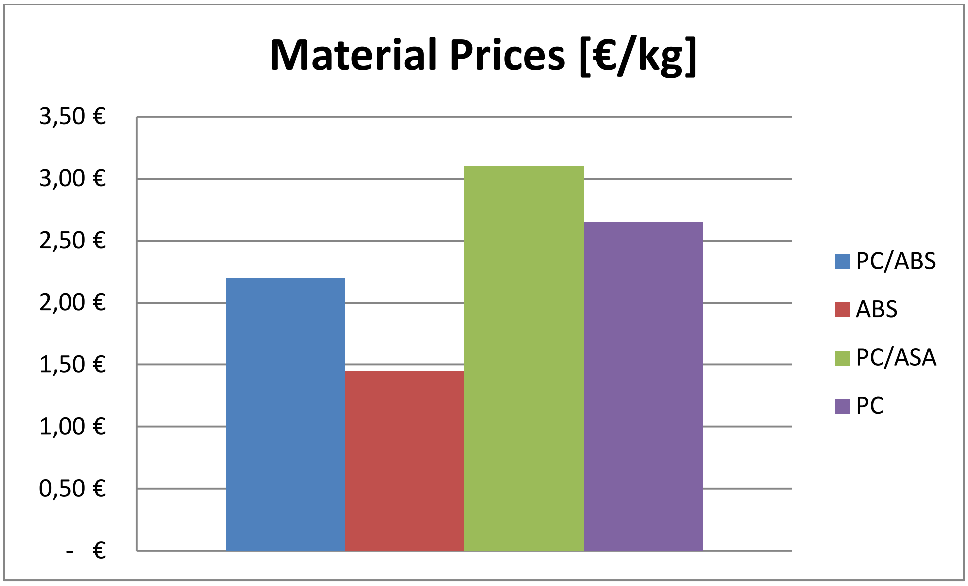


FIGURE 6. Graph shows material price for each material

8.2 Material comparison by processability

In this comparison part I compared test run results for each test material and summarized them. The comparisons are divided up into three main categories: temperatures, pressures and times. The most important comparison is cycle time because the time has a direct impact on the production time. Temperatures and pressures are comparable to the consumption of energy, thus all three categories are directly comparable to the manufacturing costs. Comparisons are shown in FIGURES 7 - 10 on the next page.

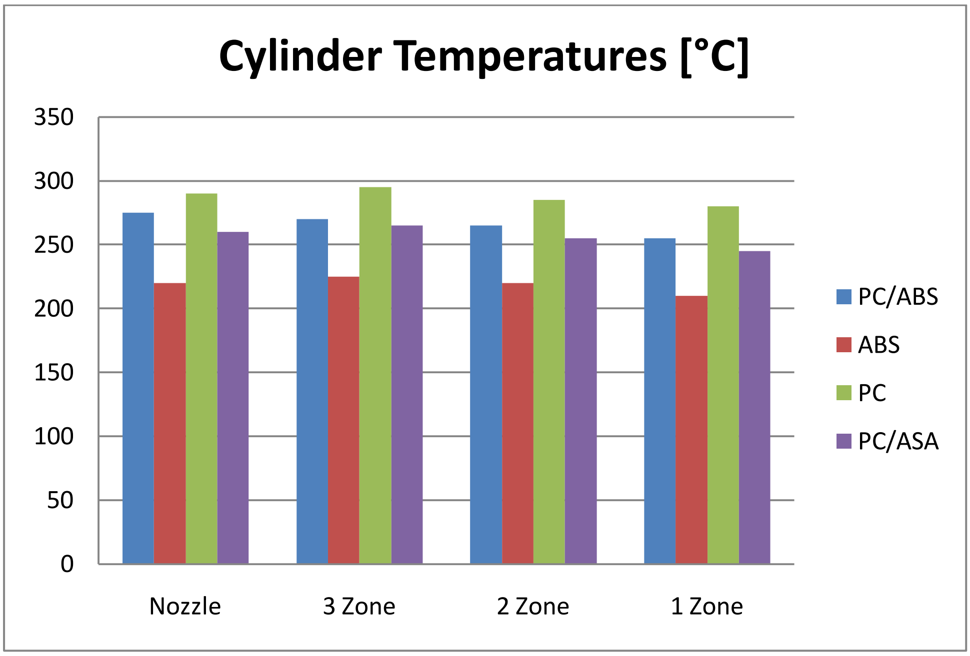


FIGURE 7. Cylinder temperatures for each material

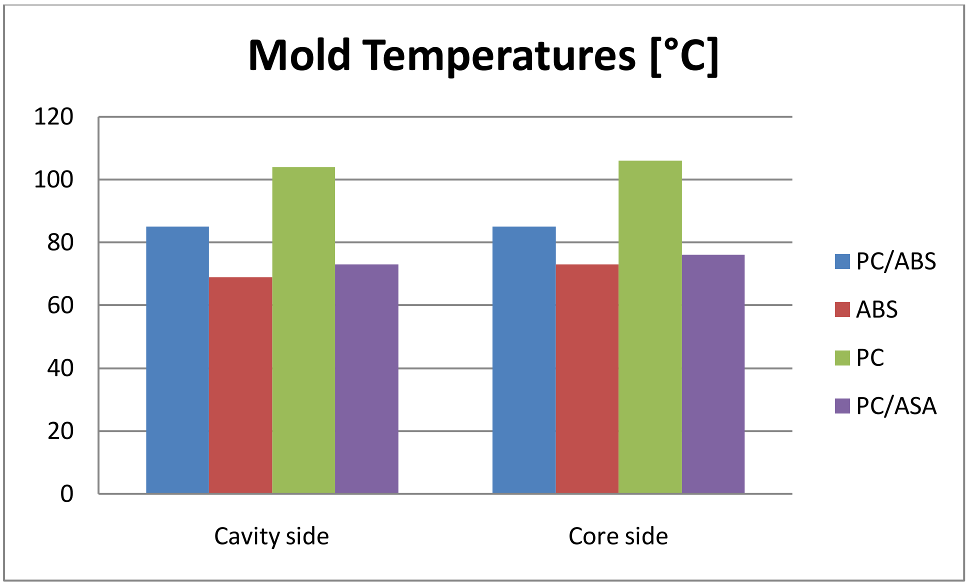


FIGURE 8. Mold temperatures for each material

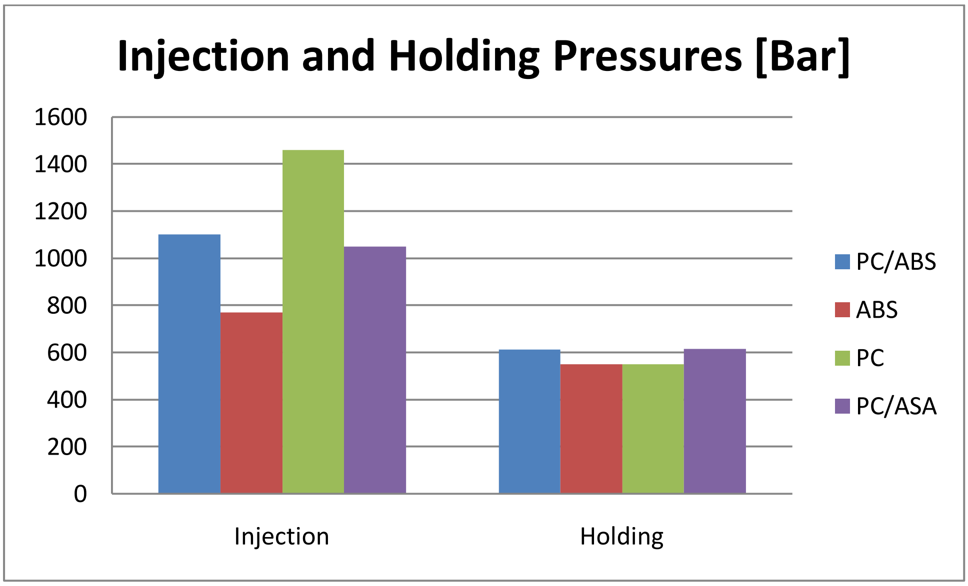


FIGURE 9. Injection pressures and holding pressures for each material

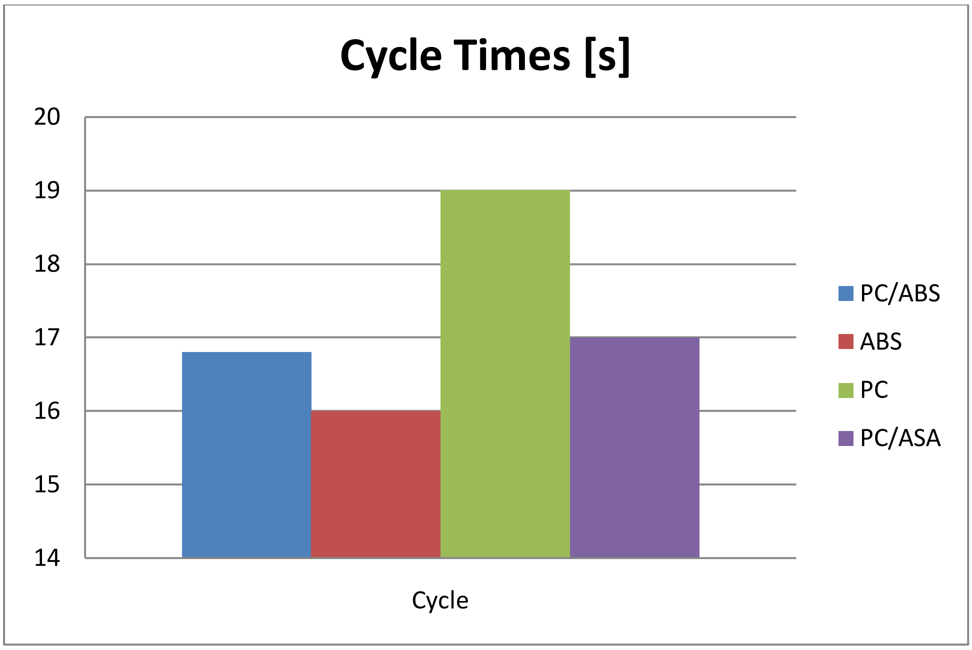


FIGURE 10. Cycle times for each material.

The last four figures show that ABS is absolutely the easiest to process and ABS also has the shortest cycle time. PC has the highest temperatures, highest pressures and longest cycle time so it is the hardest material to process. Test run values are shown in APPENDIX 6.

8.3 Material comparison by total manufacturing costs

Manufacturing costs were calculated by following a calculation form (APPENDIX 5) and costs were calculated for parts 101167 and 101166 because the results of the test run from these parts were available. The estimation of manufacturing costs is shown below in TABLE 1.

TABLE 1. Manufacturing costs for each material

Description	Material			
	PC/ABS	ABS	PC	PC/ASA
TOTAL MANUFACTURING COSTS [€/100000parts]	4328,2	3649,8	5252,7	4902,8
TOTAL MANUFACTURING COSTS COMPARED PERCENTUALLY	0,0 %	-15,7 %	21,4 %	13,3 %

The results show that with ABS the manufacturing costs are 15.7% lower than today's material PC/ABS and the manufacturing costs with PC and PC/ASA are higher. The Reasons for lower costs when manufacturing with ABS are that the material price is lower, it needs less energy for processing and it is also faster to process than the other test materials.

8.4 Material comparison by UV stability

In this part of the study UV test results are shown in FIGURES 11 - 17 on the following pages. The results are shown in comparisons by total color difference, delta b difference and by visual estimation. The value called delta b tells the color difference in blue/yellow axis.

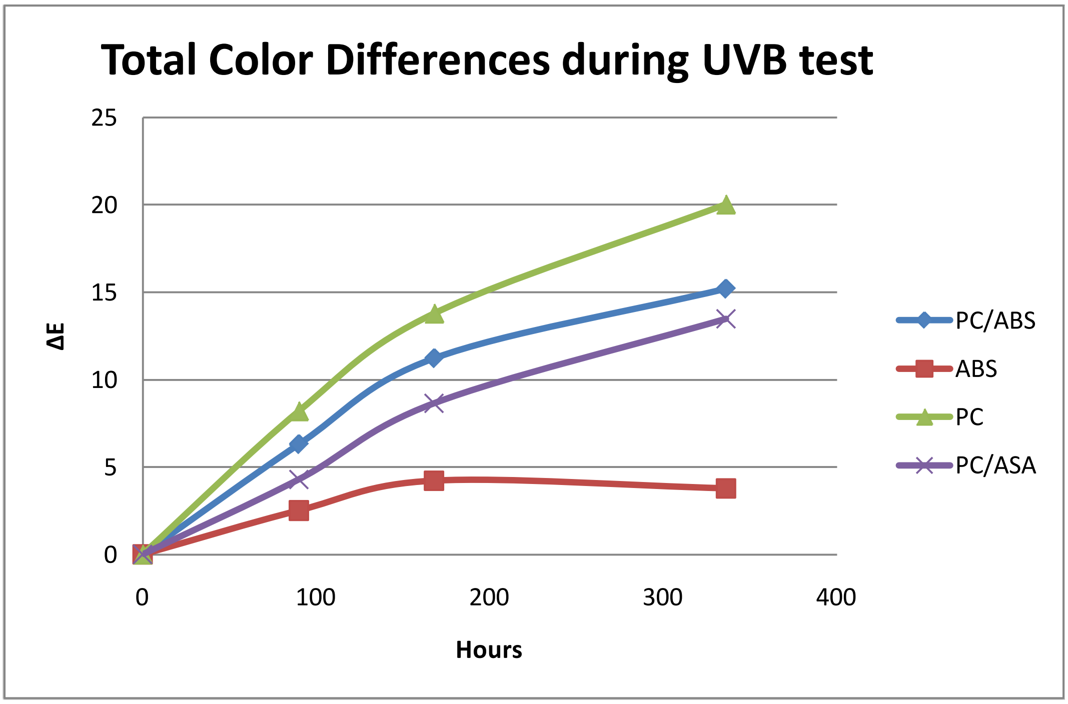


FIGURE 11.Total color difference during UVB test

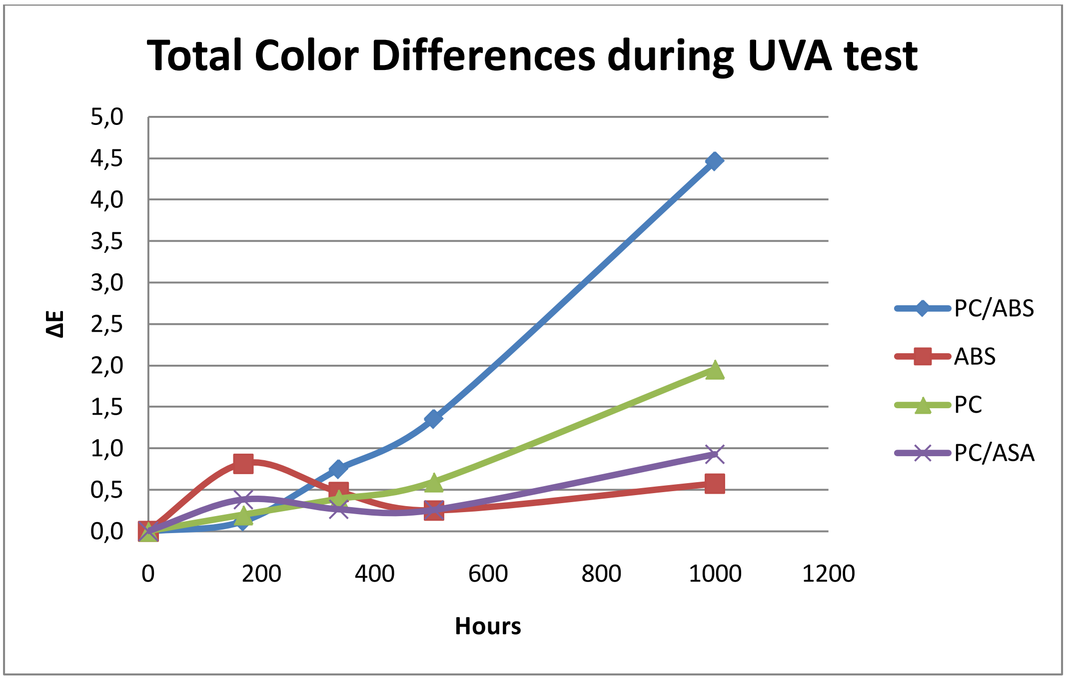


FIGURE 12. Total color difference during UVA test

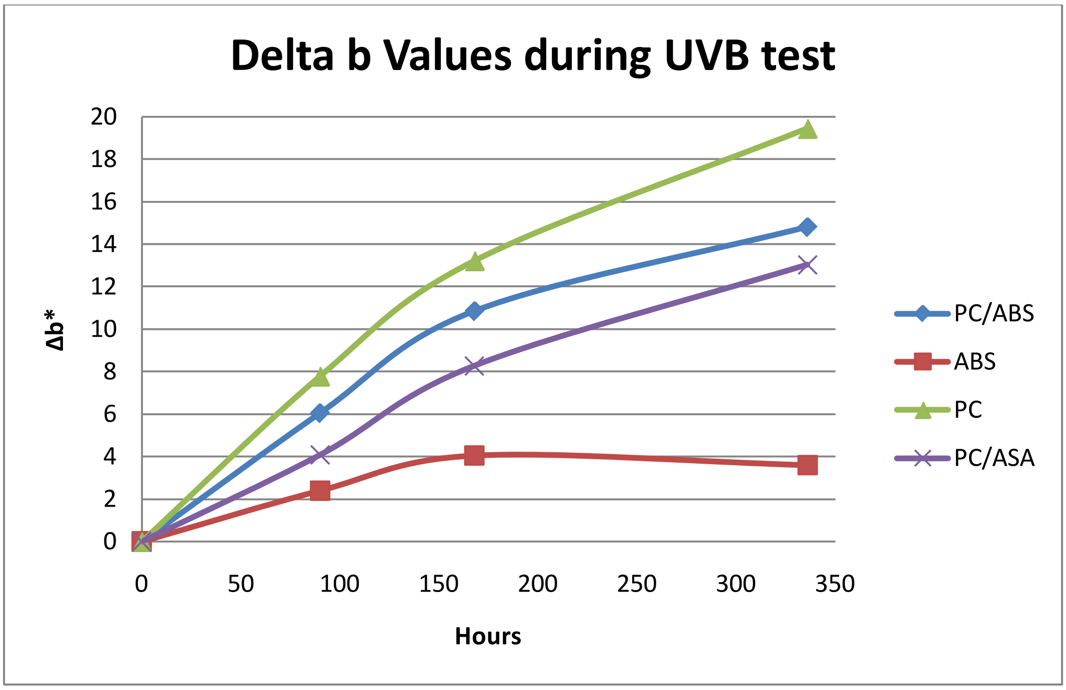


FIGURE 13. Yellowing for each material during UVB test

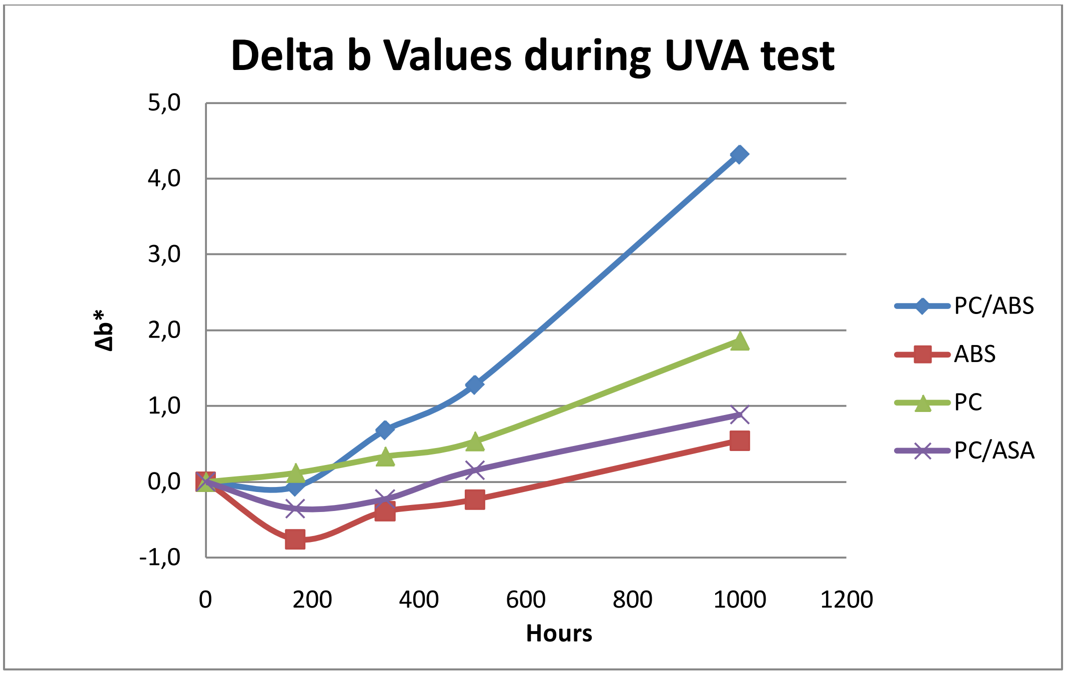


FIGURE 14. Yellowing for each material during UVA test

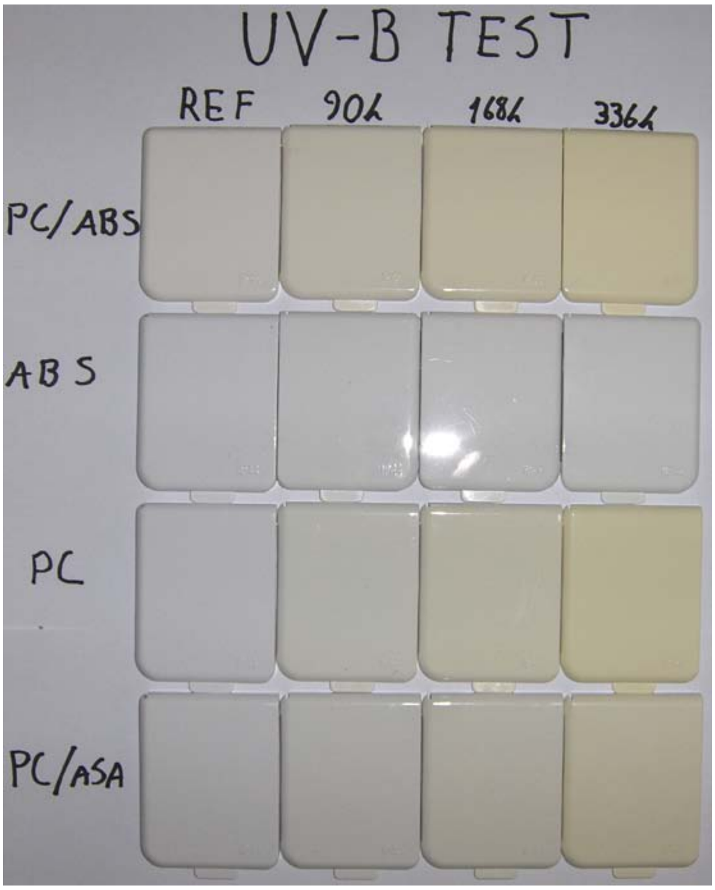


FIGURE 15. All samples after UVB test

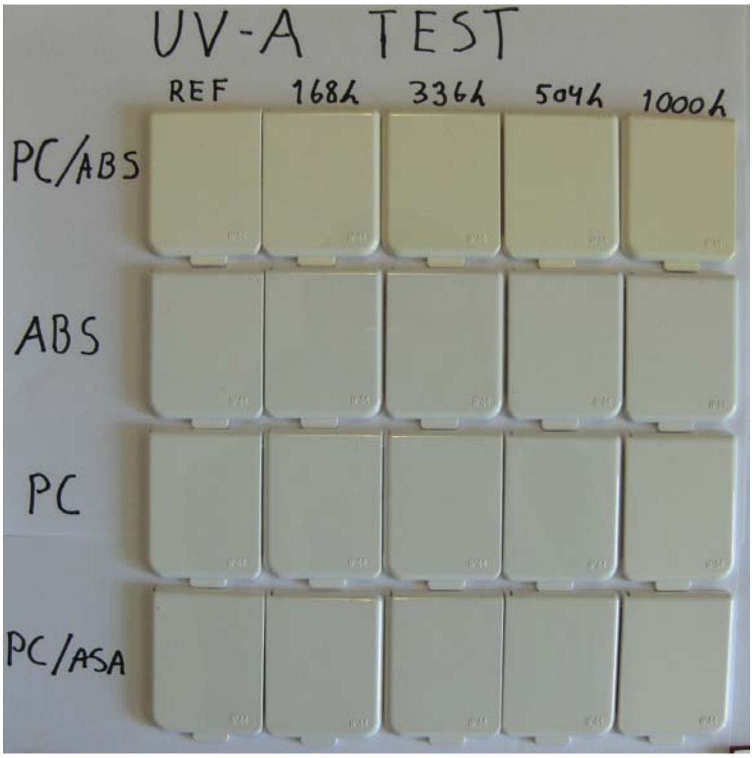


FIGURE 16. All samples after UVA test

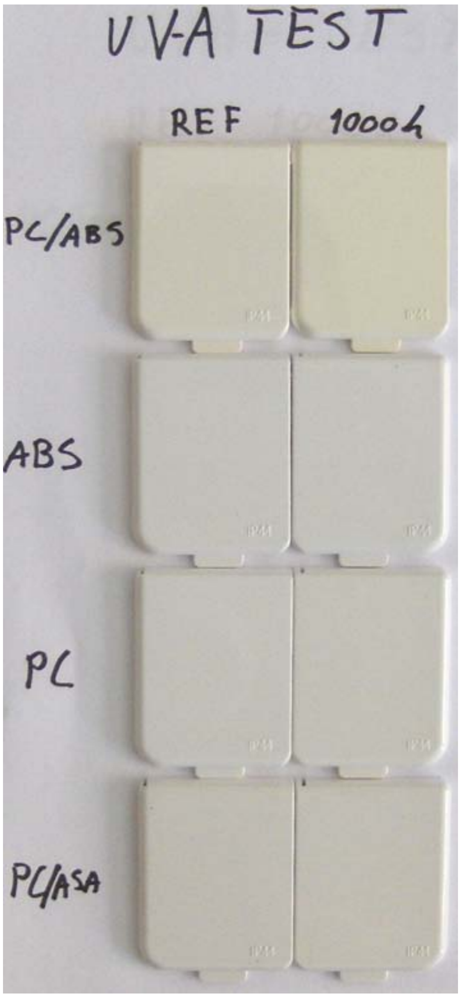


FIGURE 17. 1000 h samples compared with reference parts after UVA exposure

The results from the UVB test (FIGURE 11, 13 and 15) show that PC discoloured the most of all according to comparison by delta b values and total color difference. In FIGURE 15 it seems like PC/ABS is the most discoloured part after 336 h exposure time but its reference part colour was the yellowest so the most discoloured and weakest material was PC and UV stabilized ABS has the best UV stability.

The results from the UVA test (FIGURES 12, 14, 16 and 17) show that after 1000 h UVA exposuring PC/ABS yellowed the most and PC the second most. FIGURES 16 and 17 show samples after the test and it is hard to see the discolouration with human eye but the results of colour measurements in FIGURE 12 and 14 shows the yellowing clearly. Also in this test ABS was the best material.

The problem was to determine which UV test correspond the most with natural conditions. The results that we have to look at critically are UVB test results because the used fluorescent tubes exposure mostly UVB radiation and in nature radiation consists only 5% of UVB. I think that the results are still indicative and 336 h exposure time corresponds approximately to 13 - 17 years in outdoor application. Fluorescent tubes used in the UVA test exposure quite similar radiation than sunlight on earth so it corresponds approximately to 1 to 1.5 years outdoor using.

8.5 Saving calculations

In below, there are FIGURES 18 and 19 which show the material costs per year and calculated savings for each material combination.

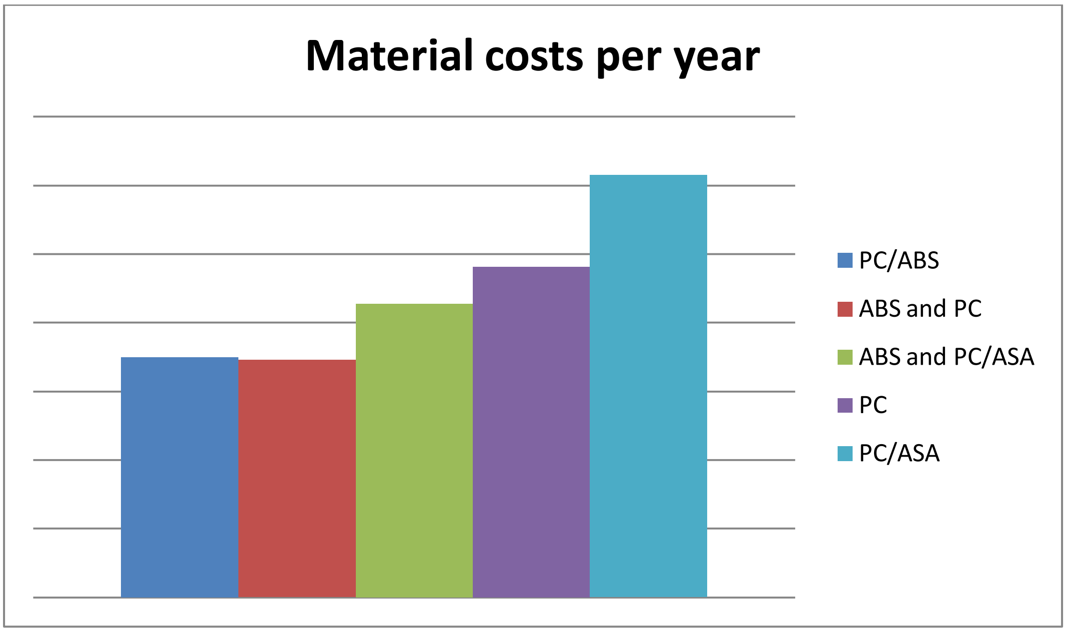


FIGURE 18. Material costs for each material or material combination

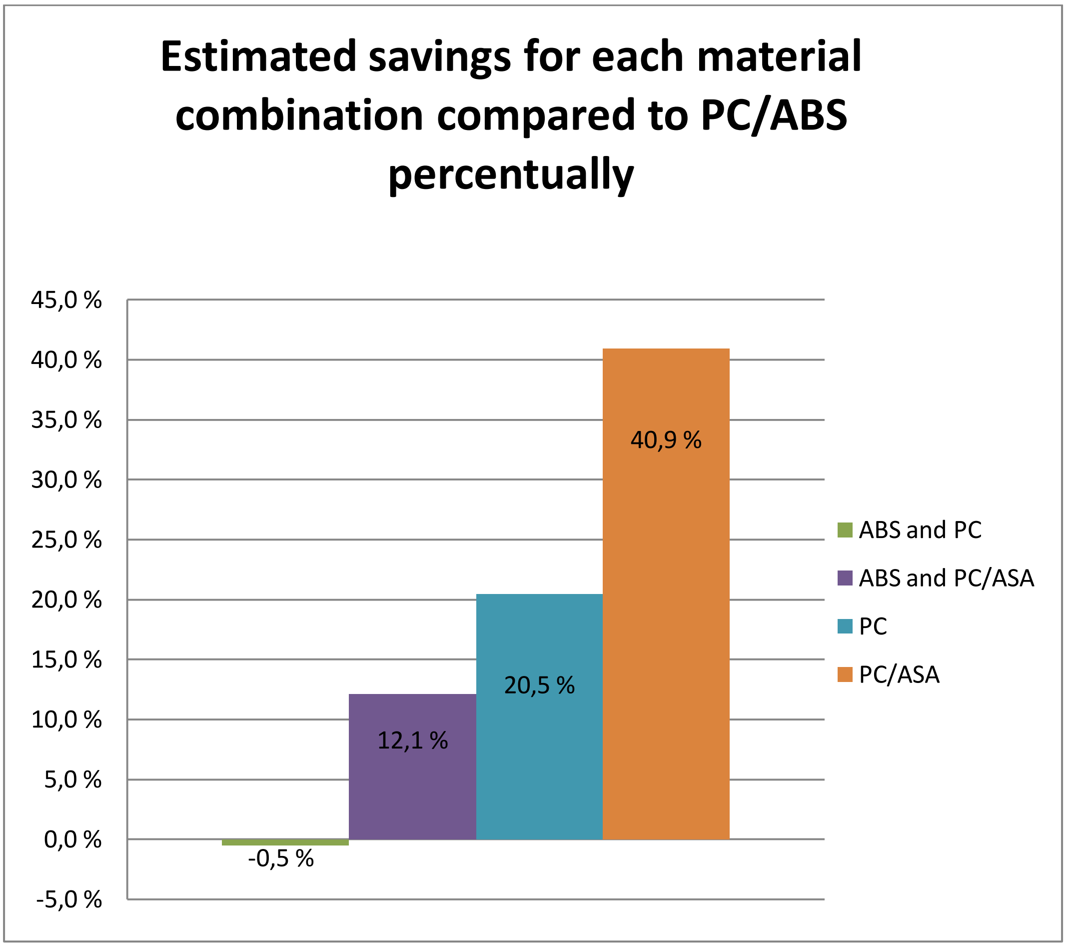


FIGURE 19. Material costs for each combination compared to present material PC/ABS

The results in FIGURE 19 show that the combination where ABS is used in other parts and PC is used in socket outlet parts is 0.5 % cheaper than the present material PC/ABS. All other combinations are more expensive, and thus they are not so profitable to use. Material costs per year are shown in FIGURE 18.

9 SUMMARY AND CONCLUSIONS

After all the comparisons between the four test materials it is time to summarize the results and make conclusions based on that. The aim of this study was to examine the four materials and find among them the material or material combination that Strömfors Electric and also the whole of Schneider Electric could use to get savings in material costs and also get a better material for their products than PC/ABS, which is used at present.

All results show that ABS has the lowest price, the best UV stability, the lowest manufacturing costs and also its processing consumes the least energy and we can clearly see that PC and PC/ASA are much more expensive as raw materials and also more expensive to manufacture. Based on the UV test results, there is one material combination that could perhaps be used, namely the combination of ABS and PC/ASA. PC/ASA could be used in socket outlets and ABS in other parts but the price of PC/ASA is so high that the total material costs would increase by 12.1%. The combination where ABS is used in other parts and PC is used in socket outlets is a little cheaper (0.5%) than the present material. Even if the UV stability of PC improved in the future and therefore it would be possible to use it, the payback time of the changeover would be too long.

Although the results of this study show that changing the material would not be profitable, it is important to keep in mind that if ABS could also be used in socket outlets, it would be possible to get very big savings in manufacturing costs and it would also consume less energy, which is important in today's industry. Savings in material costs would be 34.1% (APPENDIX 11) if ABS were the only material used.

This study left an open question. It is the estimation of material age after these UV tests. To make age estimation easier the next step in Strömfors Electric could be the development of UV testing equipment in accordance with the standard.

REFERENCES

Adobe systems. 2000. Color models [referenced 6.4.2010]. Available on: http://dba.med.sc.edu/price/irf/Adobe_tg/models/cielab.html

Chroma meter. 1988. User Manual. Japan: Minolta Camera Ltd.

Cielab. 2008. What does cielab means? [referenced 1.4.2010]. Available on: http://www.cielab.com.au/whatiscielab.php

Green Facts. 2009. Ultraviolet radiation [referenced 1.4.2010]. Available on : http://www.greenfacts.org/glossary/tuv/ultraviolet-radiation.htm

Harper, C. & Petrie, E. 2003. Plastic Materials and Processes. New Jersey: John Wiley & Sons Inc.

Huttunen, M. 2005. Värit pintaa syvemmältä. Helsinki: WSOY

Järvelä, P., Syrjälä, K. & Vastela, M. 1999. Ruiskuvalu. Tampere: Plastdata Ltd

Järvinen, P. 2008. Uusi muovitieto. Multia: Muovifakta Ltd

Macdermott, C. & Shenoy, A. 1997. Selecting thermoplastics foor engineering applications. Second edition. New York: Marcell Dekker Inc

Moran, M. & Sheldon, W. 2000. Carbon loss and optical property change during long-term photochemical and biological degradation of estuarine dissolved organic matter [referenced 9.4.2010]. Available on: http://www.aslo.org/lo/toc/vol_45/issue_6/1254.pdf

Schneider Electric. 2008. Installation products 07 [referenced 7.4.2010]. Available on: http://ecatalogue.schneider-electric.fi/GroupList.aspx?navid=22107&navoption=1

Schneider Electric. 2010. Company and Careers [referenced 7.4.2010]. Available on: http://www.schneider-electric.com/sites/corporate/en/group/group.page

SFS 5610. 2004. Plugs and socket-outlets for household and similar purposes. Part 1: General requirements. Helsinki: Finnish Standards Association

SFS-EN 60669-1. 2000. Switches for household and similar fixed electrical installations. Part 1: General requirements. Helsinki: Finnish Standards Association

TLC Plastic Group LLC. 2008. Injection molding in a Nutshell [referenced 5.4.2010]. Available on: http://www.tlcplastic.com/Injection_Molding_Basics_files/Picture%204.png

Tropospheric Emission Monitoring Internet Service. 2008. UV radiation [referenced 15.3.2010]. Available on: http://www.temis.nl/uvradiation/info/index.html

TUKES. 2010 Frontpage [referenced 7.4.2010]. Available on: http://www.tukes.fi/en/

World Health Organization. 2010. Ultraviolet radiation and health [referenced 2.4.2010]. Available on: http://www.who.int/uv/uv_and_health/en/

APPENDICES

APPENDIX 5

Calculations for manufacturing costs

	Definition and equation	Material			
		PC/ABS	**ABS**	**PC**	**PC/ASA**
A	Plastic Price [€/kg]	2,2	1,45	2,65	3,1
B	Specific Gravity [g/cm^3]	1,1	1,05	1,2	1,16
C	Part Weight [g]	5,02	4,79	5,47	5,29
D	100000 Parts Weight [g] = C x 100000	501600	478800	547200	528960
E	Material Cost [€/100000 units] = (D x A)/1000	1103,52	694,26	1450,08	1639,78
F	Cycle time [sec]	16,8	16	19	17
G	Number of Cavities	2	2	2	2
H	Parts/Hour = (G x 3600s)/F	428,6	450,0	378,9	423,5
I	Projected Part Area [mm^2]	2519	2519	2519	2519
J	Total Projected Part Area [mm^2]= I x G	5038	5038	5038	5038
K	Clamp Needed [tons] = Inject pressure [Mpa] x J/Gravity x 1000	56,5	39,6	75,0	53,9
L	Machine Clamp Capacity [tons] =	60	40	80	60
M	Machine Hour Rate [€/hour]	13,82	13,30	14,41	13,82
N	Processing Cost [€/100000parts] = (M x 100000)/(H)	3224,67	2955,56	3802,64	3263,06
O	**TOTAL MANUFACTURING COSTS [e/100000Parts] =E+N**	**4328,19**	**3649,82**	**5252,72**	**4902,83**

APPENDIX 6

Testrun results

Definiton	Temperatures [°C]			
	PC/ABS	ABS	PC	PC/ASA
Mould				
Cavity side	85	69	104	73
Core side	85	73	106	76
Cylinder				
Nozzle	275	220	290	260
3 Zone	270	225	295	265
2 Zone	265	220	285	255
1 Zone	255	210	280	245
Drying	90	80	100	100
	Pressures [Bar]			
	PC/ABS	ABS	PC	PC/ASA
Injection	1100	770	1460	1050
N/mm2	110	77	146	105
Holding	613	550	550	615
	Times [s]			
	PC/ABS	ABS	PC	PC/ASA
Cycle	16,8	16	19	17

APPENDIX 7

UVA test results

OUTDOOR TEST (Lab)

Mat.		REF	168h	336h	504h	1000h	Δ_{168h}	Δ_{336h}	Δ_{504h}	Δ_{1000h}	$\Delta E^*_{ab\ 0h}$	$\Delta E^*_{ab\ 168h}$	$\Delta E^*_{ab\ 336h}$	$\Delta E^*_{ab\ 504h}$	$\Delta E^*_{ab\ 1000h}$
PC/ABS	L	**93,867**	**93,763**	**93,630**	**93,580**	**93,157**	**-0,103**	**-0,237**	**-0,287**	**-0,710**	**0,000**	**0,122**	**0,751**	**1,356**	**4,463**
	a	**-0,927**	**-0,913**	**-1,130**	**-1,270**	**-1,793**	**0,013**	**-0,203**	**-0,343**	**-0,867**					
	b	**5,123**	**5,060**	**5,807**	**6,403**	**9,443**	**-0,063**	**0,683**	**1,280**	**4,320**					
ABS	L	**93,233**	**93,157**	**93,007**	**93,177**	**93,073**	**-0,077**	**-0,227**	**-0,057**	**-0,160**	**0,000**	**0,816**	**0,475**	**0,249**	**0,572**
	a	**0,007**	**0,303**	**0,157**	**0,073**	**-0,073**	**0,297**	**0,150**	**0,067**	**-0,080**					
	b	**0,210**	**-0,547**	**-0,180**	**-0,023**	**0,753**	**-0,757**	**-0,390**	**-0,233**	**0,543**					
PC	L	**93,173**	**93,330**	**93,327**	**93,240**	**93,033**	**0,157**	**0,153**	**0,067**	**-0,140**	**0,000**	**0,198**	**0,389**	**0,594**	**1,952**
	a	**-0,213**	**-0,230**	**-0,333**	**-0,460**	**-0,767**	**-0,017**	**-0,120**	**-0,247**	**-0,553**					
	b	**-0,060**	**0,060**	**0,277**	**0,477**	**1,807**	**0,120**	**0,337**	**0,537**	**1,867**					
PC/ASA	L	**92,210**	**92,327**	**92,323**	**92,263**	**92,093**	**0,117**	**0,113**	**0,053**	**-0,117**	**0,000**	**0,381**	**0,263**	**0,255**	**0,927**
	a	**0,350**	**0,430**	**0,280**	**0,153**	**0,107**	**0,080**	**-0,070**	**-0,197**	**-0,243**					
	b	**0,893**	**0,540**	**0,667**	**1,047**	**1,780**	**-0,353**	**-0,227**	**0,153**	**0,887**					

APPENDIX 8

UVB test results

UV-B OUTDOOR TEST (Lab)

Mat.		REF	90h	168h	336h	Δ_{90h}	Δ_{168h}	Δ_{336h}	$\Delta E^*_{ab\ 90h}$	$\Delta E^*_{ab\ 168h}$	$\Delta E^*_{ab\ 336h}$
	L	93,8667	93,2500	92,6900	92,2467	-0,6167	-1,1767	-1,620			
PC/ABS	a	-0,9267	-2,5667	-3,5033	-3,9033	-1,6400	-2,5767	-2,977	6,299	11,214	15,186
	b	5,1233	11,1733	15,9733	19,9267	6,0500	10,8500	14,803			
	L	93,2333	92,8833	92,8833	92,8167	-0,3500	-0,3500	-0,417			
ABS	a	0,0067	-0,6933	-1,1767	-1,1167	-0,7000	-1,1833	-1,123	2,518	4,224	3,785
	b	0,2100	2,6033	4,2500	3,8000	2,3933	4,0400	3,590			
	L	93,1733	92,5367	92,0267	91,1633	-0,6367	-1,1467	-2,010			
PC	a	-0,2133	-2,7100	-3,9767	-4,6000	-2,4967	-3,7633	-4,387	8,202	13,793	20,036
	b	-0,0600	7,7267	13,1600	19,3867	7,7867	13,2200	19,447			
	L	92,2100	91,8700	91,3333	91,1133	-0,3400	-0,8767	-1,097			
PC/ASA	a	0,3500	-0,9433	-2,0067	-2,9033	-1,2933	-2,3567	-3,253	4,294	8,647	13,468
	b	0,8933	4,9733	9,1667	13,9167	4,0800	8,2733	13,023			

APPENDIX 9

Sylvania FT40/ BL350 data sheet

SYLVANIA 0000185 F40W/BL350

Product selected: F40W/BL350

A range of UVA fluorescent tubes developed to attract flies and other airborne insects towards insect traps.

General Application

- For attracting flies and other airborne insects
- Photosensitization and photochemical reactions

Features

- These tubes emit highly concentrated radiation between 315 nm and 400 nm (at peak 352 nm)
- Same shape, structural and electrical characteristics and control circuits as standard T12 and T8 fluorescent tubes

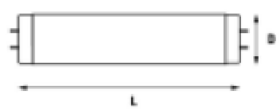
Product Attributes

Product name	F40W/BL350
Lamp Watt	40
Voltage	103
Bulb shape	Tubular
Bulb finish	Coated
Lamp base	G13
Lamp Length	1200
Lamp Diameter	38
Packing Quantity	25
Ordering number	0000185

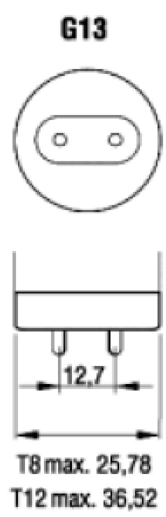
Fixture rating

Product Image

Drawing image



Cap Drawing



APPENDIX 10A

Philips TL 20W/ 12 RS data sheet

TL 20W/12 RS SLV

Product family description

Tubular or compact single-ended low-pressure mercury vapour fluorescent lamps

Product Features

- Emit radiation for therapeutic and other applications

Application

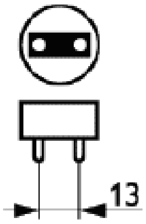
- Phototherapy in dermatology (psoriasis, SUP)
- Meteorological testing equipment
- These lamps produce UV-B radiation which is harmful to human skin and eyes. They are therefore only available for medical and industrial applications

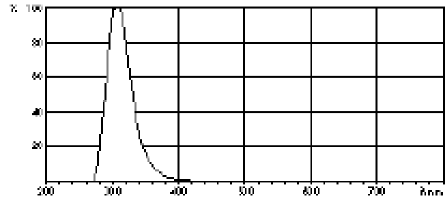
System

- Compact, single-ended lamps have the same lamp caps and can operate on the same universal ballasts as compact, single-ended lamps for general lighting
- Tubular lamps can be operated in normal switch-start as well as pre-heat rapid-start systems

Product data	
Order code	628831 40
Full product name	TL 20W/12 RS SLV
Packing type	Sleeve
Pieces per pack	1
Net weight per piece	148.700 GR
Successor order code	
System Description	Rapid Start
Cap-Base	G13
Bulb	T38
Main Application	Medical Therapy
Packing Type	1SL [Sleeve]
Packing Configuration	25
Useful Life	3000 hr
Life to 50% failures EM	9000 hr
Lamp Wattage	20W
Lamp Wattage Technical	19.3 W
Lamp Voltage	59 V
Lamp Current	0.37 A
Color Code	12
Color Designation (text)	Ultra Violet B
UV-B Radiation 100hr (IEC)	1.80 W

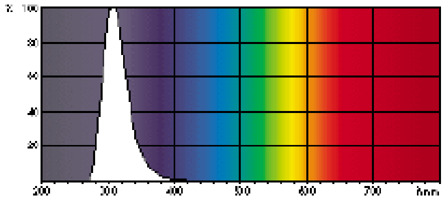
PHILIPS





TL/12

Cap-Base G13



TL/12

PHILIPS

APPENDIX 11

Saving calculations

	Today costs	
Group	Price/ most 30	Material
Other parts	249 471,41 €	PC/ABS
Socket outlet parts	399 748,19 €	PC/ABS
Total	**649 219,60 €**	0 %

	ABS and PC	
Group	Price/ most 30	Material
Other parts	164 424,34 €	ABS
Socket outlet parts	481 514,87 €	PC
Total	**645 939,20 €**	-0,5 %

	ABS and PC/ASA	
Group	Price/ most 30	Material
Other parts	164 424,34 €	ABS
Socket outlet parts	563 281,54 €	PC/ASA
Total	**727 705,88 €**	12,1 %

	PC	
Group	Price/ most 30	Material
Other parts	300 499,65 €	PC
Socket outlet parts	481 514,87 €	PC
Total	782 014,51 €	20,5 %

	PC/ASA	
Group	Price/ most 30	Material
Other parts	351 527,89 €	PC/ASA
Socket outlet parts	563 281,54 €	PC/ASA
Total	914 809,43 €	40,9 %

	ABS	
Group	Price/ most 30	Material
Other parts	164 424,34 €	ABS
Socket outlet parts	263 470,40 €	ABS
Total	427 894,73 €	-34,1 %

The comparison to today's material PC/ABS costs is calculated from equation below.

$$\frac{New\ total\ costs}{Total\ costs\ for\ PC/ABS} - 1$$