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*THE USE OF COMPOSITE MATERIALS IN AUTOMOTIVE INDUSTRY

Otomotiv Sanayinde Kompozit Malzemelerin Kullanımı

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ÖZET

Otomotiv sanayinde kompozit malzeme kullanımı 1950'li yıllarda başladı. İlk uygulamalarından itibaren kompozit malzemeler hafif, malzeme yorulmasına karşı dayanıklı ve kolaylıkla şekillendirilebilen, metallerin yerine kullanılabilecek alternatif malzeme olduğu ispatlanmıştır. Birçok özelliğinin iyi bilinmesine rağmen metallerden, kompozit malzeme kullanıma geçiş, malzeme karakteristiğindeki belirsizliklerden, üretim ve malzemelerin birleşimi gibi konulardaki belirsizliklerden dolayı tam anlamıyla yapılamamıştır. Bu projede, Ashby malzeme seçim tekniğiyle belirlenen kompozit malzemelerin otomotiv sanayinde kullanımı üzerine birçok örneklendirme yapılarak, kompozit malzemelerin iyi birer alternatif olduğu gösterilmiştir. Özellikle otobüs dış ve iç giydirme malzemelerinde elyaf destekli plastik malzemeler tez içeriğinde kullanılmıştır.
Anahtar Kelimeler: kompozit, otobüs, Ashby metodu, CTP

ABSTRACT

The automotive industry's use of structural composite materials began in the 1950s. Since those early days, it has been demonstrated that composites are lightweight, fatigue resistant and easily moulded to shape in other words, a seemingly attractive alternative to metals. However, there has been no widespread switch from metals to composites in the automotive sector. This is because there are a number of technical issues relating to the use of composite materials that still need to be resolved including accurate material characterization, manufacturing and joining. This paper reports composite materials determining by Ashby's material selection technique usage in automotive industry. Especially bus exterior and interior components manufacturing by fiber reinforced polymers (FRP) are used in this master thesis.
Key Words: composite, bus, Ashby's technique, FRP

Introduction

The requirement for energy saving in the automotive industry has risen dramatically over the years. One of the options to reduce energy consumption is weight reduction. However, the designer should be aware that in order to reduce the weight, the safety of the car passenger must not be sacrificed. A new invention in technology material was introduced with polymeric based composite materials,

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which offer high specific stiffness, low weight, corrosion free, and ability to produce complex shapes, high specific strength, and high impact energy absorption. Substitution of polymeric based composite material in automotive components was successfully implemented for fuel and weight reduction (Suddin, 2004). Material selection in the automobile industry is an artful balance among market, societal, and corporate demands, and is made during a complex and lengthy product development process. Actual selection of a particular material for a specific application is primarily driven by the trade-off between the material's cost (purchase price and processing costs) and its performance attributes (such as strength, durability, surface finish properties, and flexibility) (Andrea and Brown, 1993). The selection of the correct materials for a design is a key in the process because it is the crucial decision that links computer calculations and lines on an engineering drawing with a working design. Partly, this is due to the complexity of the comparisons and trade-offs that must be made. Often the properties compared cannot be placed on comparable terms so clear decision can be made. Partly it is due to the fact that little research and scholarly effort has been devoted to the problem (Farag, 1997).

In this study, alternative materials for automotive components were determined by Ashby's material and manufacturing selection method that is called as Cambridge Engineering Selector (CES). CES selector has two important stages as limit and graph to assist in material and manufacturing method selection. First, in the limit stage, specified material properties obtained from material universe were used to determine alternative materials and manufacturing methods. Secondly, graph stage was used to evaluate and compare pre-selected materials and manufacturing methods. At the end of the two stages, pre-selected materials and manufacturing methods were determined by properties obtained from material and process universe. Before the stages, material selections without CES selector have been performed to define alternative materials and material properties that could be used for exterior and interior components. On the other hand, alternative materials for automotive components as exterior trimming parts; bumper and fender, and as interior trimming part; headlining, were selected to carry out required material tests including mechanical, physical, thermal, burning behaviour and chemical resistance tests. In conclusion, some of comparisons were performed between materials selected without the aid of the CES selector and materials determined by CES selector.

Material and Method

Materials

E-glass fibers are very popular as composite material reinforcements on automotive industry because of low cost, high production rates, high strength, high stiffness, relatively low density, good chemical resistance, relatively insensitive to moisture, and so on. It was used in different forms such as strand, yarns, and rowing. Polipol 344-TA is a special formulation thixotropic unsaturated polyester

resin with high reactivity and medium viscosity, designed for hand lay-up application. The most characteristic properties of Polipol 344-TA polyester resin is its high HDT and Tg values. In any case, Polipol 344-TA gives products which will not be deformed and which have smooth surface and high mechanical properties. Polipol 336 is an orthophtalic based, low viscosity, GRP type unsaturated polyester resin. Most common areas of Polipol 336 are automotive industry. Polipol 336 is specially made for two side smooth, serial production with RTM and cold press systems. ABS is a three-component polymer made from Acrylonitrile, Butadiene, and Styrene. ABS is a tough, rigid thermoplastic, resistive to stress cracking and creep with a high impact strength, which is maintained at low temperatures (-40°C). It is resistive to moisture and chemicals (inorganic salts, alkalis and many acids). It possesses excellent electrical properties, is heat resistant and flame retardant. When exposed to the weather there is a reduction in the surface gloss (a graying in color). These properties make ABS suitable for thermoforming as interior trimming material. It can be easily processed through machined, bored turned, milled, sawed, routed, filed, sanded, ground buffed and polished.

Method

Composite parts in automotive industry can be classified according to their applications such as exterior and interior. Exterior components can be seen when looking at vehicle and directly opened to environmental effects such as corrosion, crashworthiness. Furthermore, they cover all of the metal construction to create aesthetic vision on vehicle. For these reasons, exterior parts need to have necessary mechanical, physical and chemical properties such as high strength against collisions, high stiffness for energy absorption, lightweight to reduce fuel consumption, corrosion resistance for increasing life time, non-softening materials to be used to resist heat and so on. Some of exterior components manufactured by composite materials are bumper, spoiler, fender, fuel tank, and side panel, etc. On the other hand, interior components design has driven a significant increase in interior comfort and functionality in recent years, requiring the use of an increasingly diverse mix of interior plastics and fabrics. Performance requirements for interior components have increased, with higher operational temperature requirements, improved emissions/environmental performance needs and reduced component cost/cycle time in production. Some of the interior components include front console, headlining, and rail covers. Exterior and interior components investigated in this work are explained in the following paragraphs.

An automobile bumper fascia is an aesthetic, flexible and non-structural component, which contributes to vehicle crashworthiness during front or rear collisions. Polymeric materials are applied in the automotive bumper system to satisfy stringent weight and performance requirements. Earlier we thought that the safety bumper of the bus could protect the bus itself. After some laboratory tests and a full-scale frontal collision test, we concluded that the safety bumper could only be effective at very low speeds (5–7 km/h). Now we know that the goal of

developing and using safety bumpers on buses is to avoid car underrun and to reduce bus aggressivity against smaller vehicles (Matolcsy, 1997).

Fender is a vehicle component that uses side of wheels on vehicle and protects the wheelhouse from direct effects came from outside. Its material properties play an important role because of impact loading effects, corrosion risk and visual component on vehicle.

Headlining satisfies the luggage place requirements of driver and co driver. The part is generally equipped with a lid and divided into two sections. one of the sections is to locate first aid kit, and the personal goods of the driver, the other section is reserved for the electronic equipment like control units, different kinds of control panels. As these explanations are seen that headlining is a very complex and high functionality component in vehicle.

Results and Discussions

Material and Process Selection for Trimming Parts

Two different types of exterior trimming parts such as bumper and fender were selected. The design requirements for bumper and fender were defined as function, constraints, objective, and free variables. Constraints used in alternative material selections were obtained from mechanical, physical, and thermal properties. Material index was found as 2 with the aid of Ashby's method. Candidate material properties have been obtained from the CES selector. CFRP, GFRP, aluminum alloy, high carbon steel (HCS), mild carbon steel (MCS), stainless steel were selected as alternative materials for the exterior parts. Interior trimming parts have different kinds of constraints compared to exterior parts. New constraints like burning behaviour, thermal shock, wear resistance, etc were added for the selection of the best materials. Design requirements were defined by means of tests used for interior parts. Alternative materials such as ABS, PU and so on were determined from automotive technical brochure. Material indices are still interested in weight reduction, lightweight materials and the same value with exterior parts.

CES selector' limit stage was used to select alternative materials for exterior and interior trimming parts. Limit stage works by input and output principle and material properties such as physical, electrical, thermal, mechanical, optical, etc. They were taken from material universe of CES selector. Initially, 91 different alternative materials for exterior parts were determined from level 2 grade of CES selector. Then, the numbers of alternative materials were reduced to 34 by entering density values between 1500 and 8100 kg/m^3 and cost values between 0.3 and 72 €/kg. Then reduction was continued by considering the mechanical properties such as young' modulus values between 15 and 216 GPa, shear modulus values between 6 and 85 GPa, bulk modulus values between 15 and 200 GPa, Poisson's ratio values between 0.265 and 0.36, hardness as Vickers between 0.11 and 5.5 GPa, elastic limit values between 0.09 and 9 GPa, tensile strength values between 0.11 and 2.24 GPa, compressive strength values between

0.09 and 1.76 GPa, elongations between 0.32 and 70%, endurance limits between 0.06 and 0.75 GPa, fracture toughness values between 0.006 and 0.15 GPa.m½, loss coefficients between 0.0001 and 0.005. The pre-selected materials were reduced to 20. When thermal values as service temperatures between -100 and 300°C, optical; translucent and opaque, processability section that includes scales between 1 as impractical and 5 as excellent; mouldability between 4 and 5 and machinability between 1 and 3, and durability properties that include flammability, fresh water, weak and strong acid, etc. are added to limit stage, two different materials, namely GFRP and CFRP were obtained.

Material properties such as density between 890 and 1580 kg/m³ and cost between 0.93 and 72.37 €/kg were entered into CES for interior parts, CES selector showed 443 materials as candidates among 2882 materials. Some of other properties related with composition and mechanical properties that include bulk modulus values between 2.9 and 80 GPa, compressive strength values between 0.025 and 0.84 GPa, elongations between 0.32 and 550 %, elastic limits between 0.012 and 0.055 GPa, fracture toughness values between 0.0015 and 0.023 GPa.m½, hardness as Vickers between 0.006 and 0.157 GPa, loss coefficients between 0.012 and 0.044, modulus of rupture values between 0.003 and 0.012 GPa, poisson's ratios between 0.305 and 0.426, shear modulus values between 0.32 and 60 GPa, tensile strengths between 0.03 and 1.05 GPa, young' modulus values between 1.31 and 550 GPa were used to optimize and reduce the numbers of alternative materials. Then, they were reduced from 443 to 40. Finally, alternative materials were obtained such as ABS, PVC, ASA, PMMA, SAN and their functions when all of important criteria were added to gaps related to material properties such as thermal that includes glass temperatures between -25 and 179°C and thermal expansions between 1.17e8 and 1.8e8 strain/°C; optical and also durability. The pre-selected materials were found in thermoplastic material groups without reinforced. ABS has lower cost as material when compared the others. Furthermore, It has good chemical and stress-resistance as well as a combination of toughness with rigidity and creep resistance. Pre-selected materials affect the material process methods. According to materials and processes technical information, the best process or processes will have been chosen from 136 different processes by means of the limit stage for interior trimming materials on CES selector. After physical attributes obtained from process universe that include mass ranges between 0.003 and 6000 kg, section thicknesses between 2.5 and 10 mm, roughness between 0.1 and 3.2 µm and quality factor between 1 and 10 were added to the limit stage, therefore remained alternative processes were reduced to 55. With adding economic attributes, the alternatives were reduced to 50. Economic attributes as economic batch size (units) between 1 and 1e6, shape as dished sheet and process characteristics as primary and discrete have been added to the limit stage. In the final step of pre-selection of processes, twelve alternative manufacturing processes and four of them related to composite materials were remained to evaluate for headlining such as SMC, hand lay-up, thermoforming, vacuum pressure bag.

CES Selector on Graph Stage for Trimming Parts

There are approximately 2882 candidate materials, which could be chosen as alternative exterior materials. By means of second helping line, minimum value of young's modulus; 15 GPa, near material index, working area was determined. After the restriction of the specified working area, the numbers of alternative materials were reduced to 150 materials. Alternative materials were searched on the graph stage list and alternative materials were obtained after evaluation as GFRP, CFRP, fiber-reinforced alumina, and some thermoplastics with and without reinforcements. On the other hand, according to pre-selected specified materials, manufacturing methods were also determined by CES selector. To determine the alternative manufacturing method, mass range vs. material class was used. SMC, BMC, transfer moulding for composite and hybrids materials; compression moulding, injection moulding for thermoset materials were found as alternative manufacturing methods. Section thickness vs. shape class was used to describe the manufacturing methods of exterior parts due to strong relationship among the shape selected, thickness, and manufacturing methods. Section thickness and material shape are also important parameters for the thermal resistance of the material. Compression moulding, BMC, SMC, transverse moulding, and injection moulding were obtained as alternative processes. The best material thickness intervals were determined between 2 and 5 mm for bus components. In this interval, the closed moulding processes were found as optimum alternative manufacturing method. Furthermore, closed mould applications reduce the component numbers, handling operations, increase the modularity, and multi-functionality. Roughness is another factor used for the selection. Roughness info was obtained from process universe of CES selector for compression moulding, SMC, transverse moulding and injection moulding. Roughness is a measure of the texture of a surface. Manufacturing method affects the roughness range on the composite materials. Expectation roughness differences are between 0.05 μm and 0.3 μm. Type and orientation of fibers affect roughness.

Material selection for headlining by means of graph stage was started with 2882 different materials. These materials were evaluated in density vs. young's modulus. Minimum values of density and young's modulus, 890 kg/m^3 and 1.31 GPa respectively, and the slope of material indices were added to optimize the results. Last, 53 alternative materials were remained to be selected. These are ABS, PMMA, PU, ASA, and SAN etc. PU shows itself as a new alternative material. As we know that two materials are alternative to each other on the automotive industry, ABS and PU. ABS fills the gaps of the PU for interior trimming parts on the bus industry and vice versa. Polyurethane offers a very wide range in which items can be produced. They range from 10 Shore to over 80 Shore D. Polyurethane when at their highest hardness levels, have significantly better impact resistance than almost all plastics. Such great toughness combined with the many other outstanding properties associated with the high hardness polyurethane, leads to many applications in engineering. Another evaluation

criteria used for the selection of the best alternative materials is the physical properties of the material. This is the elongation vs. shape factor. 2882 alternative materials were used to evaluate and finalize the best material. 163 materials were obtained after the evaluation. This total number includes 53 materials, which is evaluated in previous section. When unsatisfied materials such as oak, balsa, and epoxy resin and so on within the list of the pre-selected materials were removed from alternative materials, and finally 10 pre-selected materials stayed to be chosen such as ASA, ABS, EVOH, PA, PC, PU, PP, PMMA, SAN, and PEEK. In general, the combination of lightweight, high strength, and low processing costs make thermoplastics such as ABS, PU, etc well suited to many applications for interior parts in bus industry. The most common methods of processing thermoplastics are injection molding, extrusion, and thermoforming. Finally, all of criteria were evaluated to select the best alternative materials and manufacturing methods.

Test Results for Trimming Parts

Different testing methods were used to evaluate the properties of selected materials. All of material specimens were produced by hand lay up and RTM processes under the same condition with the finished product. The minimum requirement for bending test should be 200 MPa to satisfy necessary strength value needed in automotive applications. Average values for hand lay-up and RTM processes are 210.8 MPa and 290.5 MPa respectively. Test results showed that the closed mould applications generally have high average values than the open mould applications. Type of resin does not affect mechanical property of the part. Mechanical property generally depends on type of fibers. The heat deflection temperature results, value expected is 85°C, are useful to measure of relative service temperature for polymer when used in load-bearing parts. Thermal simulations of system show temperatures that are encountered by a specific component of that system. Three of specimens' average value are 100.9°C, were used to test RTM parts while the others' average value, 91.5°C, were used to test hand lay-up parts. HDT properties depend on the properties and behaviour the results obtained from different manufacturing methods. Average values for Barcol hardness test is 54.03 Barcol for hand lay-up samples while it is 61 for RTM specimens. Deviation on measurements is 6.7 for hand lay-up specimens while it is 4.6 for RTM samples. Hardness covers several properties like resistance to deformation, resistance to friction and abrasion. There are well-known correlations between hardness and tensile strength, and between resistance to deformation and modulus of elasticity. On the other hand, gel coat thickness could be evaluated by hardness test and its results affect the surface quality of the part after heating in furnace for the painting shop. Tension test is a mechanical test method and affects the materials strength whose values depend on the so many parameters such as material shape, material thickness, material used, and manufacturing methods. Tension test results are 114.5 MPa for hand lay-up and 132.5 MPa for RTM are strongly depend on the fibers used. The values are satisfactory because of higher

value of requirement; 100 MPa, and were determined different values because of fiber orientation and fiber type's differences. Burn off test was performed to determine the volume fractions of constituents in a glass fiber reinforced unsaturated polyester. The required between 30 and 35 % per weight for hand lay up while should be between 35 and 40 % per weight for RTM. Test result for hand lay up is 34% while test result for RTM is 40%.

Some of test methods were performed to check suitability of material; ABS, for internal parts. Burning behaviour test was done for determining the burning behaviour of materials used in the interior component of certain categories of motor vehicles, and is intended to ensure that they meet fire safety standards. Burning behaviour test results were found as satisfactory to use as interior trimming material because of the burning rate of 46 mm/min. Melting behaviour test was performed according to the same directive too and cotton was not burned during the test with the aid of the melting ABS. The result of the chemical resistance test was controlled according to required spec value and was found in satisfactory to use as trimming part. ABS contains no heavy metal stabilizers such as lead that is often used in the processing of other thermoplastics; hence, it is safe for carrying potable water. ABS is slow burning, but gives off carbon monoxide, carbon dioxide, and nitrous oxides. Test results that relate to heat cycle were in good agreement with directives. No visible distortion, deformation, discolors, tears, cracks, peeling off, etc. were observed on test results. Thermal shock test were performed to evaluate the behaviour of the material under the different temperatures, which is, living short-term temperature difference at the state, for example, desert. Abrasion is a physical property and was simulated on materials specified by means of abrasion tester. No laboratory abrasion test can guarantee success in the field. Unfortunately, there are just too many influences to be modeled in the lab. As a result, the tests that were performed may not accurately identify potential problems. The ideal solution is to analyze the product in actual use under the actual intended use conditions. But, it often takes many years before useful data becomes available. After UV test, visible color changing and fading were not observed on material. The UV resistance of plastics involves a number of factors that can affect in material choice such as thickness, opacity, and the use of stabilizers. These three factors are combined to defend plastics against ultraviolet (UV) light. Light degrades plastics by transferring its energy into the plastic. This energy can cause damage by creating heat, or this energy can actually break molecular bonds in a plastic's structure. The inner layer of plastic can retain its strength much longer the more opaque the plastic. Each material was tested for UV resistance; however, each location where automotive industry was installed has a different UV exposure level. No two locations get exactly the same amount of sunshine, and most locations do not get the same amount of sunshine from year-to-year. Vicat softening temperature test determines the heat resistance characteristics of material, and is fundamental to define precisely the thermal behaviour of the polymers. The result of the test was found above the temperature level determined as 99.2°C and quality standard was performed with the result.

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Conclusions

In this study, Ashby's material selection method was employed to select the best materials for exterior and interior trimming parts used in vehicles. Mechanical, physical, optical, thermal and durability properties were used as control factors for material selection criteria. It has been shown that CES selector provides an efficient methodology for material selection of automotive parts. This study showed that fender, bumper, and headlining can be improved significantly with polymer based composite materials used and the following conclusions can be derived from this work. First of all, alternative material selection process for exterior trimming parts was done by limit stage on CES selector. Limit stage results showed that pre-selected materials such as GFRP and CFRP could be used for exterior trimming parts. Secondly, both of alternative materials were evaluated in graph stage on CES selector. In graph stage, 150 alternative materials were determined by means of material index, working area between minimum and maximum limits of material properties. In the final stage, alternative materials were obtained after filtration such as GFRP, CFRP, and fiber reinforced aluminum composites. According to pre-selected materials, alternative manufacturing method selection processes were evaluated with the aid of these results. The optimum process were determined with the aid of assistant criterions such as section thickness, mass range, roughness, economic batch size (units), material class, shape. Respectively all of the paired constraints such as mass range vs. material class, section thickness vs. shape class, and roughness vs. primary were drawn on CES selector and determined alternative processes such as SMC, RTM, compression moulding, injection moulding and hand lay-up for the production of exterior trimming parts such as fender and bumper. Before the operations such as material and process selection for exterior trimming parts, alternative materials had been determined such as GFRP, CFRP, stainless steel, aluminum, high and mild carbon steels because of these materials are still used in automotive industry. Some of the materials such as glass fibre composites have been tested for mechanical, physical properties. These results obtained from the tests are then used as constraints in evaluation stage as design requirements in this study. Candidate materials found in the final step of the CES selector except the glass fibre reinforced plastics could be used as alternative materials for exterior trimming parts and tests were done. Interior trimming parts were evaluated in this study. On the limit stage of the interior trimming part, eight alternative materials such as ABS, PVC, ASA, PMMA and the derivative of these materials such as ABS with heat resistance, ASA with reinforced as PVC were obtained by CES selector. These alternative materials were compared by using results of the graph stage. At the result of the graph stage by means of some assistant sketches such as density vs. Young' modulus and shape factor vs. elongation, 53 alternative materials were obtained. Some of the alternative materials are ABS, ASA, PA, EVOH, PP, PU, PMMA as main material and ABS reinforced with stainless steel fibres, ASA reinforced with PC, etc. When both of the stages are combined, main alternative materials are determined as

ABS, ASA, PU, PMMA, PP, PVC, EVOH, and PA. Alternative processes compatible with these materials and required properties were determined. The limit stage was used to determine alternative processes. As a result of the limit stage, alternative materials have been determined as SMC; hand lay up, thermoforming, vacuum pressure bag, spray up, and autoclave forming related to composite materials. Manufacturing method such hand lay up, thermoforming for composite materials and deep drawing, explosive forming for other engineering materials have been found from graph stage of CES selector. Before determining alternative material for interior trimming parts, some of the requirements needed for alternative materials in automotive industry were tabulated. Then, CFRP, GFRP, PP, PVC, ABS, and PU are selected as candidate materials for evaluation. Test results were used to check the suitability of these alternative materials for automotive components. It was shown that they could be used as alternative materials for automotive industry.

GFRP and CFRP selected as alternatives for exterior materials were used to calculate cost and weight values. CFRP and GFRP' weights for bumper were calculated as 7 kg and 6.1 kg respectively while CFRP and GFRP' cost were calculated as 315 and 54.9 €/kg respectively. In the same way, the weight of fender was calculated as CFRP and GFRP, 3.6 and 3.1 kg respectively while the cost of fender was found for CFRP and GFRP as 162 and 27.9 €/kg respectively. The weight and cost values for exterior trimming parts, fender and bumper, were calculated for mild carbon steel, stainless steel and aluminum alloy determined as alternative materials before selected by CES selector. The weight of MCS was found as 30.5 kg while the cost was determined as 12.2 €/kg. The cost of stainless steel was found as 123.6 €/kg while the weight of SS was calculated as 30.9 kg. Last, the weight of aluminum alloy was determined as 10.6 kg while the cost of AA was found as 13.8 Euro/kg. Alternative interior materials were used to calculate the weight and cost values of headlining. The weights of alternative materials such as CFRP, GFRP, ABS, PU, PVC were found as 6.6, 5.7, 4.3, 4.4, 5.5 kg respectively while the cost of them were calculated as 297, 51.3, 11.6, 18.5, 14.3 €/kg respectively.

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