ME 411 MATERIALS ENGINEERING

Material Selection Process for Hair Dryer Components

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Executive Summary

In this project, it is aimed to investigate three fundamental parts of a hair dryer which are heating element wire, fan and housing in terms of material selection. To do so, prior requirements are determined for each part and then possible material candidates are selected via Cambridge Engineering Selection (CES) software. For the selection procedure, the weighted properties method is applied and weights are determined by pursuing digital logic method. For the heating element wire; resistivity, oxidation resistance, manufacturability, having lower cost and thermal conductivity are considered to decide on the material and by evaluating these properties of the material candidates Nickel-Chromium-Iron Resistance Alloy (Nichrome) is selected. The properties which are critical for the material selection of the fan can be listed as having higher specific capacity to enable operating at higher temperatures, lower cost, lower density, and good durability and mouldability. By following weighted properties method with the digital logic method, polypropylene is evaluated as the proper material for the fan of the hair dryer. In the material selection for the housing; mouldability, being electricity insulator, durability, fracture toughness, density and cost are considered and Dough Molding Compounds (DMC) is selected as the favorite candidate for the housing of the hair dryer. All the steps of the selection procedure are explained and the procedure can be easily followed by benefiting from the tables illustrated in appendices. While material selection process is accomplished for all three components of the hair dryer, recommendations and comments are committed considering different designs and concerns.

The Problem Statement

Today it is very easy to obtain a hair dryer which has a history of development more than century. One of the first patents which explain the working principle of the hair dryer is belong to 1865. In Figure 1, an early sample of the hair dryer is illustrated. (1)

Figure 1 An early hair-dryer **(4)**

A hair dryer accelerates the evaporation of water from the surface of the hair. Hair dryers generally emit hot air which increases the evaporation thanks to that phenomenon: hot air sucks moisture much more easily than cold air and makes the molecules in water droplet easily evaporated. (2)

There are two main parts of a hair dryer. One is a heating element which is a wire with some resistance that transforms the electric energy into heat and the other is a motor driven. The working principle of the hair dryer is simple as follows. When the electricity is supplied to the hair dryer, it provides the required current for the motor and the heater. Then, the heating element gives out heat. The spins of the electric motor leads the fan turning. The fan generates air flow and the supplied air is directed down to the heating resistance, and the heated air streams out of the barrel. The process may be understood easily by following the hair dryer sample illustrated in Figure 2. (3), (4).

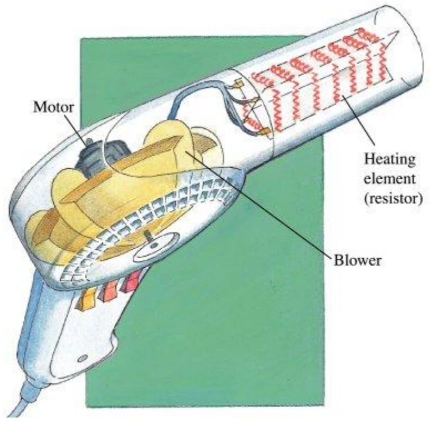

Figure 2 Hair Dryer Sample (3)

In this project, wire used in the heating element, housing and the fan parts are investigated in terms of material selection to improve the material properties of these parts of hair-dryer and obtaining much more light and cost effective design. Therefore, here are some important criterions for these specific parts:

Heating Element: A metal coil which is placed over a non-conductive material is used as the heating element of a hairdryer. A sample is illustrated in Figure 3. This kind of resistor is called as wirewound resistors and it consists of two parts. One is a cylindrical core which is generally made of ceramic, fiberglass or plastic and the other is a high resistant metal wire. The main working principle of this element is to convert the electrical energy into heat energy so as the air supplied by fan passes it becomes warmer. Therefore, heating element should be a material with high electrical resistivity to obtain more heat (ρ_e), and high melting temperature(T_m) to avoid melting of the material at operating temperature which is around 40^0C. When the temperature reaches a certain value, a safety cut off switch prevents the temperature going any further. Regarding this, maximum service temperature of the material can be defined as 60^0C (T_{max}). Furthermore being resistant to oxidation at high temperatures may be addressed as a preferable property for the material.In addition to this, processability of the material is taken into consideration regarding the hardness of the material. (5)

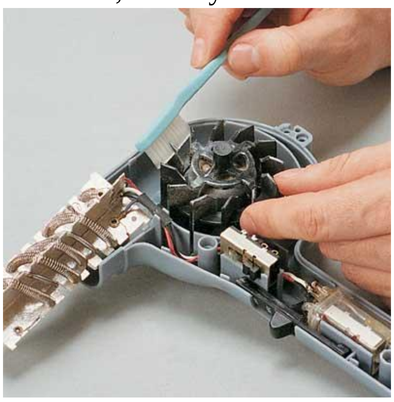

Figure 3 Inside of a hair-dryer (6)

Fan of the Hair-dryer: The fan works as a transformation mechanism which transforms the heated air outside of the hairdryer and into the hair. The mechanical energy of the motor goes through the fans which are connected to the motor. This mechanism helps the fans rotation about their axis. As a result of this rotational movement, the air from the fan passes over the heating element, blowing the heat from the coil to outside through the wet hair. Therefore material which is used to form the fan should be able to stand against high temperatures and be light-weight for easy use. So, high T_m and low ρ are preferable for the fan. (5)

Housing: The outer shell of the device houses and protects the fan, motor and heating element of the dryer. It is generally produced in L-shaped and its control switches are placed on the hand-hold portion in order to adjust the system easily with hand while using the hair dryer. Being water-proof is very important for casing, because if a hairdryer is dropped into a bathtub or sink and contact with the water it may would short circuit and lead an electrical shock. Furthermore, weight of the housing is extremely important in terms of being easy to handle during operation. Therefore, low density (ρ), low thermal conductivity (λ), and being water proof and corrosion resistant are primary criterions for housing. (5)
The primary material qualifications which are explained above are summarized in Table I.

Table I : Primary selection qualifications

Heating Element	Fan	Housing
High heating resistivity (ρ_e)> 100 µohm.cm	low density (ρ) <2000 kg/m^3	low thermal conductivity (λ)< (W/K.m)
High service temperature (T_{min}) >120^{0}C	High service temperature (T_{min}) >100^{0}C	High Service Temperature (T_{min}) >100^{0}C
Being resistant to oxidation at about 100^{0}C	Greater heat capacity (C_p)>1300J/Kg.K	High fracture toughness(K_{IC})
Low thermal conductivity (λ)	Oxidation Resistance	Good Electricity Insulator
Durability against flammability	Durability	Durability
Processability (producing the material as wire)	Mouldability	low density (ρ)< 2000 kg/m^3
Cost	Cost	Mouldability
		Cost

By starting from the primary qualifications of the materials stated in Table I, beginning of material selection process is examined via Cambridge Engineering Selection (CES) Program. By applying the stated requirements to the program as inputs, the data for the possible materials are obtained.

In the selection of the heating element materials processability criteria is evaluated from CES considering the material utilization fraction which shows the efficiency of the material processing from the raw material into the wire drawn. The evaluation is represented in a 1-5 scale where 5 is the best. Since the hair dryers have cut off mechanism which enables to turn the power off when the temperature increases over a certain value –generally in between 60-80^{0}C- , a maximum temperature of 120^{0}C and good oxidation resistance about 100^{0}C are considered. Having resistivity over 100 *µohm.cm* is stated as requirement for the material. In addition to these, durability against flammability is set to be "very good" and selection is obtained among these materials which have very good durability against flammability. The obtained list is illustrated in the following Table.

Table II : Material candidates for Heating Element

Heating Element	Resistivity µohm.cm	Max Service Temperature ^{0}C	Oxidation Resistance	Process-ability	Thermal conductivity (W/K.m)	Price TL/kg
Nickel Chromium Alloy (NIMONIC81, heat treated)	135	1130	5	5	10	25
Titanium Beta Alloy (Ti-10V-2Fe-3Al)	166	266	4	4	8	65
Nickel- Molybdenum Alloy (Hastelloy W)	150	655	5	4	10	20
Nickel-Chromium-Cobalt-Moly Alloy (Inconel 617)	125	1094	5	5	12	20
Nickel-Chromium-Iron Resistance Alloy (Nichrome,annealed)	116	1100	5	5	9	12
Nickel Tungsten Alloy (MAR-M 200)	120	987	5	3	12	20

In order to select candidate materials for the fan, the inputs are given accordingly regarding Table I. Specific heat is assigned to be greater than 1300J/Kg.K, minimum value of the maximum service temperature is set to be 100^{0}C and maximum amount of density is set to be 2000 kg/m^3. In addition to these, durability option is used to obtain materials which contain durability against to fresh water, sea water, alkalis and UV. Mouldability is also considered in 1-5 scale where 5 is the best.

Table III : Material Candidates for Fan

Fan	Specific Heat C_p	Max Service Temperature ^{0}C	Oxidation Resistance	Density ρ kg/m^3	Durability	Mouldability	Price TL/kg
Polycarbonate	1585	122	5	1175	4	5	7
Phenolics	1500	149	4	1280	4	4	2.7
Polyamides (Nylons, PA)	1630	123	5	1130	4	5	5
Polyester	1535	170	5	1200	5	4	2.4
Polyester Glass Composites (GFRP)	1100	180	5	1860	4	5	21.1
Polypropylene (PP)	1630	106.9	5	900	5	5	1.8

In the selection of housing material candidates, qualifications stated in Table I are used. For the safety reasons, materials are only selected if their electricity insulation property is very good. Fracture toughness is considered to prevent from the further crack propagation and brittle fracture for the falling case of the hair dryer. 1-5 scale is used to evaluate durability, mouldability and being good insulator criterions.

Table IV : Material Candidates for Housing

Housing	Thermal Conductivity λ	Max Service Temperature ^{0}C	Durability	Being good insulator	Mouldability	Fracture Toughness MPa.m$^{1/2}$	Density ρ kg/m^3	Price TL/kg
Dough Molding Compounds	0.37	175	5	5	5	4.5	1950	2.7
Polyester Glass Composites (GFRP)	0.47	180	4	5	5	15	1860	21.1
Polycarbonate	0.2	122	5	5	5	3.4	1175	7
Polyester	0.28	170	5	5	4	1.7	1200	2.4
Sheet Molding Compound (SMC)	0.25	200	4	5	4	9	1900	4

In the Detailed Material Selection Analysis part of the report, these materials which are selected by pursuing CES software are evaluated through weighted properties method. First weighted properties method is introduced and then the weights of the properties are determined following Digital Logic Method. While finalizing the selection with the weighted properties method, the reasoning behind the selection is explained and necessary comments and recommendations are committed.

Detailed Material Selection Analysis

To commit further analysis, weighted properties method is applied to decide which material candidate fits the best for the selected component. In weighted properties method, first all the values are scaled by dividing each property column by the highest amount in that column and then multiplying by 100. The assigned weights of each property are determined with digital logic method in this project. The sum of the weights is 1 for each property and weighted property values are obtained by the multiplication of the assigned weights and the corresponding scaled values. Then, the weighted property values are summed for each material and summation is called as material performance index (γ) of that material which implies the percentage compatibility of the material according to stated criterions comparing to others.

In digital logic method, properties are compared one by one regarding superiority of one property to another and then number of positive decisions are listed and scaled to obtain weight fractions so as to have a summation of 1 for each property.

Material Selection for Heating Element Wire

By applying digital logic method for the heating element wire, which can be found in appendices A section, following table is constructed. Regarding the positive decisions the weighting factors are determined.

Table V : Weighting Factor for Heating Element

Property	Positive Decisions	Weighting Factor
Resistivity	4	0.26
Max. Service Temperature	1	0.07
Oxidation Resistance	1	0.07
Processability	5	0.33
Thermal Conductivity	1	0.07
Cost	3	0.20
Total	15	1.00

As you shall find in the appendices B-section, table II is revised to make it easy to apply the weighted properties method by categorized cost and thermal conductivity with a range of 1to 5 where 5 means very good and 1 is very bad. Then, the revised table is scaled and then multiplied by weighting factors and the following table is obtained.

Table VI : Heating Element Wire Selection by Weighted Properties Method

Heating Element	Scaled Resistivity *0.26	Scaled Max Service Temp *0.07	Scaled Oxidation Resistance *0.07	Scaled Processability *0.33	Scaled Thermal conductivity*0.07	Scaled Relative cost class*0.20	Performance Index (γ)
Nickel Chromium Alloy (NIMONIC81, heat treated)	21.1	7	7	33	7	16	91.1
Titanium Beta Alloy (Ti-10V-2Fe-3Al)	26	1.6	5.6	26.4	7	8	74.6
Nickel- Molybdenum Alloy (Hastelloy W)	23.5	4	7	26.4	7	16	84.0
Nickel-Chromium-Cobalt-Moly Alloy (Inconel 617)	19.6	6.8	7	33	5.6	16	88.0
Nickel-Chromium-Iron Resistance Alloy (Nichrome,annealed)	18.2	6.8	7	33	7	20	92.0
Nickel Tungsten Alloy (MAR-M 200)	18.8	6.1	7	19.8	5.6	16	73.3

There is one thing to be reminded which is that since the price is categorized from 5 to 1 before scaling the Table II, the higher the scaled relative cost index, the cheaper the material. As it is stated in Table VI, Nickel-Chromium-Iron Resistance Alloy (Nichrome) is found to be the one which fits being used heating element wire better than other candidates. As it is observed, nickel chromium alloy (NIMONIC) and Nickel-Chromium-Cobalt-Moly Alloy are also good options however they are eliminated because of their price although they have slightly higher relative resistivity. If the economics is not the concern for the manufacturer, nickel chromium alloy (NIMONIC) is recommended to be used, though. Since the material will be produced by wire drawing, processability is another factor which makes the Nickel-Chromium-Iron Resistance Alloy prominent among the Nickel Tungsten Alloy, Titanium Beta Alloy and Nickel-Molybdenum Alloy. Material selection considering the economic concerns is finalized for the heating material wire of the hair dryer by choosing the candidate which has the highest performance index that is Nickel-Chromium-Iron Resistance Alloy (Nichrome).

Material Selection for Fan

Digital Logic Method is pursued for assigning the weighting factors of the fan as well. The detailed table shall be found in appendices A section. Here is the result of the digital logic method table.

Table VII : Weighting Factor for Fan

Property	Positive Decisions	Weighting Factor
Specific Heat	3	0.14
Max. Service Temperature	4	0.19
Oxidation Resistance	1	0.05
Density	3	0.14
Durability	1	0.05
Mouldability	5	0.24
Cost	4	0.19
Total	21	1

To make it easy to apply weighted properties method density and price values are transformed into categories from 5 to 1 as it is done for the material selection of the heating element wire. Since the lower density and price are preferable, 5 is denoted as very good and assigned to lower price and density and 1 is denoted as very bad and assigned to higher density and price. Both revised and scaled material list tables are illustrated in appendices B section.

Table VIII : Material Selection for Fan of the Hair Dryer

Fan	Scaled Specific Heat *0.14	Scaled Max Service Temperature *0.19	Scaled Oxidation Resistance *0.05	Scaled Density *0.14	Scaled Durability*0.05	Scaled Mouldability *0.24	Scaled Relative Price *0.19	Performance Index (γ)
Polycarbonate	13.6	12.9	5	11.2	4	24	15.2	85.9
Phenolics	12.9	15.7	4	11.2	4	19.2	19	86.0
Polyamides (Nylons, PA)	14	12.9	5	11.2	4	24	15.2	86.4
Polyester	13.2	17.9	5	11.2	5	19.2	19	90.5
Polyester Glass Composites (GFRP)	9.5	19	5	5.6	4	24	7.6	74.6
Polypropylene (PP)	14	11.3	5	14	5	24	19	92.3

As seen in the Table VIII, Polypropylene is determined to be the most suitable material candidate for the fan of the hair dryer with the highest performance index. It is superior to polyester and phenolics in terms of the mouldability which is an important case for the manufacturing process. It is also superior to Polyester Glass Composites in terms of specific heat which enables the polypropylene working at higher temperatures. Although there are cheaper alternatives of the polypropylene, it offsets not to be preferable in terms of price with its relatively low density and higher durability.

Material Selection for Housing

To determine the weighting factors for the housing of the hair dryer digital logic method is applied that is given in the appendices A section. The results are here in Table IX.

Table IX : Weighting Factors for the Housing of the Hair Dryer

Property	Positive Decisions	Weighting Factor
Thermal Conductivity	3	0.14
Max. Service Temperature	2	0.10
Durability	2	0.10
Mouldability	5	0.23
Fracture Toughness	2	0.10
Density	3	0.14
Cost	4	0.19
Total	21	1.00

In revised material list table for housing which is given in Appendices B section, price, thermal conductivity and density of the material are classified to assist the application of weighted properties method. The categorization is done following the previous categorizations.

Table X : Material Selection for Housing of the Hair Dryer

Housing	Scaled Thermal Conductivity Class *0.19	Scaled Max Service Temperature *0.10	Scaled Durability *0.10	Scaled Mouldability *0.23	Scaled Fracture Toughness Class *0.10	Scaled Density Class *0.14	Scaled Relative Price *0.14	Performance Index (γ)
Dough Molding Compounds	11.2	8.75	10	23	6	11.2	19	89.15
Polyester Glass Composites (GFRP)	8.4	9	8	23	10	11.2	7.6	77.2
Polycarbonate	14	6.1	10	23	6	14	11.4	84.5
Polyester	14	8.5	10	18.4	4	14	19	87.9
Sheet Molding Compound (SMC)	14	10	8	18.4	8	11.2	15.2	84.8

As seen in Table X, material for the housing of the hair dryer is selected as Dough Molding Compounds (DMC). Although Sheet Molding Compound (SMC) can resist relatively higher stress values they are not good at having curvature mold shapes as much as DMCs which is needed in this case. However, if the hair dryer is designed so as to that it does not have complex shape and the housing is a plate like form, then SMCs are recommended to be used. Considering a standard case, DMCs are preferable and also cheaper than their alternatives except polyester which can be eliminated because of relatively lower toughness and mouldability. DMCs are also known with typical use areas such as door handles, casing for telephones, washing machine parts which makes them appropriate candidate for the hair dryer housing material considering their use areas with the engineering sense.

Conclusions

Material selection for the specific hair dryer parts which are wire of the heating element, fan and housing is pursued in this project. Selection criterions are stated and then using Cambridge Engineering Selection (CES) software appropriate material candidates are selected. Then weighted properties method is followed to determine the most suitable materials among the candidates by benefiting from the digital logic method to assign the weighting factors for the weighted properties method. For the wire of the heating element required properties are determined such as having higher resistivity and oxidation resistance, servicing at relatively higher temperatures, being able to manufacturing by wire drawn, having lower thermal conductivity and lower cost. Considering these criterions and applying the discussed material selection process Nickel-Chromium-Iron Resistance Alloy (Nichrome) is chosen as the most appropriate candidate for the heating element wire. The properties which are considered for the fan of the hair dryer can be summarized as having higher specific heat which enables to work properly at higher temperatures, lower density and price, and good durability and mouldability which assists the manufacturing process. Following the weighted property method with the results of the digital logic method, these criterions are evaluated and polypropylene is selected for the fan part of the hair dryer. For the housing of the hair dryer, being a very good insulator is accepted as a must and candidates are selected accordingly. For the properties of the housing, mouldability is considered as the most important one, since it is not easy for the all materials to form in curvature style shapes. Although both Dough Molding Compounds (DMC) and Sheet Molding Compound (SMC) materials show good performance indexes, the DMC is chosen with its relatively easiness in molding complex shapes. In the selection process, comments for process are committed and the recommendations are stated regarding the situations with different conditions.

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Appendices

SECTION -A

Application of Digital Logic Method for heating element

	Decision Numbers														
Property	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Resistivity	1	1	0	1	1										
Max. Service Temperature	0					0	0	1	0						
Oxidation Resistance		0				1				0	0	0			
Processability			1				1			1			1	1	
Thermal Conductivity				0				0			1		0		0
Cost					0				1			1		0	1

Application of Digital Logic Method for Fan

	Decision Numbers																				
Property	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Specific Heat	0	1	1	1	0	0															
Max Service Temperature	1						1	1	0	0	0										
Oxidation Resistance		0					0					0	1	0	0						
Density			0					0				1				1	0	1			
Durability				0					1				0			0			0	0	
Mouldability					1					1				1			1		1		1
Cost						1					1				1			0		1	0

Application of Digital Logic Method for Housing

	Decision Numbers																				
Property	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Thermal Conductivity	1	0	0	1	1	0															
Max Service Temperature	0						1	0	0	1	0										
Durability		1					0					0	1	0	0						
Mouldability			1					1				1				1	0	1			
Fracture Toughness				0					1				0			0			1	0	
Density					0					0				1			1		0		1
Cost						1					1				1			0		1	0

SECTION B

Revised table for the heating element wire selection

Heating Element	Resistivity µohm.cm	Max Service Temperature ^0C	Oxidation Resistance	Processability	Thermal conductivity Class	Price Class
Nickel Chromium Alloy (NIMONIC81, heat treated)	135	1130	5	5	5	4
Titanium Beta Alloy (Ti-10V-2Fe-3Al)	166	266	4	4	5	2
Nickel- Molybdenum Alloy (Hastelloy W)	150	655	5	4	5	4
Nickel-Chromium-Cobalt-Moly Alloy (Inconel 617)	125	1094	5	5	4	4
Nickel-Chromium-Iron Resistance Alloy (Nichrome,annealed)	116	1100	5	5	5	5
Nickel Tungsten Alloy (MAR-M 200)	120	987	5	3	4	4

Scaled values for the heating element selection list

Heating Element	Scaled Resistivity µohm.cm	Scaled Max Service Temperature ^0C	Scaled Oxidation Resistance	Scaled Processability	Scaled Thermal conductivity Class	Scaled Price Class
Nickel Chromium Alloy (NIMONIC81, heat treated)	81.3	100	100	100	100	80
Titanium Beta Alloy (Ti-10V-2Fe-3Al)	100	23.5	80	80	100	40
Nickel- Molybdenum Alloy (Hastelloy W)	90.4	58	100	80	100	80
Nickel-Chromium-Cobalt-Moly Alloy (Inconel 617)	75.3	97	100	100	80	80
Nickel-Chromium-Iron Resistance Alloy (Nichrome,annealed)	81.3	100	100	100	100	80
Nickel Tungsten Alloy (MAR-M 200)	100	23.5	80	80	100	40

Revised table for material selection of the fan

Fan	Specific Heat C_p	Max Service Temperature	Oxidation Resistance	Density ρ	Durability	Mouldability	Price Class
Polycarbonate	1585	122	5	4	4	5	4
Phenolics	1500	149	4	4	4	4	5
Polyamides (Nylons, PA)	1630	123	5	4	4	5	4
Polyester	1535	170	5	4	5	4	5
Polyester Glass Composites (GFRP)	1100	180	5	2	4	5	2
Polypropylene (PP)	1630	106.9	5	5	5	5	5

Scaled values for the materials used in selection of the fan material

Fan	Scaled Specific Heat C_p	Scaled Max Service Temperature	Scaled Oxidation Resistance	Scaled Density ρ	Scaled Durability	Scaled Mouldability	Scaled Price Class
Polycarbonate	97.2	67.8	100	80	80	100	80
Phenolics	92.0	82.8	80	80	80	80	100
Polyamides (Nylons, PA)	100	68.3	100	80	80	100	80
Polyester	94.2	94.4	100	80	100	80	100
Polyester Glass Composites (GFRP)	67.5	100	100	40	80	100	40
Polypropylene (PP)	100	59.4	100	100	100	100	100

Revised material list table for housing

Housing	Thermal Conductivity Class	Max Service Temperature ^0C	Durability	Mouldability	Fracture Toughness Class	Density ρ kg/m^3	Price Class
Dough Molding Compounds	4	175	5	5	3	4	5
Polyester Glass Composites (GFRP)	3	180	4	5	5	4	2
Polycarbonate	5	122	5	5	3	5	3
Polyester	5	170	5	4	2	5	5
Sheet Molding Compound (SMC)	5	200	4	4	4	4	4

Scaled values for housing material list

Housing	Scaled Thermal Conductivity Class	Scaled Max Service Temperature	Scaled Durability	Scaled Mouldability	Scaled Fracture Toughness Class	Scaled Density Class	Scaled Price Class
Dough Molding Compounds	80	87.5	100	100	60	80	100
Polyester Glass Composites (GFRP)	60	90	80	100	100	80	40
Polycarbonate	100	61	100	100	60	100	60
Polyester	100	85	100	80	40	100	100
Sheet Molding Compound (SMC)	100	100	80	80	80	80	80