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Ships in Composite Materials

ASTM Standard for burn-off test – Task 1b

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Introduction

Assume we conducted one laboratory experiment based on the ASTM D2584 technique, that relates to the standard test method for ignition loss of cured reinforced resins, with four GRP (Glass Reinforced Plastic) specimens and obtained the measurements and data as seen in the table below:

N° of Sample	Crucible weight (g)	Crucible + specimen weight (g)	
		Before burn	After burn
1	49.300	60.471	57.138
2	49.161	60.426	56.623
3	50.099	60.237	57.216
4	50.468	61.919	58.169

Tab.1 Number of sample related of experiment

1- Compute the ignition loss in weight fractions, the standard deviation, and the ignition loss range using the ASTM technique.

The following expression, derived from the Standard Test Method for Ignition Loss of Cured Reinforced paper, can be used to calculate the ignition loss weight in fraction:

$$Ignition\ loss, weight\ \% = \left[\frac{W_1 - W_2}{W_1}\right] x\ 100$$

in which W1 and W2 are the weights of the specimen and residue, respectively. They were calculated by subtracting the weight of the crucible from the weights obtained following the initial fire.
The findings for the four samples examined are shown in the table below:

Specimen Weight	Residue Weight	"Fiber Weight"	Ignition Loss (Weight Fraction %)
W1 (g)	W2 (g)	wf (g)	
11.171	3.333	7.838	0.702
11.265	3.803	7.462	0.662
10.138	3.021	7.117	0.702
11.451	3.750	7.701	0.673

Tab.2 Experimental data of components

The standard deviation may be simply computed after obtaining the ignition loss numbers using the following formula:

$$s = \sqrt{\frac{[\sum X^2 - m(X)^2]/}{(n-1)}}$$

where:

$$s - \ estimated\ standard\ deviation$$

$$X - value\ of\ a\ single\ observation$$

$$\bar{X} - arithmetic\ mean\ value\ of\ the\ set\ of\ observations$$

If we consider the calculation of the standard deviation and the ignition loss range by subtracting the lowest specimen ignition loss form the highest specimen loss we obtain:

Sample Average (%)	Standard Deviation (%)	Ignition Loss Range
0.685	0.017	0.040
0.685	0.017	0.040
0.685	0.017	0.040
0.685	0.017	0.040

Tab.3 Calculation of sample average and standard deviation

2 – Determine the laminate density, Fiber Volume Fraction, and Matrix Volume Fraction. Assume the laminate's resin is "CRYSTIC 406" and the fiber glass density is close to the acceptable value set by BV regulations (NR546 Section 4).

The density of the fiber (ρf) and the density of the polyester resin (ρm) were obtained. In the case of polyester resin, it was discovered that the BV Rules establish two types of polyester resins, one that is often used and referred to as type E-glass and the R-glass, which is a fiber with stronger mechanical resistance owing to larger percentages of silica and alumina that it includes. The primary physical qualities of R-glass are the same as those of E-glass, with an improvement of around 20% and good interlaminar shear strength properties.

The specimens were considered to contain E-glass fiber for the computations. The mechanical properties of several resins are shown in the following figure, which contains the Polyester resin and its density:

Table 1 : Mechanical characteristics of resins

	Polyester	Vinylester	Epoxy
Density ρ_r	1,20	1,10	1,25
Poisson coefficient ν_r	0,38	0,26	0,39
Tg (°C)	around 60°	around 100°	between 80° and 150° **(1)**
Tensile Young modulus E_r (N/mm²)	3550	3350	3100
Tensile or compression breaking stress (N/mm²)	55	75	75
Tensile or compression breaking strain (%)	1,8	2,2	2,5
Shear modulus G_r (N/mm²)	1350	1400	1500
Shear breaking stress (N/mm²)	around 50	around 65	around 80
Shear breaking strain (%)	3,8	3,7	5,0

(1) The actual value of Tg is depending on the polymerisation process used and, in particular, the temperature used in post-cure.

Table 2 : Mechanical properties of fibres

		Glass		Carbon			Para-aramid
		E	R	HS	IM (1)	HM (1)	
Density ρ_f		2,57	2,52	1,79	1,75	1,88	1,45
Tensile in fibre direction	Poisson coefficient ν_f	0,238	0,20	0,30	0,32	0,35	0,38
	Young modulus $E_{f0°}$ (N/mm²)	73100	86000	238000	350000	410000	129000
	breaking strain (%)	3,8	4,0	1,5	1,3	0,6	2,2
	breaking stress (N/mm²)	2750	3450	3600	4500	4700	2850
Tensile normal to fibre direction	Poisson coefficient	0,238	0,20	0,02	0,01	0,01	0,015
	Young modulus $E_{f90°}$ (N/mm²)	73100	86000	15000	10000	13800	5400
	breaking strain (%)	2,40	2,40	0,90	0,70	0,45	0,70
	breaking stress (N/mm²)	1750	2000	135	70	60	40
Compression in fibre direction	breaking strain (%)	2,40	2,40	0,90	0,60	0,45	0,40
	breaking stress (N/mm²)	1750	2000	2140	2100	1850	500
Shear	Modulus G_f (N/mm²)	30000	34600	50000	35000	27000	12000
	breaking strain (%)	5,6	5,6	2,4	3,0	3,8	4,0
	breaking stress (N/mm²)	1700	1950	1200	1100	1000	500
(1) Taking into account the large diversity of IM and HM carbons, the values given in this Table are for general guidance only.							

By examining both tables in the figures above, it was feasible to determine the densities of the fiber and the polyester resin:

Fiber Glass Density [E] (g/cm3)	Resin Density (g/cm3)
2.570	1.200
2.570	1.200
2.570	1.200
2.570	1.200

Tab.4 Mechanical characteristics of fiber and resin

To determine the laminate density, first compute the weight and volume percentages of both components (fibre and resin). Because the resin and fiber weights from the previously calculated ignition loss test were already known, it was just a matter of dividing them by the specimen weight, as illustrated in the following calculation.

$$W_f = \frac{W_1}{W_2}$$

$$W_m = (1 - M_f)$$

After determining the weight fractions of both components, the volume fraction was calculated using the following equations:

$$V_f = \frac{\rho_c}{\rho_f} \cdot W_f$$

$$V_m = 1 - V_f \; or \; V_m = \frac{\rho_c}{\rho_m} \cdot W_m$$

And the next table represent the results of calculation:

N° of Sample	Residue Weight W2 (g)	Wf	Wm	Laminate Density (g/cm3)	Fibre Volume Fraction	Matrix Volume Fraction
	3.333					
1	3.803	0.702	0.298	1.917	0.523	0.477
2	3.021	0.662	0.338	1.855	0.478	0.522
3	3.750	0.702	0.298	1.918	0.524	0.476
4	3.477	0.673	0.327	1.871	0.490	0.510
Average	0.369	0.685	0.315	1.890	0.504	0.496
Stand. Deviation	0.300	0.020	0.020	0.032	0.023	0.023
Aver. Deviation		0.017	0.017	0.027	0.020	0.020

Tab. 5 Results of calculations

The laminate (composite) density was then calculated by:

$$\rho = \rho_f \cdot V_f + \rho_m \cdot V_m$$

Laminate Density (g/cm3)
1.917
1.855
1.918
1.871
1.890
0.032
0.027

Tab. 6 Laminate density

3 – Based on the results, what considerations can you make about the sort of manufacturing method used to create these specimens?

Based on the findings, the lamination is composed of approximately 51.2 percent fiber and 48.8 percent resin. Because the BV rules define the defined values for laminating processes such as infusion and pre-pregs with a precise range of values due to the precision on the ratio that can be obtained when using these types of procedures, it was determined that the laminate in inquiry was generated using a Hand lay-up process of unidirectional reinforcement, since the put greater fit within the range of values shown in the table below, which was derived from BV regulations.

Table 1 : Resin/fibre mix ratios (in %)

Laminating process		V_f	M_f		
			Glass	Carbon	Para-aramid
Hand lay-up	CSM	from 15 to 20	from 25 to 35	-	-
	WR	from 25 to 40	from 40 to 60	from 35 to 50	from 30 to 45
	UD	from 40 to 50	from 60 to 70	from 50 to 60	from 45 to 55
Infusion	CSM	30	50	55	50
	WR or UD	45	60		
Pre-pregs		from 55 to 60	from 60 to 70	from 65 to 70	from 60 to 65

Consideration and conclusions

Given the data, we are now requested to demonstrate what kind of considerations we may make regarding the sort of manufacturing technique used to create these specimens.

Given the low standard deviation and the similarity of the Density and Volume Fractions values obtained, we may assume that the manufacturing process for these specimens took place under similar conditions (equipment and procedures). For these figures to be so close, we must also consider that the curing procedure was carried out under identical conditions for around the same period of time. However, because the Volume Fraction numbers were so different from the rest of the samples, we must conclude that there was a major variation in either the procedure's procedures or the equipment employed, despite the fact that the density of the laminate is reasonably similar to the other example.

With the completion of this assignment, the researcher was able to even further improve his knowledge and know-how of this type of testing, as well as the calculations required to perform the analysis of the testing's quality, giving him a better understanding of the possible differences obtained when performing the same test but under different conditions.