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DETERMINATION OF DESIGN ALLOWABLES FOR AIRCRAFT COMPOSITE STRUCTURES

Jiyeon Choung*, Jinwon Kim*, Inhee Hwang*
***Korea Aerospace Research Institute**

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Abstract

Federal Aviation Administration (FAA) requires material design allowable for the aircraft structural usage. This study shows calculation of the aerospace material allowables by using Composite materials Handbook (CMH)-17 STATS software which has been developed by National Center for Advanced Materials Performance (NCAMP) with material property data of HG181/AR1222 Glass fabric lamina produced by Hankuk fiber and CP150NS/K.015 Unidirectional carbon tape laminate produced by Hankuk carbon for aerospace usage.

The results of this study have been utilized for the domestic composite material qualification system and material characteristic database sharing system.

1 Introduction

Estimation on material for the aircraft structural usage is the significant factor to have the safety of aircraft structure design. For estimation on materials, it is a base to verify the material allowables. Generally, both material allowables of composite and metal have a common result but have a different about the process of calculation.

Material allowables are classified two value: one is A-basis value (A-basis), another is B-basis value (B-value). The necessary value is determined by applied structure. A-basis is that at least 99% of population equals or exceeds value about the material property with 95% confidence. When the applied load is delivered to structure of aircraft through only one element, A-basis is selected. For instance, if only one element which is able to deliver the load is destroyed, the integrity of component will be damaged. B-basis is that at least 90% of population equals or exceeds value about the material property with 95% confidence. In case of multiplex structures, the applied load is distributed to other elements safely even though one element is destroyed.

In this study, we focused only on the B-basis since the test data set of the A-basis have not met the requirements of certification of NCAMP [1]. We calculated material allowables by using CMH-17 STATS software that has been developed by NCAMP.

Two types of composite material data were selected in other to compute the B-basis material allowables: HG181/AR1222 Glass fabric lamina produced by Hankuk fiber and CP150NS/K.015 Unidirectional carbon tape laminate produced by Hankuk carbon for aerospace usage.

Aim of this study is to make the material property database of material allowables depends on the method of NCAMP within the level of a global approval. And the result will be applied to set up the materials certification procedure system for domestic composite materials for aircraft.

2 Method

Generally, material allowable is calculated with the statistically-based basis values. When $\bar{x}$ is sample mean, s is sample variance and k_B is one-sided tolerance limit factor of B-basis, B-basis value is calculated using equation (1).

$$B\text{-}basis = \bar{x} - k_B s \quad (1)$$

NCAMP introduced the method of single point and pooling for getting the more accurate result from the limited data set. The pooling

method is employed when the assumption that there are data set can combine with multiple material batches under the fixed effect as environment. If requirements for data are not met, then single-point method is employed. There are different approaches are applied depending on the data sets within the single-point procedures. Among Normal, Weibull, or lognormal distribution is selected for modeling unstructured data. Otherwise, nonparametric determine the basis values. On the other hand, structured data are modeled using the analysis of variance (ANOVA).

In order to apply the pooling, the modified coefficient variation (Mod CV) is employed by NCAMP. The coefficient of variation (CV) is the ratio of the standard deviation to the mean. In contrast to the CV, the Mod CV is change of CV value according to the Mod CV method [2].

2.1 Process of calculation using CMH-17

Single point method is used for calculation of the material allowables. Mod CV and pooling method are recommended applying statistical analysis when the statistical data fully meet the requirements of CMH-17 Rev G. Initial produced coupons do not tend to have enough real variations of material characteristics. NCAMP recommends to use Mod CV instead of CV since Mod CV is taken into consideration expected real variations. When pooling across environments in each test conditions is available, pooled coefficient of variation based on Mod CV of pooled data is used for calculations of the B-basis material allowables. Test data sets are normalized with a nominal cured ply thickness (CPT). Both statistics of normalized and as-measured data sets are calculated.

When test data sets passed K-Sample Anderson Darling test for batch equivalence, Anderson-Darling test for Normality and Levene's test for equality of standard deviation, pooling across environments was applied to calculate the B-basis values. If data had normality and pooling method was not allowable, Mod CV method was introduced to calculate the B-basis values. Otherwise, single point method was employed to calculate the B-basis values.

3 Result of CMH-17 STATS software

Material allowables was calculated and analyzed with CMH-17 STATS software. If it is possible to calculate the basis value with the Mod CV, and then the value was selected as recommend basis value. Estimates is not able to be a recommend basis value. Furthermore only normalized basis value was provided about the normalized material property. Environmental condition was presented in Table 1.

Table 1. Environmental condition abbreviation

Environmental Condition	Temperature	Abbreviation
Cold Temperature Dry	-54℃	CTD
Room Temperature Dry	24℃	RTD
Elevated Temperature Dry	82℃	ETD
Elevated Temperature Wet	82℃	ETW

3.1 Results of HG181/AR1222 Glass fabric Lamina

All results basis value of HG181/AR1222 Glass fabric lamina produced by Hankuk fiber were summarized in figure 1 and 2. When the B-basis meet the requirement of CMH-17 Rev. G, the B-basis can be shown in figure 1. However all of test data cannot meet the requirement so that the value which do not meet the requirement was described as estimates. All A-basis, B-basis and estimates can be shown in figure 2.

Figure 3 shows the result of statistics and basis value in case of warp (0°) tension (WT) properties. Data of CTD, RTD and ETD environment was pooled in both normalized and as measured data set. In case of ETW environment, converted data through the Mod CV was not success to pass the Anderson-Darling test for normality so that the data were not included into pooling. All of B-basis from pooling method on normalized data set was reduced as average around 2.95%. B-basis in

ETD environment was the mostly reduced as 5.8% reduce. About as measured data set, B-basis of CTD, RTD and ETD is overall reduced as 2.8%.

B-basis Values for HFG HG181/AR1222 Glass Fabric

All B-basis values in this table meet the standards for publication in CMH-17G Handbook
Values are for normalized data unless otherwise noted

Lamina Strength Tests (Unit: MPa)

Environment	Statistic	WT	WC	FT	FC	SBS*	IPS* 0.2% Offset	IPS* 5% Strain
CTD (-54°C)	B-basis	423.92	-	-	500.64	63.21	42.43	
	Mean	464.93	594.64	438.53	563.48	71.60	47.38	
	CV	6.00	4.32	6.89	6.27	6.85	6.00	
RTD (24°C)	B-basis	370.13	-	333.64	-	47.99	30.75	-
	Mean	411.13	470.00	384.61	450.03	54.25	34.25	53.60
	CV	6.00	6.34	7.45	6.54	6.49	6.00	2.00
ETD (82°C)	B-basis	324.98	293.63	287.67	287.48	-	-	-
	Mean	365.77	329.23	321.81	321.81	36.34	21.07	29.55
	CV	6.00	6.08	6.00	6.00	6.74	4.35	3.85
ETW (82°C)	B-basis	309.55	-	265.33	255.78	23.99	-	20.94
	Mean	345.74	296.96	296.62	289.08	27.64	17.44	23.60
	CV	6.01	5.62	6.00	6.48	7.46	5.43	6.22

Notes: The modified CV B-basis value is recommended when available.
The CV provided corresponds with the B-basis value given. If no B-basis value is provided, the as measured CV is given.

NA implies that tests were run but data did not meet KARI recommended requirements.
"NA:A" : ANOVA with 3 batches, "NA:I" : insufficient data
"NA:S" : corresponding material specification limit does not meet CMH-17G guideline of α=1% & n=5
* Data is as measured rather than normalized
** CMH-17 Single point method B-basis value is greater than 90% of the mean value

Fig. 1. KARI Recommend B-basis value on Lamina test data

Material : HFG HG181/AR1222 — HFG HG181/AR1222 Glass Fabric Lamina Properties Summary

Fiber : DE75 1/0 — Resin : AR1222

Tg(dry) : 115.76℃ — Tg(wet) : 89.22℃ — Tg method : DMA, Single Cantilever mode (SACMA SRM 18R-94)

Processing : 공정규격서(HFPS-001, Rev 2)

Date of Fiber manufacture : 2012/11/14 ~ 2012/12/10 — Date of testing : 2013/12/19 ~ 2015/05/04

Date of resin manufacture : 2013/09/02 — Date of data submittal : 2015/05/21

Date of prepreg manufacture : 2013/09/02 ~ 2013/09/04

Date of composite manufacture : 2013/09/26 ~ 2013/11/07

Lamina mechanical property B-basis Summary for HFG HG181/AR1222 Glass Fabric.
Data reported: As measured followed by normalized values in parentheses, normalizing CPT=0.253mm
Values shown in shaded boxes do not meet all CMH-17G requirements and are estimates only
These values may not be used for certification unless specifically allowed by the certifying agency

	CTD			RTD			ETD			ETW		
	B-Basis	Modified CV B-Basis	Mean	B-Basis	Modified CV B-Basis	Mean	B-Basis	Modified CV B-Basis	Mean	B-Basis	Modified CV B-Basis	Mean
F_1^{tu} (MPa)	428.37 (423.29)	423.92 (416.51)	464.93 (456.81)	374.76 (380.26)	370.13 (363.87)	411.13 (404.17)	344.96 (325.90)	324.98 (319.78)	365.77 (359.87)	321.53 (297.91)	309.55 (-)	345.74 (339.44)
E_1^t (GPa)			24.78 (24.35)			23.95 (23.54)			22.57 (22.28)			22.16 (21.78)
ν_{12}^t			0.134			0.119			0.096			0.087
F_2^{tu} (MPa)	400.92 (396.22)	- (-)	438.53 (440.84)	337.42 (349.72)	333.64 (-)	384.61 (387.38)	303.47 (306.08)	287.67 (288.39)	321.81 (322.61)	278.79 (276.87)	265.33 (-)	296.62 (296.17)
E_2^t (GPa)			24.15 (24.28)			23.54 (23.70)			21.54 (21.59)			20.85 (20.82)
ν_{21}^t			0.132			0.118			0.097			0.090
F_1^{cu} (MPa)	531.18 (536.02)	- (514.31)	594.64 (575.73)	420.12 (407.36)	- (-)	470.00 (456.09)	304.90 (296.45)	293.64 (285.25)	329.23 (319.52)	265.42 (257.34)	- (-)	296.96 (288.52)
E_1^c (GPa)			25.96 (25.12)			25.65 (24.70)			23.78 (23.14)			23.79 (23.07)
F_2^{cu} (MPa)	518.00 (495.36)	500.64 (-)	563.48 (551.16)	401.88 (392.88)	- (-)	450.03 (438.18)	299.10 (293.30)	287.48 (279.26)	321.81 (312.61)	263.62 (245.59)	255.78 (-)	289.08 (280.25)
E_2^c (GPa)			25.44 (24.37)			24.80 (23.76)			23.34 (22.25)			22.75 (21.64)
F_{12}^{su} (MPa)				49.76	-	53.61	27.41	-	29.55	21.70	20.94	23.60
$F_{12}^{su,2\%}$ (MPa)	46.22	42.43	47.38	32.97	30.75	34.25	19.94	-	21.07	16.33	-	17.44
G_{12}^s (GPa)			4.28			3.35			2.21			1.79
SBS (GPa)	64.52	63.21	71.60	49.45	47.99	54.25	30.75	-	36.34	24.26	23.99	27.64

Fig. 2. Summary of Lamina test data results

Warp Tension Strength(MPa) Basis Values and Statistics								
	Normalized				As Measured			
Env	CTD	RTD	ETD	ETW	CTD	RTD	ETD	ETW
Mean	464.93	411.13	365.77	345.74	456.81	404.17	359.87	339.44
Stdev	18.63	12.68	11.85	13.92	15.80	13.94	13.00	15.27
CV	4.01	3.08	3.24	4.03	3.46	3.45	3.61	4.50
Mod CV	6.00	6.00	6.00	6.01	6.00	6.00	6.00	6.25
Min	430.51	383.30	327.00	316.68	417.96	378.18	333.59	317.71
Max	493.99	440.05	387.01	374.82	489.15	440.92	390.21	369.72
No. Batches	5	5	5	5	5	5	5	5
No. Spec.	30	30	32	34	30	30	32	34
Basis Value and/or Estimates								
B-basis Value	428.37	374.76	344.96	321.53	423.29	380.26	325.90	297.91
A-estimate	388.54	349.49	329.85	303.91	387.00	363.99	302.13	268.92
Method	Weibull	ANOVA	Normal	Normal	Weibull	Log Normal	ANOVA	ANOVA
Modified CV Basis Values and/or Estimates								
B-basis Value	423.92	370.13	324.98	309.55	416.51	363.87	319.78	-
A-estimate	395.54	341.75	296.56	283.23	388.62	335.98	291.85	-
Method	pooled	pooled	pooled	Normal	pooled	pooled	pooled	-

Fig. 3. WT Strength data statistics, basis value and(or) estimate

3.2 Results of CP150NS/K.015 Unidirectional carbon tape Laminate

All results basis value of CP150NS/K.015 Unidirectional carbon tape laminate produced by Hankuk carbon were summarized in figure 4 and 5. When the B-basis meet the requirement of CMH-17 Rev. G, the B-basis can be shown in figure 4. However all of test data cannot meet the requirement so that the value which do not meet the requirement was described as estimates. All A/B-basis and estimates can be shown in figure 5.

Figure 6 shows the result of statistics and basis value in Quasi Isotropic Open Hole Tension (OHT1) properties. All environment data set of normalized and as measured can be pooled with Mod CV and CV method. All of B-basis from pooling method both on normalized and as measured data set was reduced as average around 4.28%. The trend of reduced account was similar with normalized data set and as measured data as about 4.7% in CTD, 4.3% in RTD and 3.8% in ETW.

B-basis Values for CP150NS/K.015 Unidirectional

All B-basis values in this table meet the standards for publication in CMH-17G Handbook
Values are for normalized data unless otherwise noted

Laminate Strength Tests (Unit: MPa)

Lay-up	Environment	Statistic	OHT	OHC	FHT
25/50/25	CTD(-54℃)	B-basis	408.39		443.66
		Mean	463.84		500.14
		CV	6.51		6.13
	RTD(24℃)	B-basis	446.88	259.50	477.18
		Mean	502.05	287.76	533.65
		CV	6.11	6.00	6.00
	ETW(82℃)	B-basis	497.35	197.36	492.60
		Mean	552.81	225.62	549.08
		CV	6.00	6.00	6.00
10/80/10	CTD(-54℃)	B-basis	283.68		336.77
		Mean	316.17		374.33
		CV	6.00		6.14
	RTD(24℃)	B-basis	282.49	239.82	330.79
		Mean	314.98	266.51	368.35
		CV	6.00	6.00	6.00
	ETW(82℃)	B-basis	252.81	161.43	266.33
		Mean	285.30	188.12	303.90
		CV	6.00	7.00	6.00
40/20/40	CTD(-54℃)	B-basis	621.77		623.61
		Mean	719.06		707.40
		CV	6.48		6.00
	RTD(24℃)	B-basis	715.46	350.36	649.88
		Mean	812.75	389.44	734.20
		CV	6.00	6.00	6.00
	ETW(82℃)	B-basis	1021.86	277.23	722.83
		Mean	1119.15	316.30	807.15
		CV	3.51	6.12	6.00

Notes: The modified CV B-basis value is recommended when available.
The CV provided corresponds with the B-basis value given. If no B-basis value is provided, the as measured CV is given.

NA implies that tests were run but data did not meet KARI recommended requirements.
"NA:A" : ANOVA with 3 batches. "NA:I" : insufficient data
"NA:S" : corresponding material specification limit does not meet CMH-17G guideline of α=1% & n=5
* Data is as measured rather than normalized
** CMH-17 Single point method B-basis value is greater than 90% of the mean value

Fig. 4. KARI Recommend B-basis value on Laminate test data

Material: ㈜티비카본 CP150NS/K.015 Unidirectional

㈜티비카본 CP150NS/K.015 Unidirectional Tape Laminate Properties Summary

Fiber: T700 12K Resin: K.015

Tg(dry): 151.45℃ Tg(wet): 114.86℃ Tg method: DMA(SRM 18R)

Processing: 공정규격서(TCPS-RD-006)

Date of Fiber manufacture: 2013/01 Date of testing: 2014/01/23 ~ 2015/01/24
Date of resin manufacture: 2013/03/19 Date of data submittal: 2015/05/30
Date of prepreg manufacture: 2013/03/22
Date of composite manufacture: 2013/05/27 ~ 2014/04/17

Laminate mechanical property B-basis Summary for ㈜티비카본 CP150NS/K.015 Unidirectional
Data reported: As measured followed by normalized values in parentheses, normalizing CPT=0.144mm

Values shown in shaded boxes do not meet all CMH-17G requirements and are estimates only. These values may not be used for certification unless specifically allowed by the certifying agency.

Test	Property	Layup:		Quasi Isotropic 25/50/25			"Soft" 10/80/10			"Hard" 40/20/40		
		Test Condition	Unit	B-value	Mod. CV B-value	Mean	B-value	Mod. CV B-value	Mean	B-value	Mod. CV B-value	Mean
OHT (normalized)	Strength	CTD	MPa	428.32	408.39	463.84	303.55	283.68	316.17	655.59	621.77	719.06
		RTD	MPa	466.71	446.88	502.05	301.25	282.49	314.98	749.28	715.46	812.75
		ETW	MPa	517.29	497.35	552.81	271.57	252.81	285.30	1055.68	1021.86	1119.15
OHC (normalized)	Strength	RTD	MPa	276.65	259.50	287.76	248.83	239.82	266.51	336.03	350.36	389.44
		ETW	MPa	214.51	197.36	225.62	165.81	161.43	188.12	289.85	277.23	316.30
FHT (normalized)	Strength	CTD	MPa	458.03	443.66	500.14	342.63	336.77	374.33	653.11	623.61	707.40
		RTD	MPa	514.99	477.18	533.65	350.25	330.79	368.35	696.27	649.88	734.20
		ETW	MPa	511.23	492.60	549.08	291.85	266.33	303.90	780.96	722.83	807.15

Fig. 5. Summary of Lamina test data results

Quasi Isotropic Open Hole Tension Strength(MPa) Basis Values and Statistics						
	Normalized			As Measured		
Env	CTD	RTD	ETW	CTD	RTD	ETW
Mean	463.84	502.05	552.81	472.82	510.59	565.59
Stdev	23.26	21.17	14.77	22.81	21.39	15.54
CV	5.01	4.22	2.67	4.82	4.19	2.75
Mod CV	6.51	6.11	6.00	6.41	6.09	6.00
Min	420.20	464.73	521.84	426.80	473.95	537.52
Max	508.60	544.41	577.02	512.20	552.21	588.22
No. Batches	3	3	3	3	3	3
No. Spec.	18	19	18	18	19	18
Basis Value and/or Estimates						
B-basis Value	428.32	466.71	517.29	437.12	475.07	529.89
A-estimate	404.64	443.00	493.61	413.32	451.24	506.09
Method	pooled	pooled	pooled	pooled	pooled	pooled
Modified CV Basis Values and/or Estimates						
B-basis Value	408.39	446.88	497.35	416.55	454.61	509.31
A-estimate	371.42	409.86	460.39	379.04	417.04	471.81
Method	pooled	pooled	pooled	pooled	pooled	pooled

Fig. 6. OHT1 Strength data statistics, basis value and (or) estimate

4 Conclusion

Material allowables is one of the significant factor to estimate the material for the aircraft structural usage. In this research, we selected CMH-17 STATS software to calculate material allowables with Mod CV and pooling method. The overall results through pooling method was shown the reduced the material allowables. The results of this study may be shared other manufacturers through database of the domestic composite materials certification system.

References

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