NUMERICAL ANALYSIS OF HYBRID COMPOSTE PIPING FOR OIL AND GAS APPLICATION

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CERTIFICATION OF APPROVAL

Numerical Analysis of Hybrid Composite Piping for Oil and Gas Application

By

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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMAD NUR BIN ZUKIFLI

ABSTRACT

The advantage of composite material over conventional engineering materials stem largely from their high specific strength, stiffness and fatigue characteristics. Composite materials over the years have emerged as a strong contender for replacing steel in piping application. The research is focuses on the design and mechanism of drill pipe used in the drill string. The design of the drill pipe will take into account the analysis on the two main factors of process and material parameters with regards to stress distribution and strength-to-weight ratio. Furthermore, the study only concentrates on the composite pipe fabricated based on only the filament winding technique used for manufacturing open (cylinders) or closed end structures (pressure vessels or tanks). The design properties of the drill pipe will be determined with regard to different material composition. The analyses on these two parameters will indicate whether the composite drill pipe could possibly be used to replace the conventional steel pipe. For that purposes, the research will be carried out using the models developed via the mathematical calculation and finite element analysis (FEA) on ANSYS codes.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Oil and gas wells are predominantly drilled using a rotary drilling. The rotary drilling system creates a borehole by means of a rock-cutting tool which known as drill bit. Deep wells for the exploration and production of oil and gas are drilled with a rock-cutting tool driven from the surface. The mechanism used to transfer the torque between the torque generating unit and the cutting tool is typically a series of connected, hollow steel drill pipes called the drill string. Figure 1 shows the configuration of a drill string.

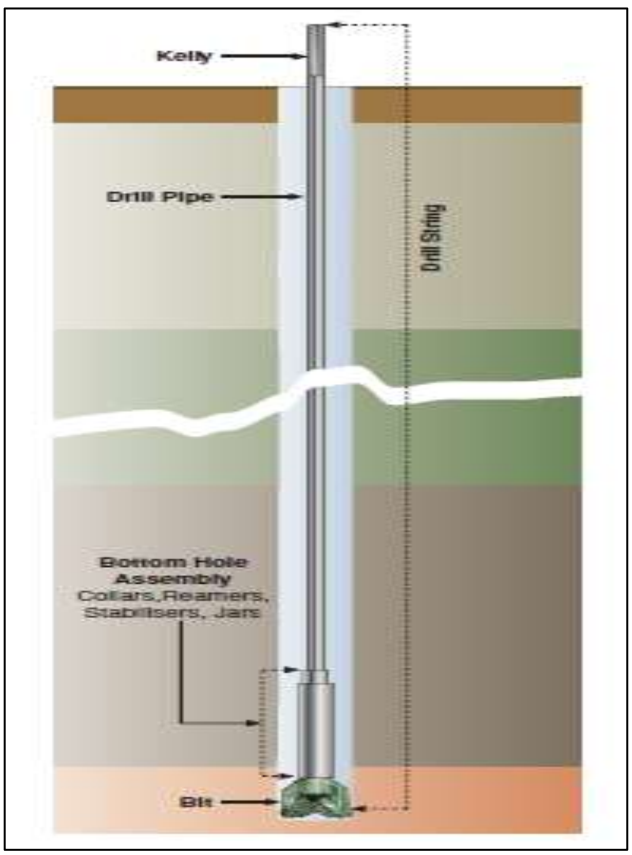

Figure 1: Drill String

The term drill string is used to describe the tubulars and accessories on which the drill bit is run to the bottom of the borehole. The drill string consists of drill pipe, drill collars, the kelly and various other pieces of equipment such as stabilizers and reamers, which are included in the drill string just above the drill bit (Figure 1). The drill collars and the other equipment which is made up just above the bit are collectively called the Bottom Hole Assembly (BHA). It is known that the drill pipe is the major component of the drill string, as it generally constitutes 90-95% of the entire length of the drill string.

A composite drill pipe (CDP) has been used recently to replace the conventional steel material in the drill pipe. It consists of a composite material tube with steel box and pin connections. The tube is manufactured by winding carbon/ graphite fibers and epoxy resin around a metal mandrel. Once the composite is cured, the metal mandrel is removed, and subsequently, the cured pipe section is machine-finished and abrasion resistant coating is applied.

It has been anticipated that the (CDP) could bring new life to thousands of idle wells drilled in the early 20th century. In many fields, unproduced oil-bearing formations lie 30.5 meters (100 feet) or less below the total depth (TD) of existing wells or remain bypassed behind casing as the reserves were not considered significant when the well was drilled. However, using a short radius drilling to drill horizontal laterals into these formations from existing wells could bring many of these older wells back into production without the environmental disturbance that could be created when drilling new wells.

In addition to its short radius drilling applications, the CDP also shows promise for enabling the technological development of oil and gas resources in other challenging locations. Since CDP combines lighter weight (less than half the weight of steel) with the performance properties of steel pipe, it is considered one of the technologies needed for resource development in extended reach (Callister & Rethwisch 2007), ultra-deep (UD), and deep directional drilling (DDD) applications.

Traditionally, the use of steel drill pipe has caused fixed weight-to-strength ratios, setting a limit that has been particularly bothersome in ultra-deep, deep directional and/or extended reach drilling. This ratio is comprised of either by the weight of the pipe or by the weight induced friction of the rotating pipe string as it rests on the walls of the well bore, or rubs against the casing wall.

With the advance of material technology, composite structures begin to demonstrate performance capabilities that are comparable to steel. With the materials cost is becoming less and pipe designs are turning into more sophisticated ones, the opportunity exists to develop drill pipe that can be competitive with steel.

1.2 Problem Statement

Several main problems that are associated with the extended reach, ultra-deep, and deep directional drilling were well described by Smith et al., (2001). They pointed out that current limits are controlled by the strength to weight ratio of steel drill pipe. However, materials with higher specific strength ratios could help to increase these limits in all those three drilling applications. The strength-to-weight ratio of nominal 6-inch composite drill pipe is 625,000 in 30-foot (9.14 m) sections and 1,011,000 in 45-foot (13.7m) sections, compared to 480,000 for 135 steel and 750,000 for titanium. This results in a 62.4% or 101% improvement over steel drill pipe and -9.3% (30-foot section) or 34.8% (45-foot section) improvement over titanium. Such example is provided based on the recent calculations for drill pipe in 10 pounds-per-gallon drill mud as the following comparisons: the maximum depth allowable would be 32,000 feet (9,754m) for 6 5/8 inch (15.6 cm) 27.70 Grade S steel drill pipe, 50,000 feet (15,240 m) for titanium, and 50,000 –70,000 feet (15,240–21,366 m) for composite drill pipe depending on the grade of carbon fiber used (Leslie, et.al, 2006).

Besides that, drill string will experience high tensile axial loads near the surface and high compressive loads at the bottom of the hole especially in the highly inclined and long tangential section of an extended reach drilling well .In order to provide satisfactory weight on bit, the drill string is further compressed and if this compression exceeds the critical buckling load, buckling could occur, hence will damage the structure.

Last but not least, corrosion is also a factor which has a bearing on the magnitude of stress in the metallic drill pipe. The flow of water in the string could potentially erode the inner diameter of the pipe. As results, many of the failures have resulted from fatigue cracks which have been originated at erosion/corrosion pits on the inside of the pipe. However, the use of the proposed CDP may completely solve the issue.

1.3 Objective

i. To develop mathematical modeling in analyzing the hoop and axial stress of cylinder pipe.
ii. To analyze the Von-Mises stress of isotropic materials and orthotropic materials.
iii. To analyze the effect of filament winding angle and number of ply on Von-Mises stress distribution
iv. To analyze the effect of different types of loading on Von-Mises stress distribution
v. To analyze the effect of different types of composite material on Von-Mises stress distribution.

1.4 Scope of Study

This study focuses on the design and mechanism of drill pipe used in the drill string. The design of the drill pipe will take into account the analysis on the two main factors of process and material parameters with regards to stress distribution and strength-to-weight ratio. Furthermore, the study only concentrates on the composite pipe fabricated based on only the filament winding angle used for manufacturing open (cylinders) or closed end structures (pressure vessels or tanks). The design properties of the drill pipe will be determined with regard to different material composition. The analyses on these two parameters will indicate whether the composite drill pipe could possibly be used to replace the conventional steel pipe. For that purposes, the research will be carried out using the models developed via the finite element analysis (FEA) on ANSYS codes.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter will review the past study of steel drill pipe, development of steel drill pipe, problem of steel drill pipe and composite drill pipe (CDP).

2.1 Drill Pipe

A drill pipe is a tube shaped conduit made of steel that is fitted with specially made threaded ends that are known as tool joints. Drill that is fitted with a pipe provides effective connection to the rig surface equipment or application with the bit and the bottom hole assembly for the purpose of pumping the drill fluid to the bit. Pipe also helps in connecting the rig surface equipment for raising, rotating as well as lowering the bottom hole bit and assembly. The Drill is hollow and thick walled tubing that is made of steel with a variety of uses. Pipe for drilling provides for the drilling of a well bore and is available in a number of sizes.

Drill pipes also provide strength and weight and are typically 30 ft. to 33 ft. long. This statement is supported by (Iqbal & Zolkepeli, 2008). They mentioned that a drill string is typically about 15,000 feet in length for oil or gas well vertically drilled onshore in the United States and may extend to over 30,000 feet for an offshore deviated well. Rabia H. (1985) also stated that the drill string is a long (up to several kilometers) flexible tubular structure (diameter 100–200 mm) which drives the drill bit to produce the well for oil production. Drill Pipe is also hollow in nature as it helps the fluid to pass through the pipe, down the hole and back up to the annulus. Drill pipe also uses rotational power with the Kelly or top drive to the bit. Drill Pipe helps make an effective transition to the drilling collars and pipes by providing flexible transition. Drill pipes reduce the fatigue failures of the BHA and add additional weight to the Drill bit.

2.1.1 Drill pipe Grades and Specifications

Steel drill pipe consist of a few grades which have different specifications. The available grades are E-75, X-95, G-105, and S-135. Table below showed the mechanical properties of steel drill pipe.

Grade	E-75	X-95	G-105	S-135
Min. Yield Strength (psi)	75,000	95,000	105,000	135,000
Max. Yield Strength (psi)	105,000	125,000	135,000	165,000
Tensile Strength (psi)	100,000	105,000	145,000	145,000

Table 1: Mechanical Properties of Steel Drill

Table 2 showed the dimension of the existing drill pipe based on grades provided by API SPEC 5D.

Size designation, in	**Calculated weight**	**Grade**	**Wall thickness, in**	**Wall thickness, mm**
2 3/8	6.65	E,X,G,S	0.28	7.11
2 7/8	10.4	E,X,G,S	0.362	9.19
3 1/2	13.3	E,X,G,S	0.368	9.35
3 1/2	15.5	E,X,G,S	0.449	11.4
4	14	E,X,G,S	0.33	8.38
4 1/2	16.6	E,X,G,S	0.337	8.56
4 1/2	20	E,X,G,S	0.43	10.92
5	19.5	E,X,G,S	0.362	9.19
5	25.6	E,X,G,S	0.5	12.7
5 1/2	21.9	E,X,G,S	0.361	9.17
5 1/2	24.7	E,X,G,S	0.415	10.54
6 5/8	25.2	E,X,G,S	0.33	8.387
6 5/8	27.7	E,X,G,S	0.362	9.19

Table 2: Dimension of Steel Drill based on grades

2.2 Standard

In terms of drill string design and specifications, the American Petroleum Institute (API) has recommended practices and specifications that are dominant throughout the industry. The drill string elements and materials therefore conform to a set of standard rules. The most important standards are:

I. API Spec. 7, specification for rotary drill stem elements.

II. API RP 7G, recommended practice for drill stem design and operating limits.

III. API Spec. 5D, specification for drill pipe.

IV. ISO 10407, petroleum and natural gas industries – drilling and production equipment – drill stem design and operating limits.

V. NORSOK M-702, drill string components.

API Spec. 5D covers the drill pipe body dimensions and material grades. Spec. 7 dictates the standard form and geometry of the threaded connections and is necessarily prescriptive in order to achieve widespread interchangeability of drill string elements. Any consideration of static or fatigue strength of the tool joint is historically embodied in the designs given. RP 7G, on the other hand, provides specific methods for the drill string design based on mathematical calculation. API (American Petroleum Institute) classifies drill pipes according to degree of wear as:

i. Class One—new drill pipes.

ii. Premium—pipes having a uniform wear and a minimum wall thickness of 80% (once a drill pipe has been in a hole, it is downgraded to premium).

iii. Class two—pipes having a minimum wall thickness of 65% with all wear on one side provided that the cross-sectional area is the same as that of the premium class.

iv. Class Three—pipes having a minimum wall thickness of 55% with all wear on one side.

NEW DRILL PIPE — TORSIONAL, TENSILE, COLLAPSE AND INTERNAL PRESSURE DATA

Size O.D. in.	Nom. Wt. T & C lb./ft.	Torsional Data * Torsional Yield Strength, ft. – lb.				Tensile Data Based on Min. Values Load at Min. Yield Strength, lb.				Collapse Pressure Based On Minimum Values, psi.				Internal Pressure At Minimum Yield Strength, psi.			
		E-75	X-95	G-105	S-135	E-75	X-95	G-105	S-135	E-75	X-95	G-105	S-135	E-75	X-95	G-105	S-135
2 3/8	4.85	4760	6030	6670	8570	97820	123900	136940	176070	11040	13980	15460	19040	10500	13300	14700	18900
	6.65	6250	7920	8750	11250	138210	175070	193500	248790	15600	19760	21840	28080	15470	19600	21660	27850
2 7/8	6.85	8080	10240	11320	14550	135900	172140	190260	244620	10470	12940	14020	17030	9910	12550	13870	17830
	10.40	11550	14640	16180	20800	214340	271500	300080	385820	16510	20910	23110	29720	16530	20930	23140	29750
3 1/2	9.50	14150	17920	19810	25460	194260	246070	271970	349680	10000	12080	13060	15750	9530	12070	13340	17150
	13.30	18550	23500	25970	33390	271570	343990	380200	488830	14110	17880	19760	25400	13800	17480	19320	24840
	15.50	21090	26710	29520	37950	322780	408850	451890	581000	16770	21250	23480	30190	16840	21330	23570	30310
4	11.85	19470	24670	27260	35050	230760	292290	323060	415360	8380	9980	10710	12620	8600	10890	12040	15470
	14.00	23290	29500	32600	41920	285360	361450	399500	513650	11350	14380	15900	20140	10830	13720	15160	19490
	15.70	25810	32690	36130	46460	324120	410550	453770	583410	12900	16340	18060	23210	12470	15790	17460	22440
4 1/2	13.75	25910	32820	36270	46630	270030	342040	378050	486060	7170	8410	8960	10280	7900	10010	11070	14230
	16.60	30810	39020	43130	55450	330560	418710	462780	595000	10390	12770	13830	16770	9830	12450	13760	17690
	20.00	36900	46740	51660	66420	412360	522320	577300	742240	12960	16420	18150	23340	12540	15890	17560	22580
	22.82	40910	51820	57280	73640	471240	596900	659740	948230	14820	18770	20740	26670	14580	18470	20420	26250
5	16.25	35040	44390	49060	63080	328070	415560	459300	590530	6940	8110	8620	9830	7770	9840	10880	13990
	19.50	41170	52140	57630	74100	395600	501090	553830	712070	9960	12030	13000	15670	9500	12040	13300	17110
	25.60	52260	66190	73160	94060	530140	671520	742200	954260	13500	17100	18900	24300	13130	16630	18380	23630
5 1/2	19.20	44070	55830	61700	79330	372180	471430	521050	669930	6040	6940	7310	8090	7260	9190	10160	13060
	21.90	50710	64230	70990	91280	437120	553680	611960	786810	8410	10020	10750	12680	8620	10910	12060	15510
	24.70	56570	71660	79200	101830	497220	629810	696110	895000	10460	12930	14010	17020	9900	12540	13870	17830
6 5/8	25.20	70580	89400	98810	127040	489460	619990	685250	881040	4790	5320	5500	6040	6540	8280	9150	11770
	27.70	76300	96640	106810	137330	534200	676650	747880	961560								

* Based on the shear strength equal to 57.7% of minimum yield strength and nominal wall thickness.

NOTE: Calculations are based on formulas in Appendix A, API RP7G and API Bul. 5C3.
Table is based on API RP7G, Tables 2.2 and 2.3.

Table 3: New Drill Pipe - Torsional, Tensile,Collapse and Internal Pressure Data

PREMIUM (USED) DRILL PIPE — TORSIONAL, TENSILE, COLLAPSE AND INTERNAL PRESSURE DATA

Size O.D. in.	Nom. Wt. T & C lb./ft.	Torsional Data * ** Torsional Yield Strength, ft. – lb.				Tensile Data Based on Min. Values Load at Min. Yield Strength, lb. **				Collapse Pressure Based On Minimum Values, psi. ***				Internal Pressure At Minimum Yield Strength, psi. ***			
		E-75	X-95	G-105	S-135	E-75	X-95	G-105	S-135	E-75	X-95	G-105	S-135	E-75	X-95	G-105	S-135
2 3/8	4.85	3730	4720	5220	6710	76890	97400	107650	138410	8520	10160	10910	12890	9600	12160	13440	17280
	6.65	4810	6090	6740	8660	107620	136310	150660	193710	13380	16950	18730	24080	14150	17920	19810	25470
2 7/8	6.85	6330	8020	8870	11400	106950	135470	149730	192500	7640	9020	9630	11190	9060	11470	12680	16300
	10.40	8860	11220	12400	15950	166540	210950	233150	299760	14220	18020	19910	25600	15110	19140	21150	27200
3 1/2	9.50	11090	14050	15530	19970	152980	193770	214170	275360	7070	8280	8810	10090	8710	11030	12190	15680
	13.30	14360	18190	20110	25850	212150	268720	297010	381870	12020	15220	16820	21630	12620	15980	17660	22710
	15.50	16150	20450	22610	29060	250620	317450	350870	451120	14470	18330	20260	26050	15390	19500	21550	27710
4	11.85	15310	19390	21430	27560	182020	230550	254820	327630	5700	6510	6830	7450	7860	9960	11000	14150
	14.00	18200	23050	25470	32750	224180	283960	313850	403530	9010	10800	11620	13840	9900	12540	13860	17820
	15.70	20070	25420	28090	36120	253850	321540	355390	456930	10910	13830	15190	18590	11400	14440	15960	20520
4 1/2	13.75	20400	25840	28560	36730	213260	270130	298560	383860	4690	5190	5350	5910	7230	9150	10120	13010
	16.60	24140	30580	33800	43450	260170	329540	364230	468300	7530	8870	9470	10960	8990	11380	12580	16180
	20.00	28680	36330	40160	51630	322920	409030	452080	581250	10980	13900	15350	18810	11470	14520	16050	20640
	22.82	31590	40010	44220	56860	367570	465580	514590	661620	12660	16030	17120	22780	13330	16890	18670	24000
5	16.25	27610	34970	38650	49690	259160	328260	362820	466480	4490	4940	5070	5660	7100	9000	9950	12790
	19.50	32290	40900	45200	58110	311540	394610	436150	560760	7040	8240	8770	10030	8690	11010	12160	15640
	25.60	40540	51360	56760	72980	414690	525270	580570	746440	11460	14510	16040	20510	12000	15200	16800	21600
5 1/2	19.20	34760	44040	48670	62580	294260	372730	411970	529670	3740	4130	4340	4710	6630	8400	9290	11940
	21.90	39860	50490	55810	71750	344780	436720	482690	620600	5730	6540	6870	7500	7880	9980	11030	14180
	24.70	44320	56140	62050	79780	391290	495630	547800	704310	7640	9010	9630	11180	9060	11470	12680	16300
6 5/8	25.20	55770	70640	78070	100380	387470	490790	542450	697440	2930	3250	3350	3430	5980	7570	8370	10760
	27.70	60190	76240	84270	108340	422420	535060	591390	760350								

* Based on the shear strength equal to 57.7% of the minimum yield strength.

** Torsional and Tensile data based on 20% uniform wear on outside diameter.

*** Collapse and internal pressure data based on minimum wall of 80% of nominal (new) and uniform O.D. wear.

Note: Calculations for Premium Class drill pipe are based on formulas in Appendix A, API RP7G and API Bul. 5C3.
Table is based on API RP7G, tables 2.4 and 2.5.

Table 4: Premium (used) Drill Pipe - Torsional, Tensile, Collapse and Internal Pressure Data

CLASS 2 (USED) DRILL PIPE — TORSIONAL, TENSILE, COLLAPSE AND INTERNAL PRESSURE DATA

Size O.D. in.	Nom. Wt. T & C lb./ft.	Torsional Data * ** Torsional Yield Strength, ft. – lb.				Tensile Data Based on Min. Values Load at Min. Yield Strength, lb. **				Collapse Pressure Based On Minimum Values, psi. ***				Mini
		E-75	X-95	G-105	S-135	E-75	X-95	G-105	S-135	E-75	X-95	G-105	S-135	E-75
2 3/8	4.85	3220	4080	4510	5800	66690	84470	93360	120040	6850	8000	8490	9660	8400
	6.65	4130	5230	5780	7430	92870	117640	130020	167170	12140	15380	16990	21850	12380
2 7/8	6.85	5480	6950	7680	9870	92800	117550	129920	167040	6060	6960	7340	8120	7930
	10.40	7590	9620	10630	13660	143560	181840	200980	258400	12940	16390	18110	23290	13220
3 1/2	9.50	9610	12180	13460	17300	132790	168200	185910	239030	5540	6300	6600	7140	7620
	13.30	12370	15660	17310	22260	183400	232300	256760	330120	10860	13750	15040	18400	11040
	15.50	13830	17520	19360	24890	215970	273560	302350	388740	13170	16690	18440	23710	13470
4	11.85	13280	16820	18590	23910	158130	200300	221390	284640	4310	4700	4880	5440	6880
	14.00	15740	19940	22030	28330	194360	246190	272110	349850	7300	8570	9130	10520	8660
	15.70	17320	21930	24240	31170	219740	278340	307630	395530	9530	11470	12370	14840	9980
4 1/2	13.75	17720	22440	24800	31890	185390	234830	259550	333700	3400	3850	4020	4290	6320
	16.60	20910	26480	29270	37630	225770	285980	316080	406390	5950	6830	7190	7920	7860
	20.00	26750	31350	34650	44540	279500	354040	391300	503100	9630	11600	12520	15030	10030
	22.82	27160	34400	38030	48890	317500	402160	444500	571500	11460	14510	16040	20510	11670
5	16.25	23970	30370	33560	43150	225320	285400	315440	405570	3280	3700	3850	4070	6220
	19.50	27980	35440	39170	50360	270430	342550	378610	486780	5510	6260	6550	7080	7600
	25.60	34950	44270	48930	62910	358730	454390	502220	645720	10340	12640	13690	16590	10500
5 1/2	19.20	30210	38260	42290	54370	255950	324210	358340	460720	2840	3130	3220	3270	5800
	21.90	34580	43800	48410	62250	299530	379410	419350	539160	4330	4730	4900	5470	6890
	24.70	38380	48620	53740	69090	339530	430080	475350	611160	6050	6960	7330	8120	7920
6 5/8	25.20	48500	61430	67900	87300	337240	427170	472130	607030	2230	2340	2350	2350	5230
	27.70	52310	66260	73230	94150	367450	465440	514440	661420					

* Based on the shear strength equal to 57.7% of the minimum yield strength.
* Torsional and Tensile data based on 30% uniform wear on outside diameter.
*** Collapse and internal pressure data based on minimum wall of 70% of nominal (new) wall and uniform O.D. wear.

Note: Calculations for Class 2 drill pipe are based on formulas in Appendix A, API RP7G and API Bul. 5C3.
Table is based on API RP7G, tables 2.6 and 2.7.

Table 5: Class 2(used) Drill Pipe - Torsional, Tensile, Collapse and Internal Pressure Data

NEW DRILL PIPE DIMENSIONAL DATA

1 Size O.D. in. D	2 Nominal Weight Threads & Couplings lb./ft.	3 Plain End Weight * lb./ft.	4 Wall Thickness in.	5 I.D. in. d	6 Section Area Body of Pipe ** sq. in. A	7 Polar Sectional Modulus *** cu. in. Z
2 3/8	4.85	4.43	0.190	1.995	1.3042	1.321
	6.65	6.26	0.280	1.815	1.8429	1.733
2 7/8	6.85	6.16	0.217	2.441	1.8120	2.241
	10.40	9.72	0.362	2.151	2.8579	3.204
3 1/2	9.50	8.81	0.254	2.992	2.5902	3.923
	13.30	12.31	0.368	2.764	3.6209	5.144
	15.50	14.63	0.449	2.602	4.3037	5.847
4	11.85	10.46	0.262	3.476	3.0767	5.400
	14.00	12.93	0.330	3.340	3.8048	6.458
	15.70	14.69	0.380	3.240	4.3216	7.157
4 1/2	13.75	12.24	0.271	3.958	3.6004	7.184
	16.60	14.98	0.337	3.826	4.4074	8.543
	20.00	18.69	0.430	3.640	5.4981	10.232
	22.82	21.36	0.500	3.500	6.2832	11.345
5	16.25	14.87	0.296	4.408	4.3743	9.718
	19.50	17.93	0.362	4.276	5.2746	11.415
	25.60	24.03	0.500	4.000	7.0686	14.491
5 1/2	19.20	16.87	0.304	4.892	4.9624	12.221
	21.90	19.81	0.361	4.778	5.8282	14.062
	24.70	22.54	0.415	4.670	6.6296	15.688
6 5/8	25.20	22.19	0.330	5.965	6.5262	19.572
	27.70	24.21	0.362	5.901	7.1226	21.1 56

* lb./ft. = 3.3996 x A(col. 6)

** $A = 0.7854 \times (D^2 - d^2)$

*** $Z = 0.19635 \times 1/D \times (D^4 - d^4)$

NOTE: Table is based on API RP7G, Table 2.1

Table 6: New Drill Pipe Dimension Data

2.3 Design and Development of Steel Drill Pipe

Wider application of horizontal and extended-reach drilling has increased the need for lightweight drill pipe to reduce the greater torque and drag caused by increasing hole angles. Lightweight aluminum and titanium drill pipes were developed but are not widely used because they are much more costly than heavier steel drill pipe. Therefore, from an economic viewpoint, lightweight steel drill pipe is the best type of pipe for horizontal and extended-reach applications. Some researchers have done with the design and development of steel drill pipe. The drill pipe was developed according to three design objectives and verified by full-size and material-evaluation tests. The design objectives are:

i. The ID had to be as large as possible to minimize hydraulic loss

ii. The stress concentration at upset transitions had to be reduced to prevent fatigue failures

iii. The upset had to be as thin as possible on the basis of the allowable section modulus.

2.3.1 Wall Thickness

The lightweight steel drill pipe has two advantages over standard API G-I05 pipe with the same pipe-body OD-it weighs 25% less and has a 20% lower hydraulic loss (loss of fluid pressure) but maintains a performance level comparable with that of G-I05 pipe. Tsukano Y. & Ueno M. (1991) mentioned that the weight of steel drill pipe can be reduced by decreasing the pipe's wall thickness. They also stated that the drill pipe performance maintained since they are using high-strength steel. On top of that, they have done some torsional, tensile, fatigue, burst, and collapse test to verify the performance of the lightweight steel drill pipe. As a result, they come out with the performance properties of lightweight steel and G-105 drill pipe as shown in table 7.

Property	Lightweight Steel	G-105
OD x wall thickness (in.)	5 x 0.256	5 x 0.359
Torsional yield (lbf-ft)	68,116	57,594
Tensile yield (lbf)	629,956	552,863
Burst pressure (psi)	16,825	13,340
Collapse pressure (psi)	7832	13,050
Weight (lbf/ft)	16.6	21.9
Hydraulic loss ratio	0.785	1.000

Table 7: Mechanical Properties of Lightweight steel and G-105 Drill Pipes

From the table above, the design capabilities of the lightweight steel drill pipe are superior to those of the G-105 pipe. The lightweight steel drill pipe weighs about 25 % less than the G-105 pipe and experiences 20% less hydraulic loss. The lower collapse pressure of the lightweight drill pipe will not cause any practical problems because there are few occasions when the outside mud pressure of drill pipe greatly exceeds the inside pressure during drilling.

2.3.2 Finite Elements

Khulief and Naser, (2005) have done the experiment on drill string vibrations using finite element analysis. A dynamic model of the drill string including both drill pipe and drill collars is formulated. The equation of motion of the rotating drill string is derived using Lagrange approach together with the finite-element method. The drill string components with circular cross-section are discretized into a number of finite shaft elements with 12 degrees of freedom each. The model accounts for the gyroscopic effect, the torsional/bending inertia coupling, and the effect of the gravitational force field. Explicit expressions of the finite element inertia coupling and axial stiffening matrices are derived using a consistent mass formulation. Modal transformations are invoked to obtain a reduced order modal form of the dynamic equations. The developed model is integrated into a computational scheme to calculate the modal characteristics and to perform time-response analysis of the drill string system.

Khulief and Naser, (2005) presented that consistent mass FEM formulation with 25 nodes connected by 24 equal finite shaft elements. This number of elements was found to achieve convergence for the chosen drill string configuration. Numerical tests showed that further increase of number of elements resulted in insignificant improvement in the calculated values.

2.4 Design and Development of CDP

In the recent design and development of drill pipe, composite material has been used. Composite drill pipe could bring new life to thousands of idle wells drilled in the early 20th century. In many fields, unproduced oil-bearing formations lie 100 feet (30.5 meters) or less below the total depth (TD) of existing wells or remain bypassed behind casing because the reserves were not considered significant when the well was drilled. Some researchers have carried out the analysis on CDP recently.

CDP shows promise for enabling the economic development of oil and gas resources in other challenging locations. This is because CDP combines lighter weight (less than half the weight of steel) with the performance properties of steel pipe (Leslie et al. 2006). (Rawat & Attia, 2009) support the statement by stated that CDP contain unique mechanical properties, light weight, used in high strength applications and low fabrication cost. Most composites are created to improve combinations of mechanical characteristics such as stiffness, toughness, high resistance to corrosion, ambient and high-temperature strength and reduced wear compared to monolithic materials like steel and alloy (Callister & Rethwisch, 2007).

2.4.1 Finite Elements Analysis

Finite Element Analysis (FEA) has been widely practiced nowadays as it is able to solve numerous kinds of problem, from the numerical solutions to a very complex and complicated engineering problem as cited by Roylance (2001). Antal et al. (2003) also added that the FEA is applicable in wide range of engineering principles, including hydrodynamics, mechanical, and heat transfer and gas diffusion phenomena. Basically, in the FEA, it involves the model generation of some material or design that is stressed or analyzed for obtaining a specific results. It is commonly used to evaluate and analyzed the new product design or existing product for refinement works in order to verify that the proposed design will be able to function according to the client's specifications prior to manufacturing of the proposed design. However, despite the countless advantages that FEA possessed, there is a quite small flaw with this method. Roylance (2001) explained that FEA approach does not necessarily reveal how the stresses are influenced by the important problem variables such as materials properties and geometrical features, with an error in input data can produce inaccurate results that may be overlooked by the analysis.

2.4.2 Filament Winding

Filament winding is a fabrication technique mainly used for manufacturing open (cylinders) or closed end structures (pressure vessels or tanks). The process involves winding the filaments under tension over a male mandrel. The mandrel rotates while a wind eye on a carriage moves horizontally, laying down fibers in the desired pattern. The mechanical strength of the filament wound parts is not only depends on composition of component material but also on process parameters like winding angle, fiber tension, resin chemistry and curing cycle.

Xia et.al (2001) stated that the filament-wound composite pipe made of fiber-reinforced plastics have many potential advantages over pipes made from conventional materials, including high specific stiffness and strength, good corrosion resistance and thermal insulation.

Lea and Yang (1998) describe benefits of multi-angle filament-wound structures (e.g. improved tension and bending characteristics of composite pipe) in comparison to such wound at the traditional $\pm54^0$ angle. An experimental investigation on the effect of multi-angle filament winding on the strength of tubular composite structures has been conducted by Mertiny et.al (2004). They added that by using internal pressure and axial force, experiments under biaxial tensile stress ratios were carried out to investigate the performance of multi-angle filament wound structures. As a result, they make a conclusion that multi-angle filament winding is valuable method for producing tubular structures, particularly if variable loading conditions need to be considered.

Besides that, Jia et.al, (2013) have done an analysis of compression testing of sample of CFRP cylinder by using different types of pressure and modeling the crushing behavior. Jia et.al (2013) presented that the CFRP cylinder with end reinforcing layer showed higher compressive properties along with failure mode of crack propagating in its central circumference. With winding angle increasing, the compressive strength, compressive modulus and crack length of the cylinder generally exhibited the decreasing trend, whereas the crushing efficiency showed the opposite trend.

Ansari et.al (2010) conducted an analysis on multi-layered filament wound composite pipes subjected to cyclic internal pressure and temperature loading. They found that the time-dependent stress, strain and deformation distributions were obtained. It has been demonstrated that the hoop rotation tends to zero as fiber orientation tends to axial or circumferential directions. Also, it has been presented that hoop and axial stresses increase as fiber orientation tends to circumferential and longitudinal directions, respectively. The axial strain for cylindrical pipes with isotropic material is always positive

CHAPTER 3

METHODOLOGY

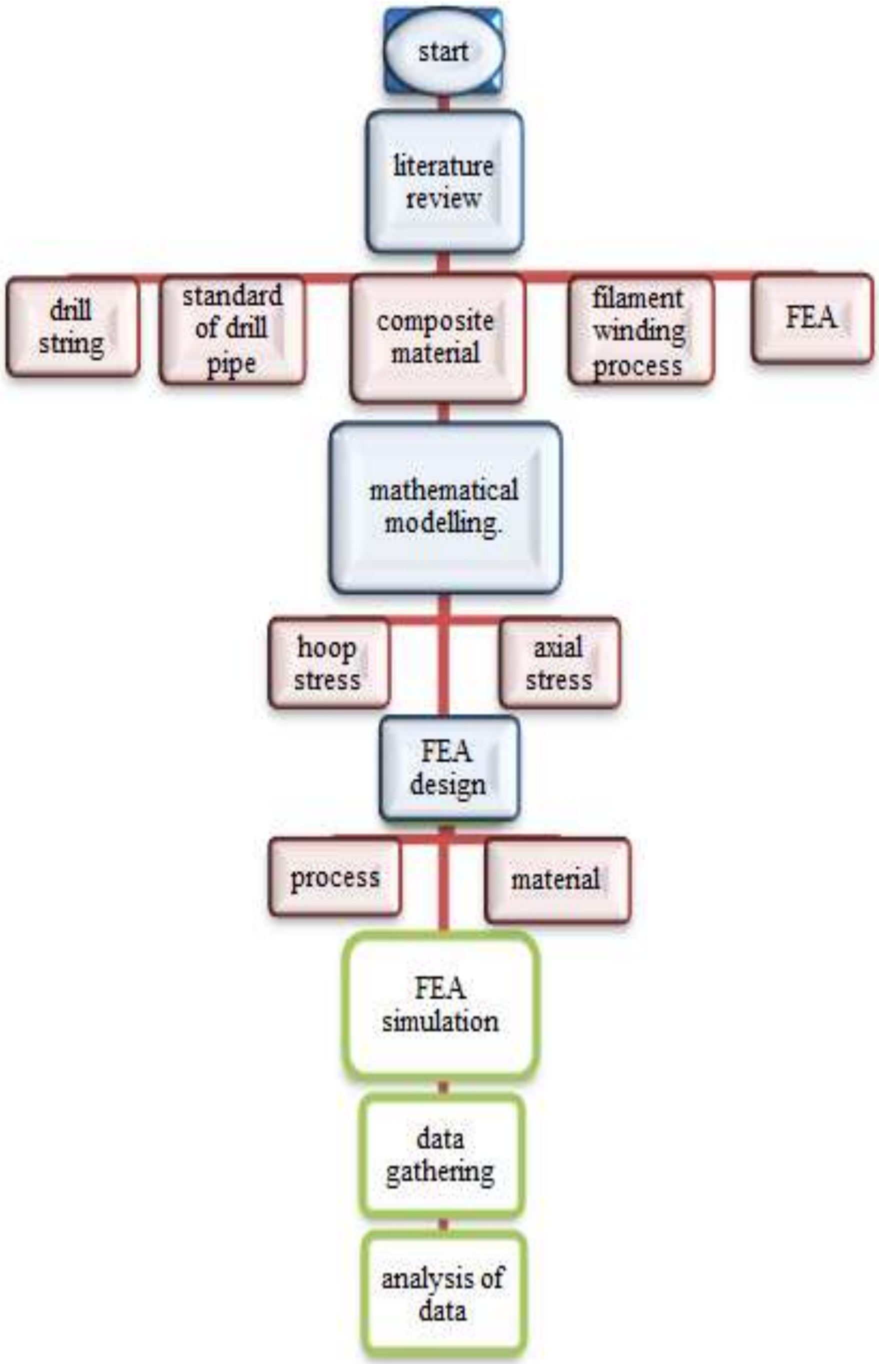

Figure 2: Project Flow Chart

3.1 Literature Review

The analysis is to improve the mechanical failure of conventional steel drill pipe mainly on development of composite drill pipe. To be precise, the author would like to study the effect of wall thickness on strength to weight ratio. Resources like journals, books, and article from internet have been very helpful as a supporting statement for the literature review. The process of filament winding and type of composite material used were important parameter to understand before conducting the analysis.

3.2 Mathematical Modeling

Consider the cylindrical having a wall thickness, t inner radius r, and pressure that developed within the vessel by a contained gas. Due to this loading, a small element of the vessel that is sufficiently removed from the ends and oriented as shown in figure 3, is subjected to normal stresses σ_1 in the circumferential or hoop direction and σ_2 in the longitudinal or axial direction.

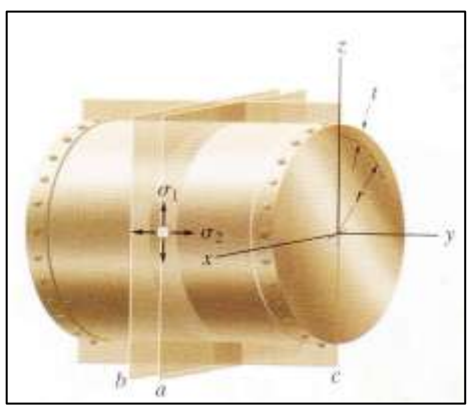

Figure 3: Stresses acting on cylinder vessel

The hoop stress can be determined by considering the vessel tube sectioned by planes a, b, and c. A free-body diagram of the back segment along with the contained gas is shown in Figure 4.

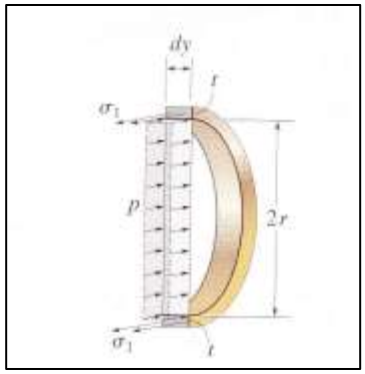

Figure 4: Hoop stress acting on cross section of cylinder vessel

Here only the loading in the x-direction are shown. These loading are developed by the uniform hoop stress σ_1, acting on the vessel's wall, and the pressure acting on the vertical face of the gas. For equilibrium in the x-direction, we require:

$$\sum F_x = 0; \qquad 2[\sigma_1(t\ dy)] - p(2r\ dy) = 0$$

$$\sigma_1 = \frac{pr}{t} \qquad \text{(eq.1)}$$

The longitudinal stress can be determined by considering the left portion of section b of the cylinder. As shown in figure 5, σ_2 acts uniformly throughout the wall, and p acts on the section of the contained gas.

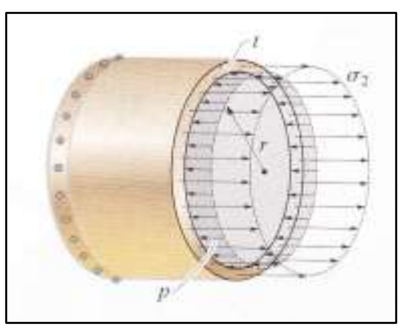

Figure 5: Longitudinal stresses acting on cylinder vessel

Since the mean radius is approximately equal to the vessel's inner radius, equilibrium in the y-direction requires:

$\sum F_y = 0;$ $\sigma_2(2\pi rt) - p(\pi r^2) = 0$

$$\sigma_2 = \frac{pr}{2t} \qquad \text{(eq. 2)}$$

In the above equations,

σ_1, σ_2 = the normal stress in the hoop and longitudinal directions, respectively. Each is assumed to be constant throughout the wall of the cylinder, and each subjects the material to tension.

p = the internal gauge pressure developed by the contained gas

r = the inner radius of the cylinder

t = the thickness of the wall ($r/t \geq 10$)

3.4 Simulation Modelling

The process of simulations of composite material was the important part in this project. The author have to understand the mechanism of ANSYS very well in order to run the simulations. There were a lot of steps that need to consider to make sure the simulations ran succeed. Figure 6 shown how the process of simulation have been done by the author.

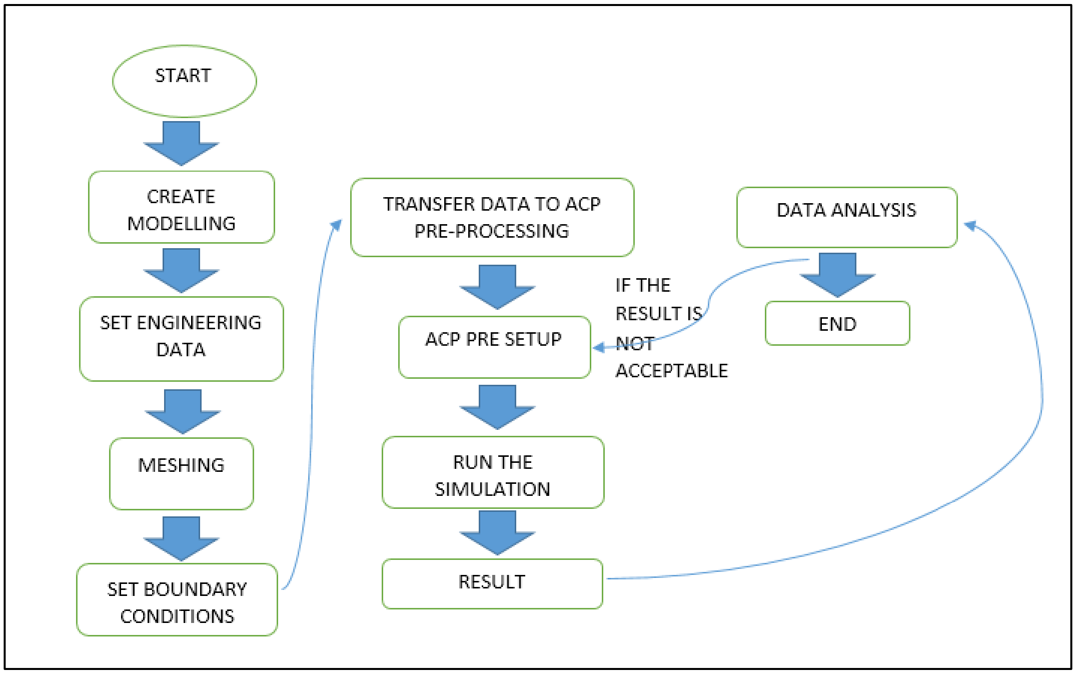

Figure 6: Simulation flow chart

Structural analysis is probably the most common application of the finite element method. In this project, author has decided to use static structural analysis which used to determine displacement, stresses under static loading. Since the project is involve the composite material, author used ANSYS ACP pre-post to analyze the stress of the drill pipe. Figure below show the setup simulation done using ACP pre-post.

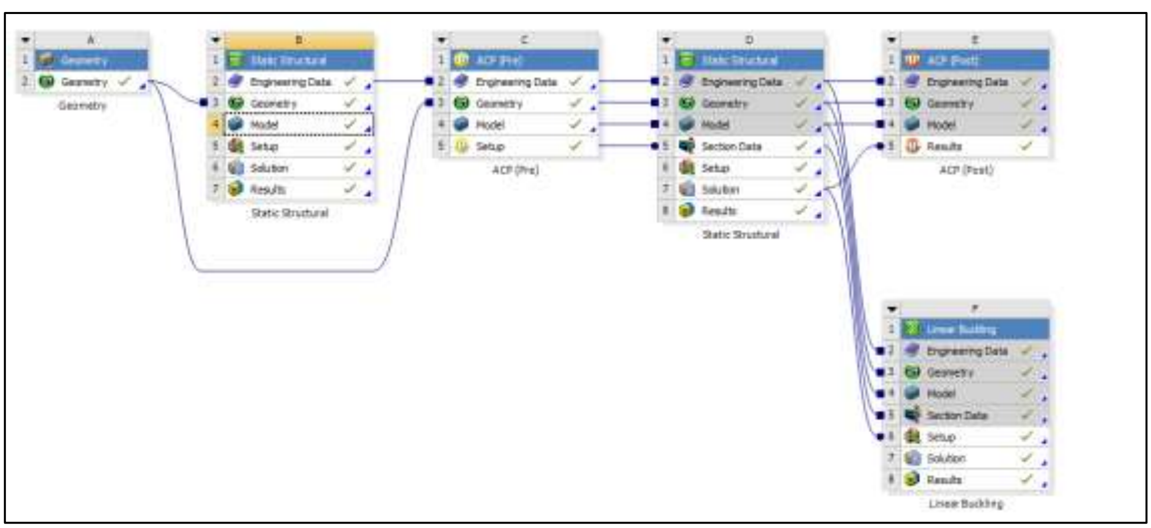

Figure 7: ANSYS ACP pre-post project schematic

3.4.1 Engineering Data

The properties and material for the component that have been used in the analysis is defined in the engineering data. Table below shows the material and properties used for the analysis.

Material	Properties
Structural Steel	Density : 7850 kg/m³ Tensile strength : 2.5x10^8 Pa Ultimate strength : 4.6x10^8 Pa Young modulus : 2 x 10 ^11 Pa Poisson ratio : 0.3
Titanium	Density : 4620 kg/m³ Tensile strength : 9.38 x10^8 Pa Ultimate strength : 1.07 x 10^9 Pa Young's modulus : 9.6 x 10^10 Pa Poisson's ratio : 0.36
Aluminum alloy	Density : 2770 kg/m³ Tensile strength : 2.8 x 10^8 Pa Ultimate strength : 3.1 x 10^8 Pa Young modulus : 7.1 x 10^10 Pa Poisson ratio : 0.33
Stainless steel	Density : 7750 kg/m³ Tensile strength : 2.07 x 10^8 Pa Ultimate strength : 5.86 x 10^8 Pa Young modulus : 1.93 x 10 ^11 Pa Poisson ratio : 0.31
Epoxy_Carbon_UD_230GPa_Prepreg	Density : 1490 kg/m³ Young modulus, E_1 : 121 GPa Young modulus, E_2 : 8600 MPa Poisson ratio, V_{12} : 0.27 Poisson ratio, V_{23} : 0.4 Tensile strength : 2231 MPa
Epoxy_EGlass_UD	Density : 2000 kg/m³ Young modulus, E_1 : 45 GPa Young modulus, E_2 : 10000 MPa Poisson ratio, V_{12} : 0.3 Poisson ratio, V_{23} : 0.4 Tensile strength : 1100 MPa
Resin_Epoxy_ampreg_22	Density : 1160 kg/m³ Young modulus, E_1 : 3780 MPa Poisson ratio, v : 0.35 Tensile strength : 54.6 Pa

Table 8: List of Material Specifications

3.4.2 Geometry

The model of the drill pipe design was shown in Figure 8.

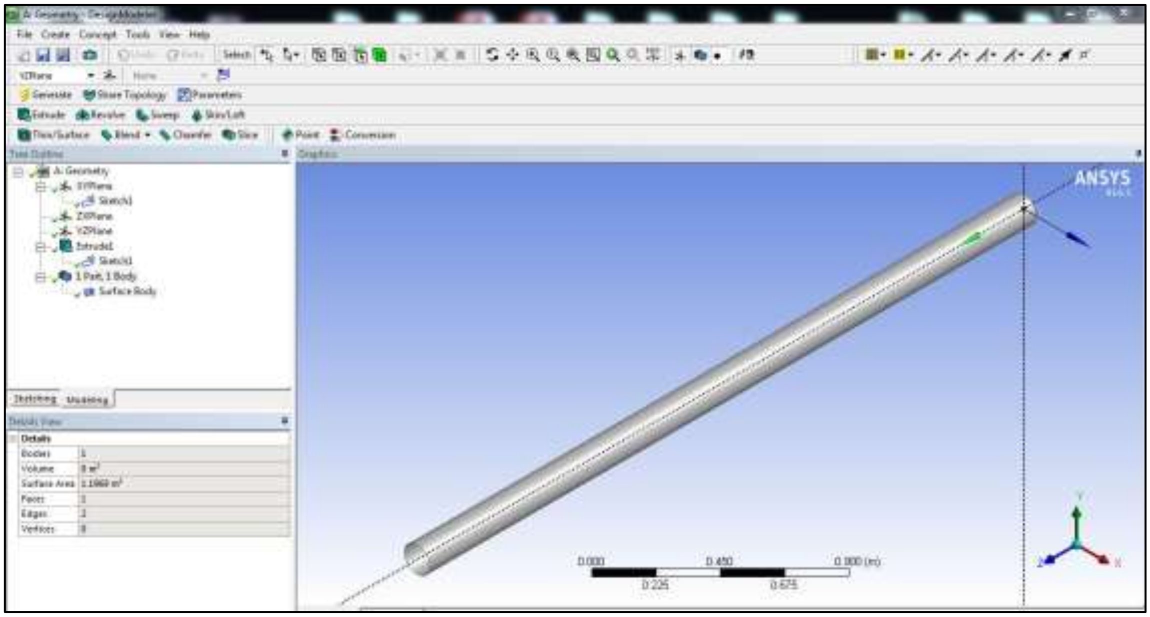

Figure 8: Design of drill pipe using ANSYS Design Modeler

Material of the geometry, coordinate, connection, meshing properties, initial condition and analysis setting are defined in ANSYS Workbench Mechanical. The outer diameter of the pipe is setup to 0.127m or 5 inch. The thickness also setup to 0.0127 m. This parameter is obtained from API SPEC 5D standard. Author also setup the length of the pipe to 3 m.

3.4.3 Meshing

Meshing is one of the important aspects in engineering simulation. Meshing is an integral part of the computer-aided engineering simulation process. The mesh influences the accuracy, convergence and speed of the solution. The meshing setting and pattern for this project was set as shown in Figure 9.

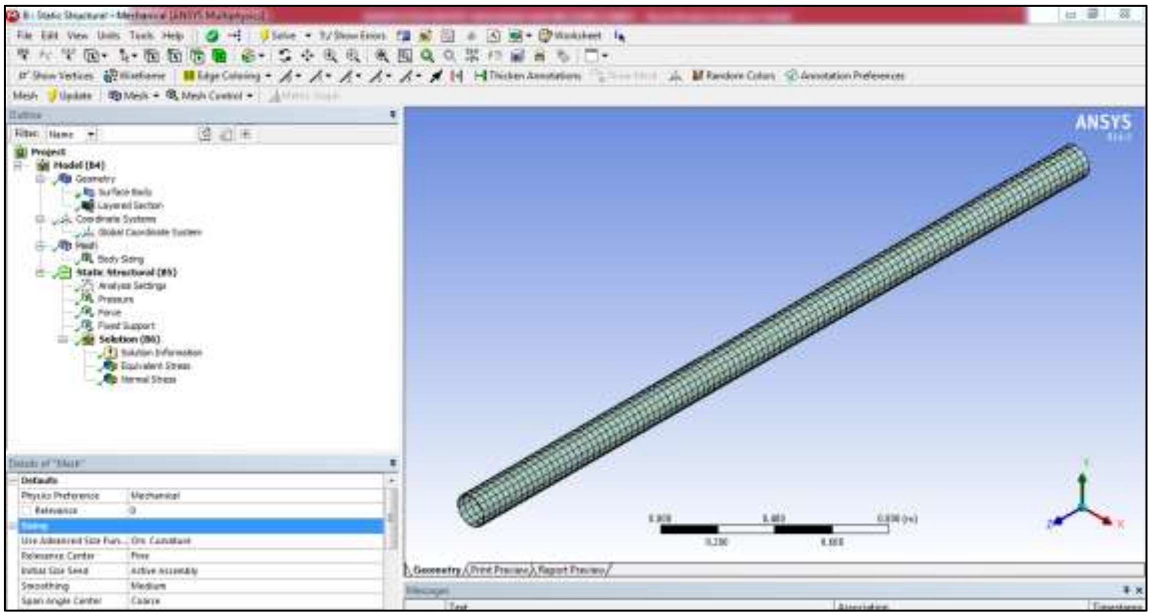

Figure 9: Meshing of drill pipe

For this part, author set the element size to 0.002 m which increase the number of nodes and elements. From the statistics, the nodes of this model is 1663 and the elements is 1648.

3.4.4 Static Structural Analysis

A static analysis calculates the effects of steady loading conditions on a structure while ignoring inertia and damping effect such as those caused by time-varying loads. In this simulation, author has decided the location of force and fixed support acts on the drill pipe model as shown in Figure 10.

The amount of pressure used in this simulation has been taken from the standard provided by API RP 7G. Other than that, author has decided to set the force to 100 N to investigate the normal stress and Von-Mises stress along the pipe model.

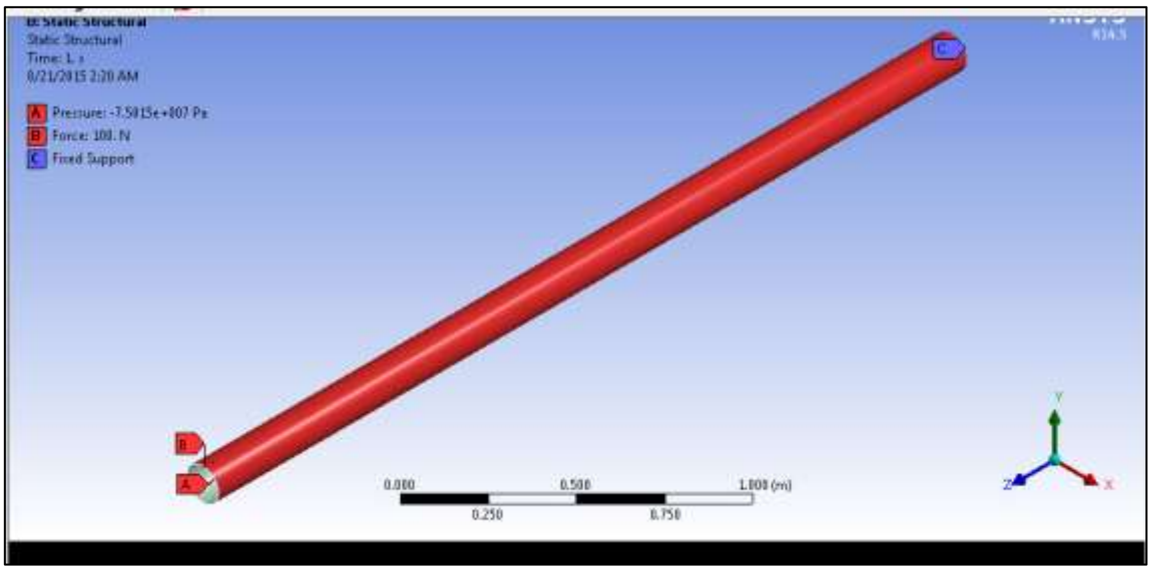

Figure 10: The applied of combined loadings on pipe model.

3.4.5 ACP Prep-Post

Composite materials are created by combining two or more layered materials, each with different properties. These materials have become a standard for products that are both light and strong. Composites provide enough flexibility so products with complex shapes, such as boat hulls and surfboards, can be easily manufactured. Engineering layered composites involves complex definitions that include numerous layers, materials, thicknesses and orientations. The engineering challenge is to predict how well the finished product will perform under real-world working conditions. This involves considering stresses and deformations as well as a range of failure criteria. ANSYS Composite Prep-Post provides all necessary functionalities for the analysis of layered composite structures.

ANSYS Composite Prep-Post (ACP) is an add-in to ANSYS Workbench and is integrated with the standard analysis features. The entire workflow for composite structure can be completed from design to final information production as a result.

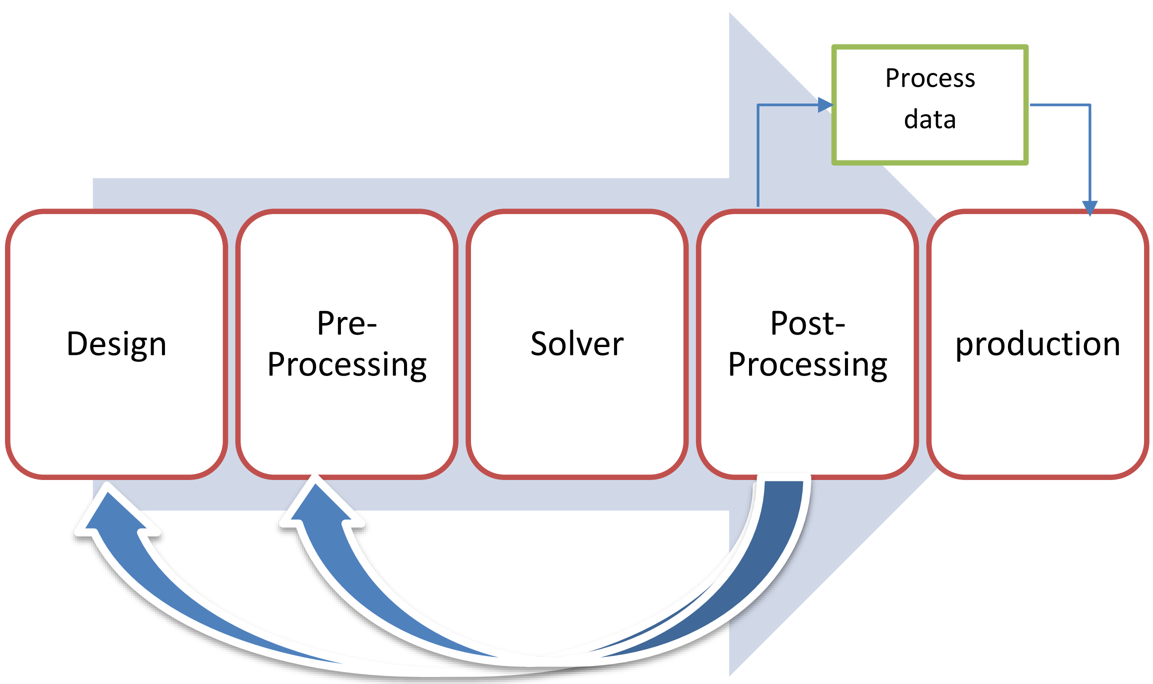

Figure 11: Workflow of ACP Pre-Post

The geometry of the tooling surfaces of a composite structure is the basis for analysis and production. Based on this geometry and a FE mesh, the boundary conditions and composite definitions are applied to the structure in the pre-processing stage as shown in Figure 12, Figure 13, and Figure 14. After a completed solution, the post-processing is used to evaluate the performance of the design and laminate. In the case of an insufficient design or material failure, the geometry or laminate has to be modified and the evaluation is repeated.

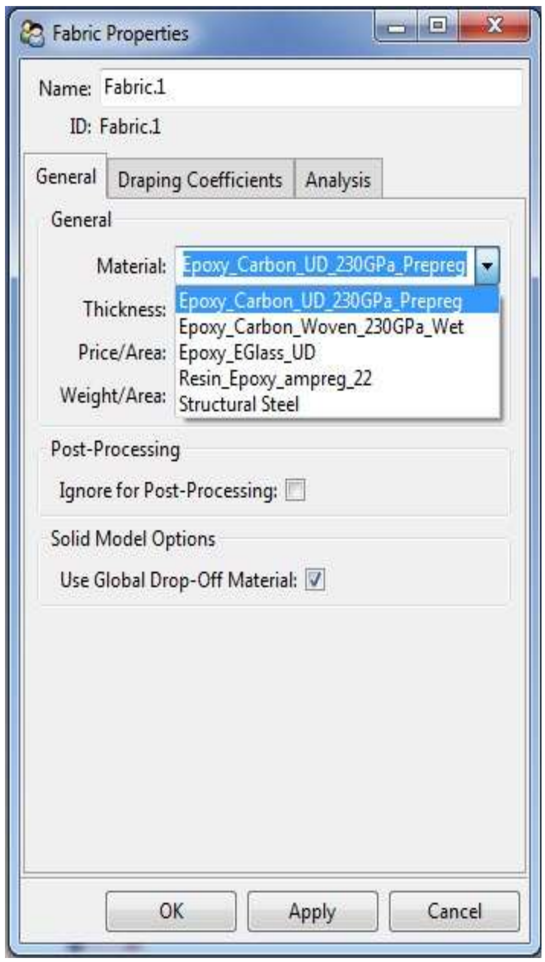

Figure 12: Fabric and core material selection

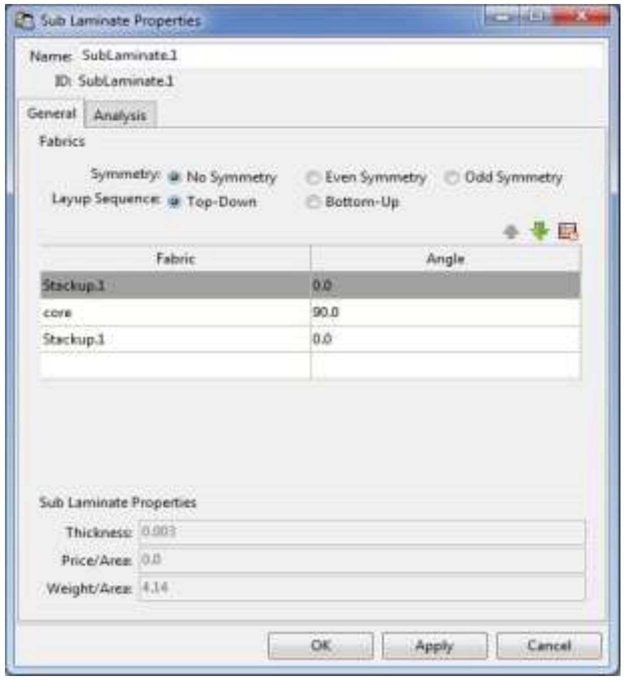

Figure 13: Sub Laminate Properties

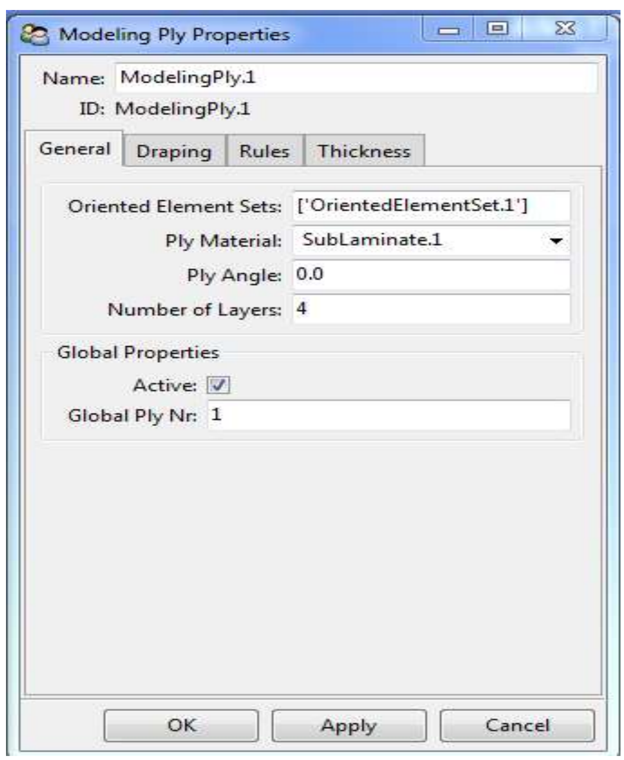

Figure 14: Modelling ply properties

ACP has a pre- and post-processing mode. In the pre-processing mode, all composite definitions can be created and are mapped to the geometry (FE mesh). These composite definitions are transferred to the FE model and the solver input file. In the post-processing mode, after a completed solution and the import of the result file(s), post-processing results (failure, safety, strains and stresses) can be evaluated and visualized.

3.4.5 Study Parameters

A parameter study is a systematic way to vary a number of model parameters and have the system automatically run one or several analyses for each combination of parameters. Author have classified some parameter to study which are:

i. Study the effect of filament winding angle on Von-Mises stress distribution
ii. Study the effect of number of ply on Von-Mises Stress Distribution
iii. Study the effect of different types of loading such as internal pressure, compressive buckling and combined loadings.
iv. Study the effect of different type of composite material on Von-Mises stress distribution.

Table 9: Project activities of final year project

Semester 1		
Required Time	**Activities**	**Remarks**
2 weeks	Start of FYP 1 I. Title proposal II. Title confirmation	Selection of the Title
4 weeks	Research and Detailed Studies I. Recent technologies II. Journal research III. Findings of the review	Submission of proposal
4 weeks	Design and Fundamental Knowledge I. Drill pipe II. Composite drill pipe (CDP)	
3 weeks	Pre-Design III. Mathematical modeling IV. Finite Element Analysis (FEA)	Submission of Interim Report
1 week	End of FYP 1 I. Discussion II. Conclusion III. Summarize project work	FYP 1 Oral Presentation

Table 10: Gantt chart and key milestone for FYP 1

No.	Detail/Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Preliminary Research Work														
3	Submission of Extended Proposal														
4	Proposal Defence														
5	Project work Continues														
6	Submission of Interim Draft Report														
7	Submission of Interim Report														

Milestone

Process

Table 11: Gantt chart and key milestone for FYP 2

No.	Detail/weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continues														
2	Submission of Progress Report														
3	Project Work Continues														
4	Pre-SEDEX														
5	Submission of Draft Final Report														
6	Submission of Dissertation (soft bound)														
7	Submission of Technical Paper														
8	Viva														
9	Submission of Project Dissertation (hard bound)														

Milestone   Process

CHAPTER 4

RESULTS AND DISCUSSIONS

In filament winding a number of carbon reinforcing strands are impregnated with resin and then applied under tension to a mandrel. Repeated passes establish a layered-construction until the desired wall-thickness is achieved. The angles at which the carbon fibers are oriented in reference to the axis of the mandrel may vary anywhere from 0 degree angle to 90 degree angle. Typical layers exhibit tensile and stiffness properties nearly 20 times higher in the direction of the fiber than in the direction perpendicular to the fibers. In this study, a few parameter has been chosen to be evaluated.

1. Mathematical modelling

Author has done a mathematical modelling of structural steel pipe using equation 1 and equation 2. The parameters that have been used is shown in Table 12.

Pressure, P	75.015 MPa
Radius, r	0.0508 m
Thickness, t	0.0127 m

Table 12: Value of parameters

The results of mathematical modelling is compared with the FEM analysis as shown in table 13. In finite element analysis, the hoop stress and axial stress is found taking from the normal stress respect to their axis. Based on the result in table 13, the variation of axial stress is quite large.

Types of stress	Analytical (MPa)	FEA (MPa)
Hoop stress	300.06	374.74
Axial stress	150.03	15.298

Table 13: Comparison of analytical and FEA results of hoop and axial stress.

2. Simulation of Isotropic Material

Isotropic material is a construction material, a profile, formed with a specific shape or cross section and certain standards of chemical composition and mechanical properties. Simulation of these material was done by applying internal pressure inside the pipe to identify the maximum Von-Mises stress occur when the loads were applied to it. The properties of the isotropic material were shown in table 14 where it was provided by ANSYS engineering data.

Materials	**Structural steel**	**Titanium**	**Aluminium**	**Stainless steel**
Density	7850 kg/m³	4620	2770	7750
Young's Modulus	2000 GPa	96 GPa	71 GPa	960 GPa
Poisson's Ratio	0.3	0.36	0.33	0.31
Bulk Modulus	166.67 GPa	114.29 GPa	69.608 GPa	169.3 GPa
Tensile Strength	250 MPa	930 MPa	280 MPa	207 MPa
Ultimate Strength	460 MPa	1070 MPa	310 MPa	586 MPa

Table 14: Material Properties of Isotropic Materials

From the data in Table 14, the weight of structural steel was the highest since it has a greater value of density. This can cause a limitation to the strength of the pipe as stated in the problem statement. From the result obtained, it can be observed that the structural steel pipe have a higher stresses compared to other materials as shown in Figure 15. While the titanium pipe has a lesser stresses at about 396 MPa. On the other hand, the maximum stresses occur on the structural steel, aluminium and stainless steel pipe exceeds the tensile strength as given in the Table14. This means that the failures have occurred on the pipes.

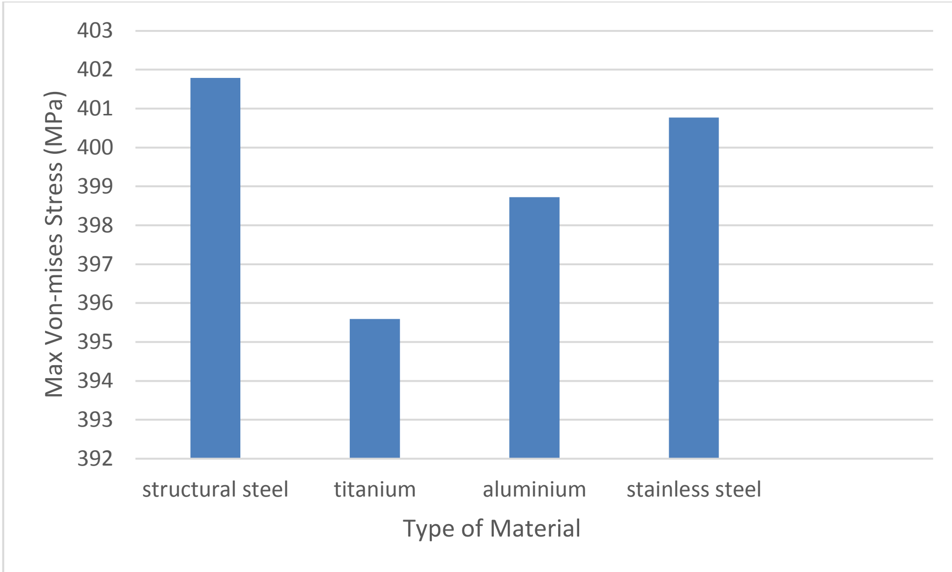

Figure 15: Maximum Von-Mises Stress of Isotropic Materials

3. Simulation of Orthotropic Material

An orthotropic material have a unique mechanical or thermal properties and independent in three mutually perpendicular directions. Examples of orthotropic materials are wood, many crystals, and rolled metals. However, in this part, author has decided to use carbon fiber and glass fiber as a materials for the pipe with 4 layer stacking. The materials properties were included in Table 15.

Material	**Carbon Fiber**	**Glass Fiber**
Density	1490 kg/m³	2000 kg/m³
Poisson's ratio	0.27	0.3
Young's modulus, E hoop	121 GPa	45 GPa
Young's modulus, E axial	8.6 GPa	10 GPa
Shear modulus	4700 MPa	5000 MPa
Tensile strength	2231 MPa	1100 MPa

Table 15: Materials Properties of Carbon Fiber and Glass Fiber

From the result of the simulations, the trends of both materials are quite different as shown in Figure 16. The highest stress of carbon fiber occurred on 65° winding angle while the highest stress of glass fiber occurred on 25°. The properties of both materials play an important part in determine their stress during the simulations process. In this case, the strength-to-weight ratio of carbon fiber was better compared to glass fiber. This because of lower density of the carbon fiber which contribute to their weight while their Young's modulus was higher. In other word, carbon fiber provide more strength with less weight compared to glass fiber.

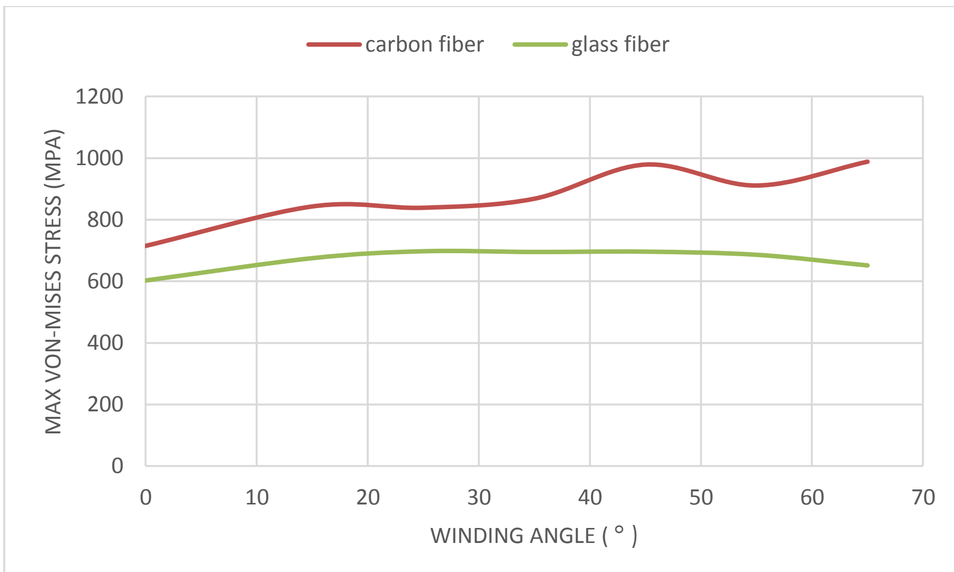

Figure 16: Results of Maximum Von-Mises Stress on Carbon Fiber and Glass Fiber

4. Simulations of Internal Pressure

Before doing this simulation, author has setup the internal pressure to 75.015 MPa. The data were collected based on different number of layer used for laminating fiber and different winding angles. The material that were used in this simulations was Carbon Fiber. Table 16 shows the stress data that have been collected. Based on the data, the Figure 17 have been plotted to show the stress of the pipe respect to angle of winding.

Angle (°)	0	15	25	35	45	55	65
Layer 1	2524.2	3273.2	3084.4	3110.6	3166.6	3123.6	3393.2
Layer 2	1299.3	1616.9	1550.1	1632.5	1749.1	1680	1823.3
Layer 3	901.88	1090.6	1067.4	1120.9	1238.4	1169.2	1273.4
Layer 4	714.93	842.96	838.83	867.96	978.94	910.89	988.18

Table 16: Results of Von-Mises Stress on Internal Pressure Loading.

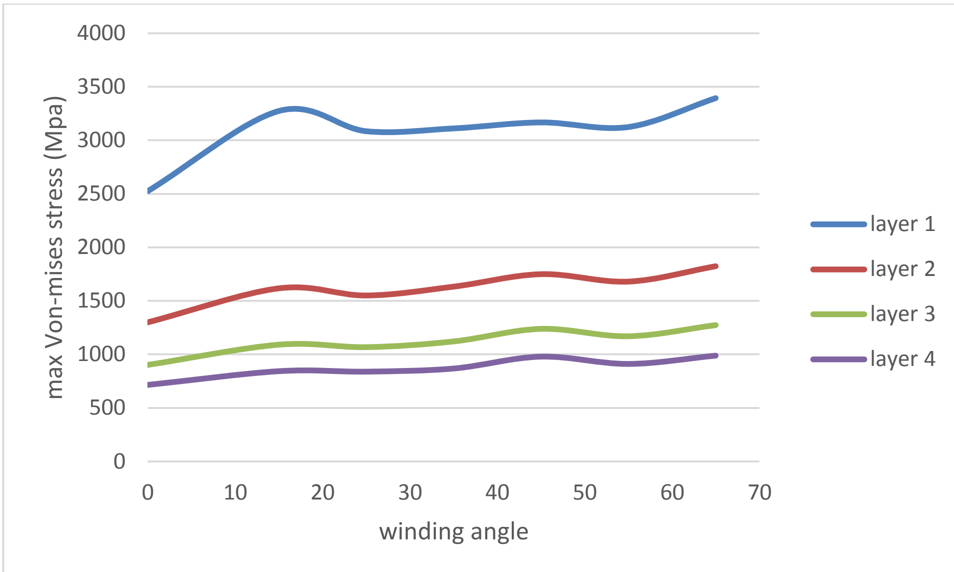

Figure 17: Internal pressure impact on different number of layers

Based on the graph plotted, layer 1 has the highest stress throughout all the winding angles compared to others. This happen because of the impact of pressure applied on the internal side. The more pressure on first layer happened due to lesser thickness it have. As compared to layer 4, the stresses occurred is lower than 1000 MPa with the same pressure applied.

5. Simulation of Compressive Buckling

As mentioned before, the drill pipe was experienced high tensile axial loads at the surface and high compression loads at the bottom. As it further compressed until exceeds the critical buckling loads, the buckling would occur and damage the structure. As part of that, the simulations of the force acting on the top surface of the pipe have been done to view the Von-Mises stress contribution along the pipe as shown in Table 17.

Angle (°)	**0**	**15**	**25**	**35**	**45**	**55**	**65**
Layer 1	153.58	247.59	267.36	253.29	233.8	227.77	197.61
Layer 2	81.436	125.72	138.15	133.93	136.13	129.54	108.25
Layer 3	60.631	85.92	95.243	93.363	98.982	93.085	76.823
Layer 4	50.483	66.311	73.763	72.684	79.031	73.774	60.306

Table 17: Results of Von-Mises Stress with Different of Layers

From the result obtained, the stresses of layer 1 is higher compared to layer 2, layer 3 and layer 4. The lower the surface area at the force applied, the higher the stress occurred on the pipe. The maximum stress of 25° winding angle is higher as compared to other angles in layer 1. This happened due to arrangement of laminating fabric or fiber configurations. As the angle increasing, the maximum stresses become lesser as shown in Figure 18.

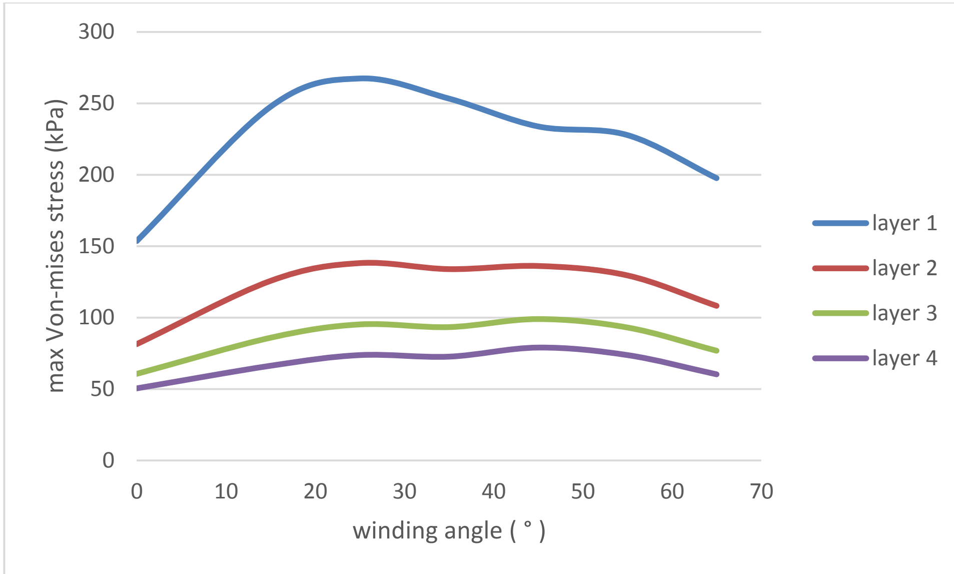

Figure 18: Maximum Von-Mises Stress against Winding Angle

In order to understand the buckling phenomena of the drill pipe, a simulation have been setup by using ANSYS linear buckling. The same parameter of different materials that have been used in this simulation was shown in Table 18.

Materials	**Structural steel**	**Carbon fiber**	**Glass fiber**
Outer diameter	0.127 m	0.127 m	0.127 m
Thickness	0.0127 m	0.0127 m	0.0127 m
Length	3 m	3 m	3 m
Number of layer	-	1	1
Winding angle	-	55°	55°
Force	100 N	100 N	100 N

Table 18: Simulation Parameters

The results of total deformation by linear buckling analysis were shown in Figure 19, Figure 20 and Figure 21.

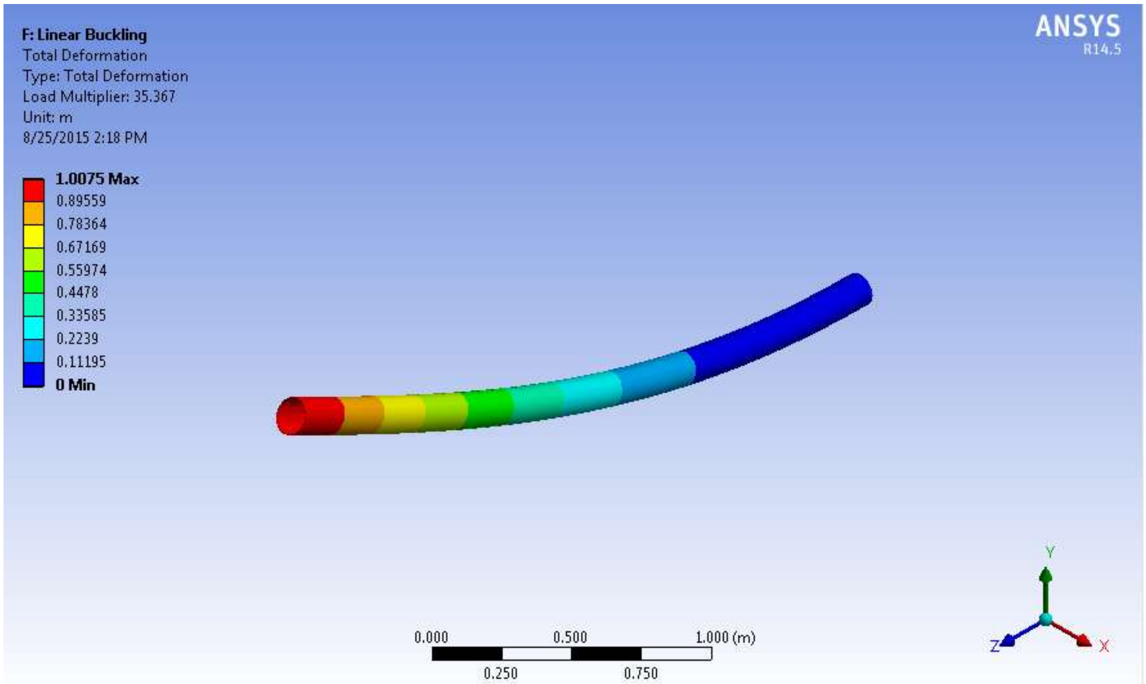

Figure 19: Total Deformation Contours of Structural Steel Materials

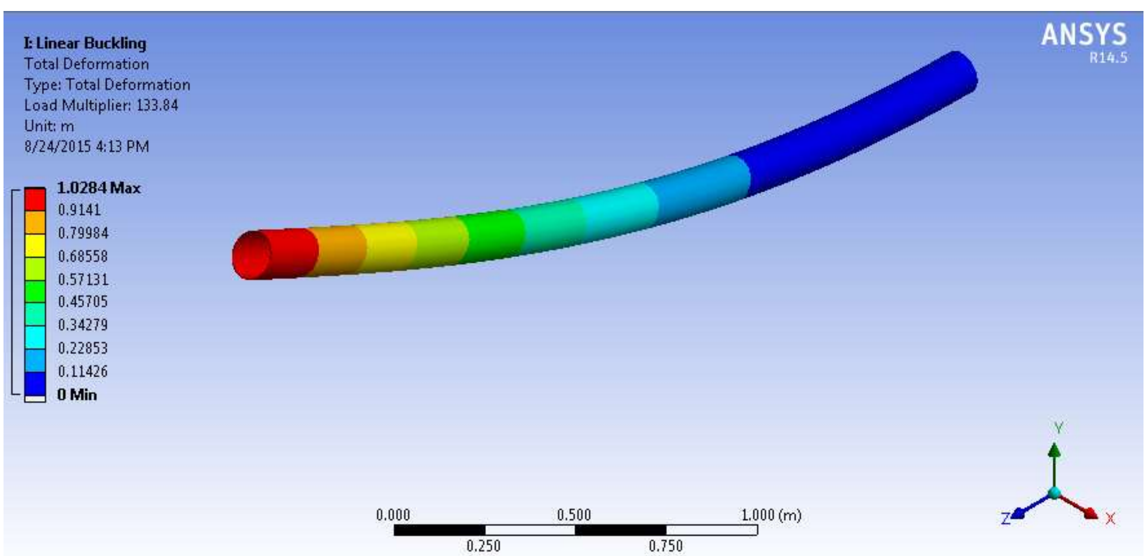

Figure 20: Total Deformations Contours of Carbon Fiber

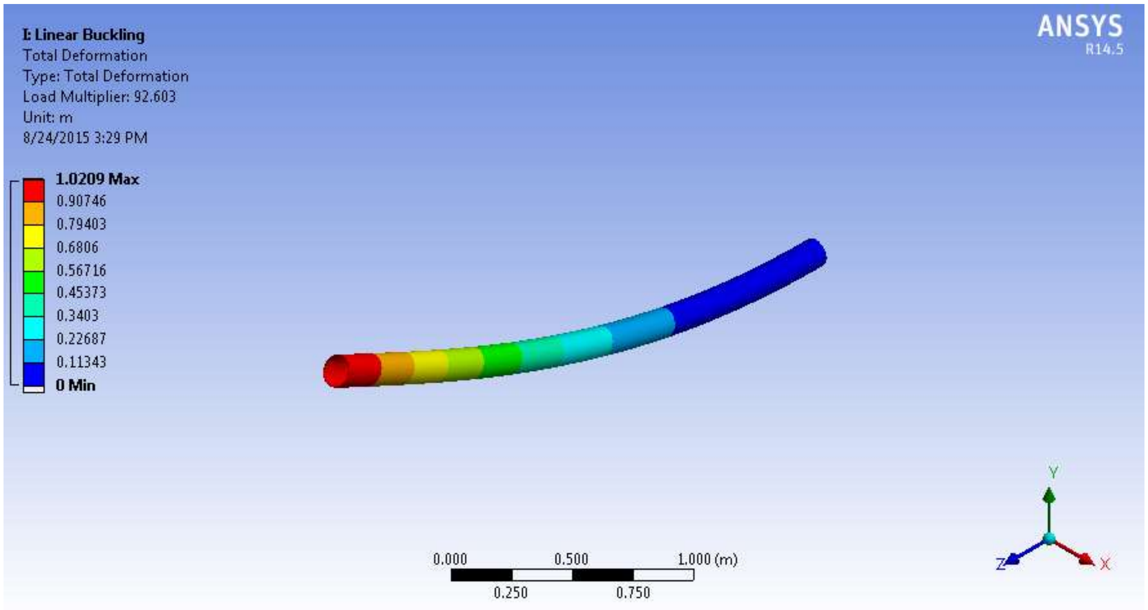

Figure 21: Total Deformations Contours of Glass Fiber

6. Simulations of Combined Loading

In this part, author has setup the pressure, force and fixed support in a pipe to analyze the stresses contribution on the pipe. The pressure used was 75.015 MPa and 100 N of force acted on top surface of pipe. Carbon fiber materials have been chosen for these simulations and the material properties were shown in Table 19.

Material	**Carbon Fiber**
Density	1490 kg/m³
Poisson's ratio	0.27
Young's modulus, E hoop	121 GPa
Young's modulus, E axial	8.6 GPa
Shear modulus	4700 MPa
Tensile strength	2231 MPa

Table 19: Material Properties of Carbon fiber

The variation of Von Mises stress with fiber orientation is shown in Figure 22. The orientation angles used for every layer are 0°, 15°, 25°, 35°, 45°, 55°, and 65°. Based on the results obtained, the layer 1 has higher stress compared to other layers. Since the thickness of layer 1 is lesser than other layers, the stress occurred on the pipe become high. This can be concluded that the area of pipe play an important role in determined the stress of the pipe.

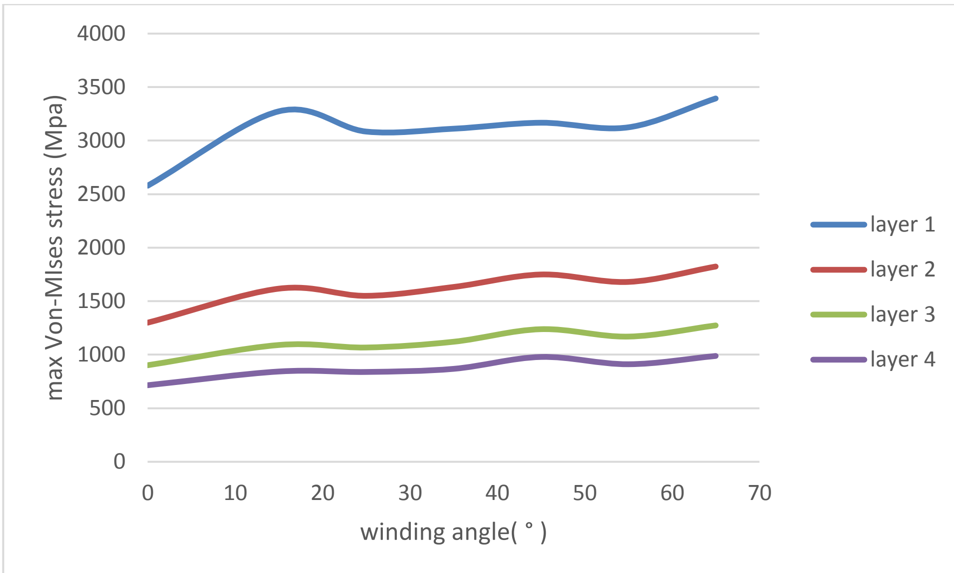

Figure 22: Maximum Von-Mises stress against winding angle

7. Simulation of stress on different no of layers

In this simulations, the angle of the layers have been set to 55° only. The layers also increase up to 7 layer in order to figure out the stress distribution on the pipe. Again, the Von Mises stress is checked for different number of plies. The material that have been selected was carbon fiber. The result of the simulations are shown in Figure 23.

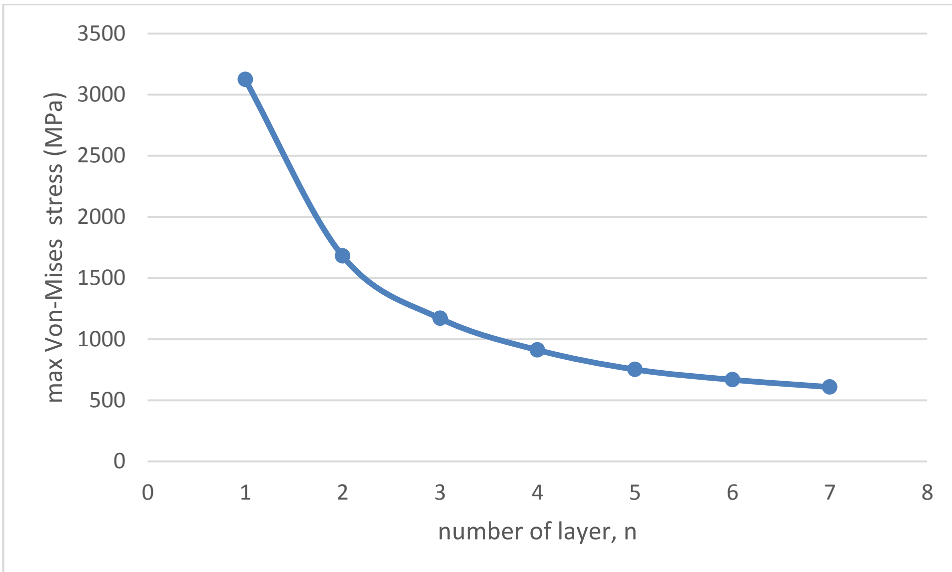

Figure 23: Maximum Von-Mises stress against number of layer

From the graph above, the maximum Von-Mises stress of the pipe decreased with increasing number of layers applied. This study supported the result of others simulations. The increasing number of layers has thicken the thickness of the pipes, so the loadings applied on the internal pipe were reduced its effect. In other words, the increasing number of layer of laminating fiber gave a better result of Von-Mises Stress.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In conclusion, this study has been focused on the development of drill pipe using composite material. In line of that, the mathematical modelling using hoop stress and axial stress has been done and compared to the finite element analysis results (refer Table 13). It was found that the different value between mathematical modelling and FEA analysis is quite small for hoop stress. From these results, it was confirmed that the method used in this study is generally valid in analyzing the performance of drill pipe.

This study also focused on analyzing the isotropic and orthotropic material regarding to the Von-Mises stress contribution. The isotropic material used in this simulation were structural steel, aluminium, titanium, and stainless steel while orthotropic materials used were carbon fiber and glass fiber. It was found that the stress of titanium was less as compared to others isotropic materials. On the other hand, the stress of carbon fiber was a little bit higher than the glass fiber. However, since the tensile strength of carbon fiber was also high, the failure would not occur unless the maximum stress exceeds the tensile strength.

Besides that, this study also focused on the effect of fabric laminating angle and number of ply assigned to Von-Misses stress distribution. In this case, author has setup the angle from 0° until 65°. Author also set the number ply from 1 until 7 in order to get a better view on the stress distribution. It was found that the maximum Von-Mises stress decrease when the number of ply and angle of winding increased. Hence, the stress concentration on the pipe became lesser when the as the number of ply and angle of winding increase.

Moreover, different type of loading also has been used in this study to analyze the effect of Von-Mises stress on the pipe. The loading used were internal pressure, compressive buckling and combined loadings. The result of these simulation show that the number of ply and angle of laminated fiber gave a positive effect on Von-Mises stress of the drill pipe.

Additionally, the study of stress distributions on 55° angle of winding with different number of ply has been done in order to analyze the Von-Mises stress distribution on the drill pipe. Based on the research paper, the angle of 55° was the optimum angle for filament winding. From the results obtained, the maximum Von-Mises stress were decreased as the number of ply increased.

It was highly recommended that the simulations of composite materials using ANSYS software to be applied in the industry as well as in the design analysis work as it could reduce a lot of money and man power by eliminate the experiment method. It also highly recommended for further study work on the filament winding parameters to be done to increase the knowledge of stress distribution on composite drill pipe.

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REFERENCES

1) Yong, T. K. (2010). Mechanical Properties of Filament Wound Composite Pipe for Well Completion Pup Joint Application.

2) Hareland, G., W.C. Lyons, D.D. Baldwin, G.M. Briggs, and R.K. Bratli, (1997), "Extended Reach in Composite Materials for Drill Pipe", SPE Paper no. 37646, SPE/IADC Drilling Conference, Amsterdam, The Netherlands, March 6, 1997.

3) S. Rawat, and H. Attia, "Wear mechanisms and tool life management of WC-Co drills during dry high speed drilling of woven carbon fiber composites," Wear, vol. 267, 2009,pp.1022-1030

5) Callister, W. D., & Rethwisch, D. G. (2007). Materials science and engineering: an introduction (Vol. 7, pp. 665-715). New York: Wiley.

7) Smith, J.E., R.B. Chandler, and P.L. Boster, (2001), "Titanium Drill Pipe for Ultra-Deep and Deep Directional Drilling", SPE Paper no. 67722, SPE/IADC Drilling Conference, Amsterdam, The Netherlands, February 24 – March 1, 2001.

8) Leslie, J. C., James, C. L. I., Heard, J., Truong, L. V., & Josephson, M. (2012). U.S. Patent No. 8,287,005. Washington, DC: U.S. Patent and Trademark Office.

9) API Specification 5D, Specification for drill pipe. 5th ed.; October 2001.

10) API Specification 7, Specification for rotary drill stem elements. 40th ed.; 2001.

11) API Recommended Practice RP 7G, Recommended practice for drill stem design & operating limits. 16th ed.; 1998

12) ISO 10407, Petroleum and natural gas industries – drilling and production equipment – drillstem design and operating limits. 1st ed.; 1993.

13) NORSOK M-702, Drill string components, Rev. 2; June 1999.

14) Macdonald, K. A., & Bjune, J. V. (2007). Failure analysis of drillstrings. Engineering Failure Analysis, 14(8), 1641-1666.

15) Roylance, D. (2001). Finite Element Analysis: An Introduction, Massachusetts Institute of Technology (MIT), Cambridge, MA

16) Antal, S., Nagy, T. and Boros, A. (2003). Improvement of Bonded Flexible Pipes According to API Standard 17K, OTC 15167.

17) Iqbal, M., & Zolkepeli, M. (2008). Failure analysis on the drill pipe due to the twist-off (Doctoral dissertation, Universiti Malaysia Pahang)

18) Tsukano, Y., & Ueno, M. (1991). Development of lightweight steel drillpipe with 165-ksi yield strength. IADC/SPE, 19960, 403-412.

19) Ansari, R., Alisafaei, F., & Ghaedi, P. (2010). Dynamic analysis of multi-layered filament-wound composite pipes subjected to cyclic internal pressure and cyclic temperature. Composite Structures, 92(5), 1100-1109.

20) Khulief, Y. A., & Al-Naser, H. (2005). Finite element dynamic analysis of drillstrings. Finite elements in analysis and design, 41(13), 1270-1288.

21) Khulief, Y. A., Al-Sulaiman, F. A., & Bashmal, S. (2007). Vibration analysis of drillstrings with self-excited stick–slip oscillations. Journal of sound and vibration, 299(3), 540-558.

22) Rahman, M. K., Hossain, M. M., & Rahman, S. S. (1999). Stress concentration incorporated fatigue analysis of die-marked drill pipes. International journal of Fatigue, 21(8), 799-811.

23) Gensmer, R. P. (1990). Field correlation between internal taper length and tube failures in 4.5-in., 16.60 E, IEU Drillpipe. SPE Drilling engineering, 5(01), 58-62.

24) Pearson, T. L. (1981, November). Tubular failure cost/frequency analysis. InProc. Tubular Goods Symp., Houston (USA): Exxon Co.

25) Chen, W. C. (1990). Drillstring fatigue performance. SPE drilling engineering, 5(02), 129-134.

26) Lu, S., Feng, Y., Luo, F., Qin, C., & Wang, X. (2005). Failure analysis of IEU drill pipe wash out. International journal of fatigue, 27(10), 1360-1365.

27) Moradi, S., & Ranjbar, K. (2009). Experimental and computational failure analysis of drillstrings. Engineering Failure Analysis, 16(3), 923-933.

28) Dao, N. H., & Sellami, H. (2012). Stress intensity factors and fatigue growth of a surface crack in a drill pipe during rotary drilling operation. Engineering Fracture Mechanics, 96, 626-640.

29) Shuan-lu, L., Ji, B. Y., Kang, Y. J., Zhang, H., Qin, T., Chi, J., ... & Yang, X. T. (2010). Cause analysis on drill pipe bending and fracture. Engineering Failure Analysis, 17(6), 1483-1489.

30) Mertiny, P., Ellyin, F., & Hothan, A. (2004). An experimental investigation on the effect of multi-angle filament winding on the strength of tubular composite structures. Composites science and technology, 64(1), 1-9.

31) Lea, R. H., & Yang, C. (1998). Improving the mechanical properties of composite pipe using multi-axial filament winding. In Proc. of NACE Annual Conference CORROSION (Vol. 98, p. 458).

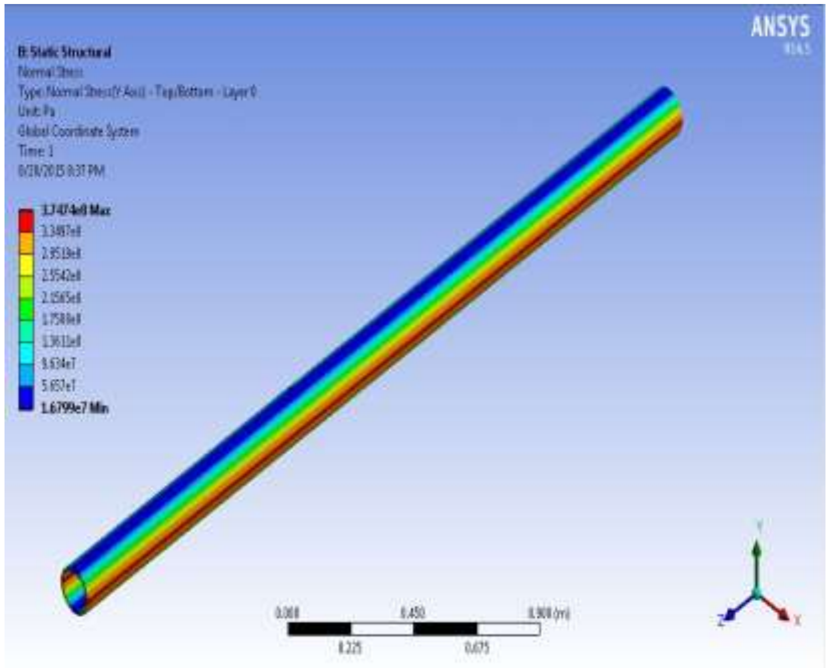
32) Jia, X., Chen, G., Yu, Y., Li, G., Zhu, J., Luo, X., ... & Hui, D. (2013). Effect of geometric factor, winding angle and pre-crack angle on quasi-static crushing behavior of filament wound CFRP cylinder. Composites Part B: Engineering, 45(1), 1336-1343.

33) Carpinteri, A., & Brighenti, R. (2000). A three-parameter model for fatigue behaviour of circumferential surface flaws in pipes. International Journal of Mechanical Sciences, 42(7), 1255-1269.

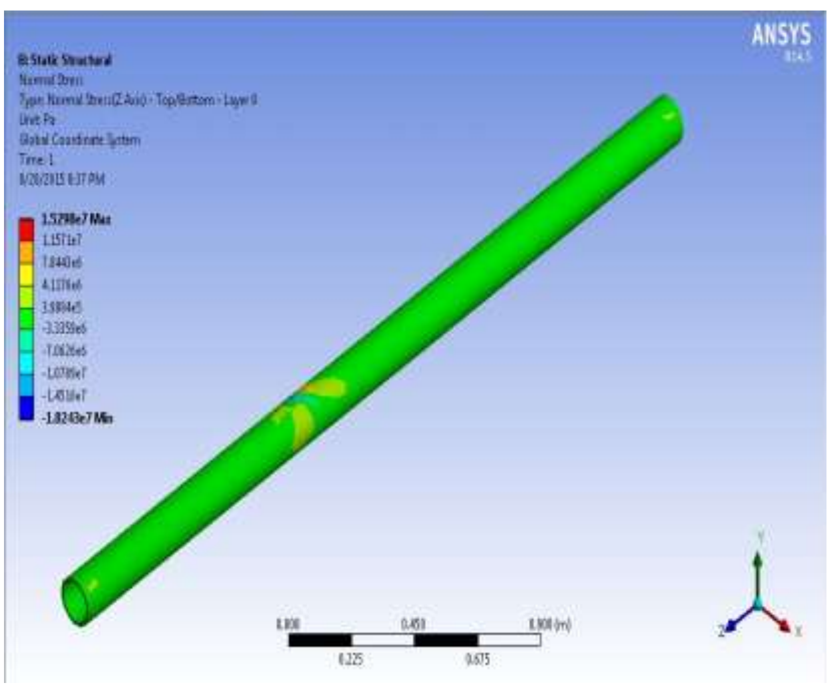
34) Carpinteri, A., & Brighenti, R. (1998). Circumferential surface flaws in pipes under cyclic axial loading. *Engineering Fracture Mechanics*, *60*(4), 383-396.

35) Carpinteri, A., Brighenti, R., & Spagnoli, A. (2000). Fatigue growth simulation of part-through flaws in thick-walled pipes under rotary bending. International Journal of Fatigue, 22(1), 1-9.

APPENDICES

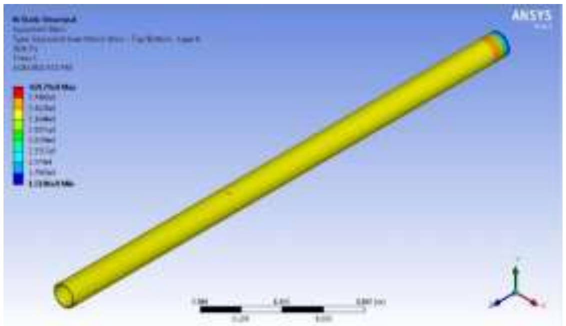


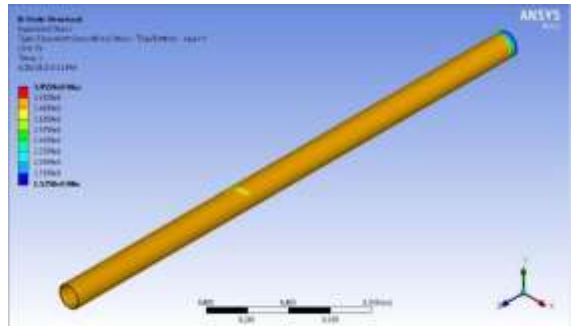
(a)



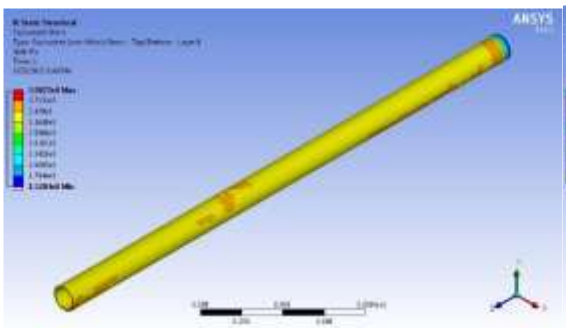
(b)

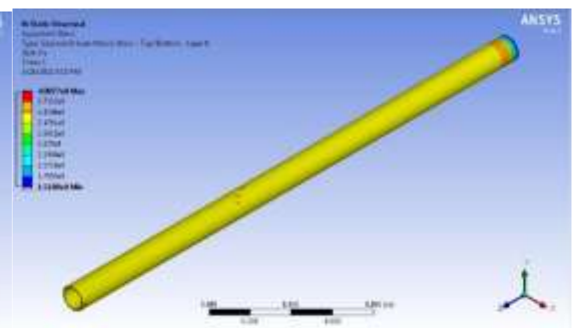
Appendix 1: Hoop stress (a) and Axial stress (b) of structural steel





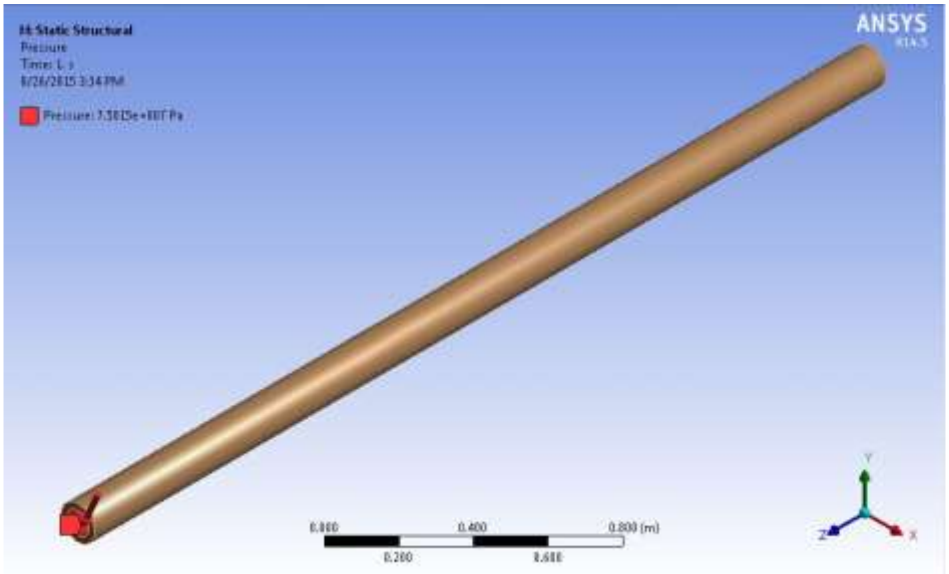
(d) (e)



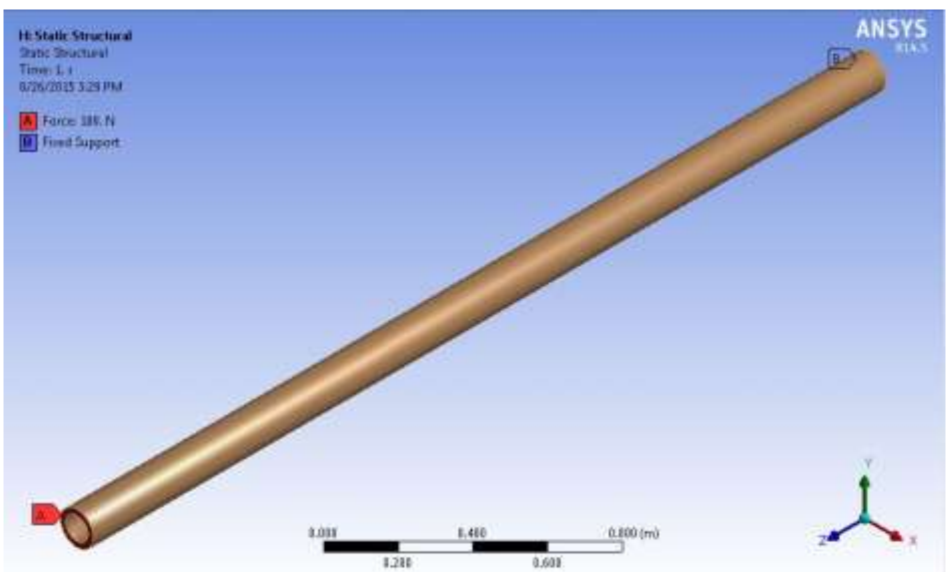


(f) (g)

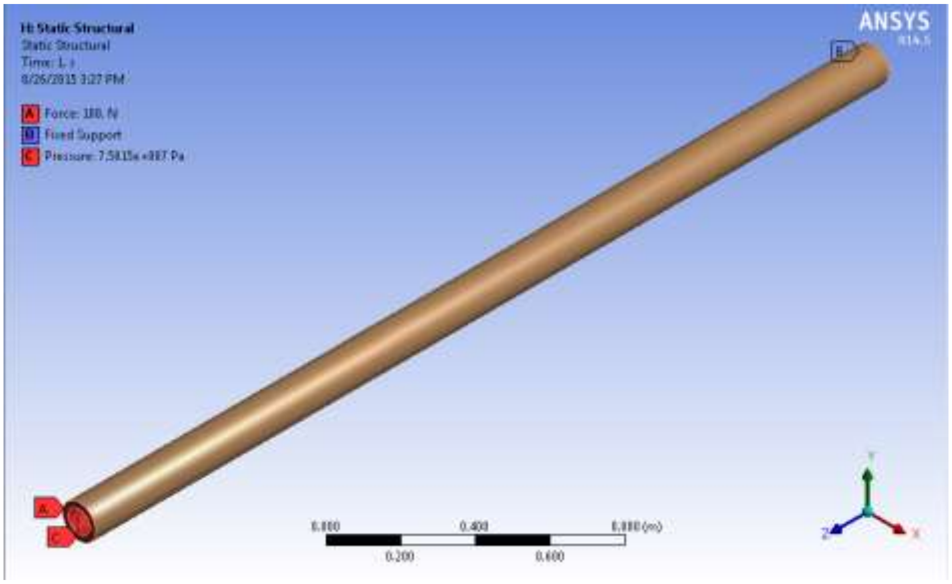
Appendix 2: FEA of isotropic materials. (a)structural steel, (b) titanium alloy, (c) aluminium, (d) stainless steel



(a) Pressure loading

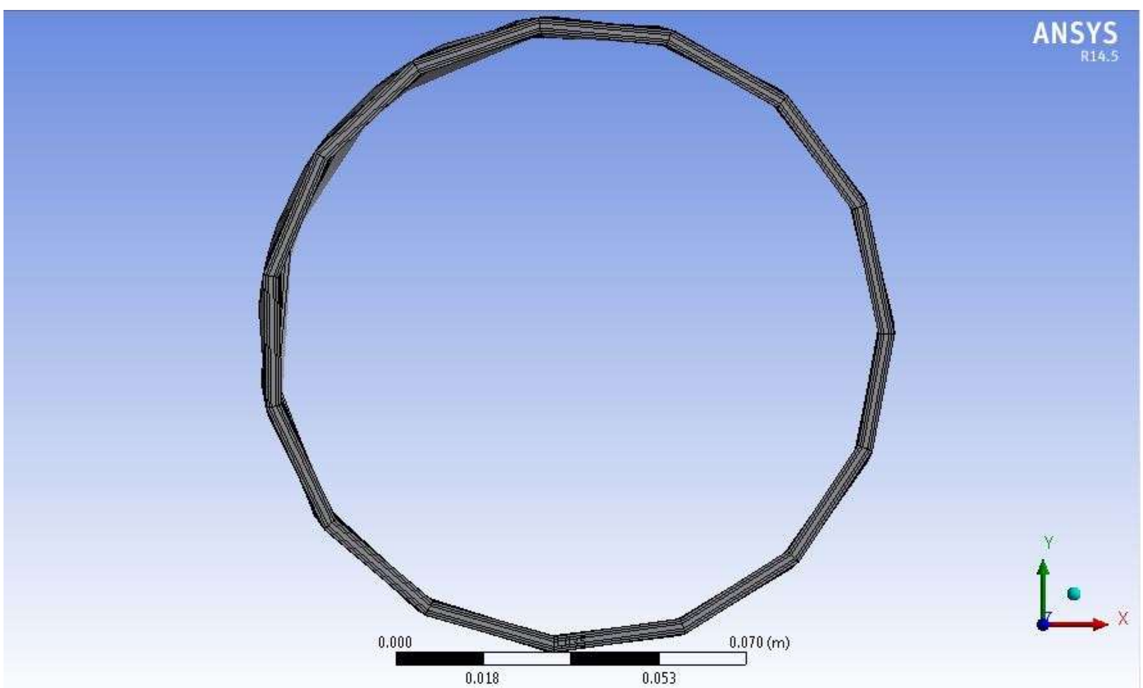


(b) Compressive buckling loadings

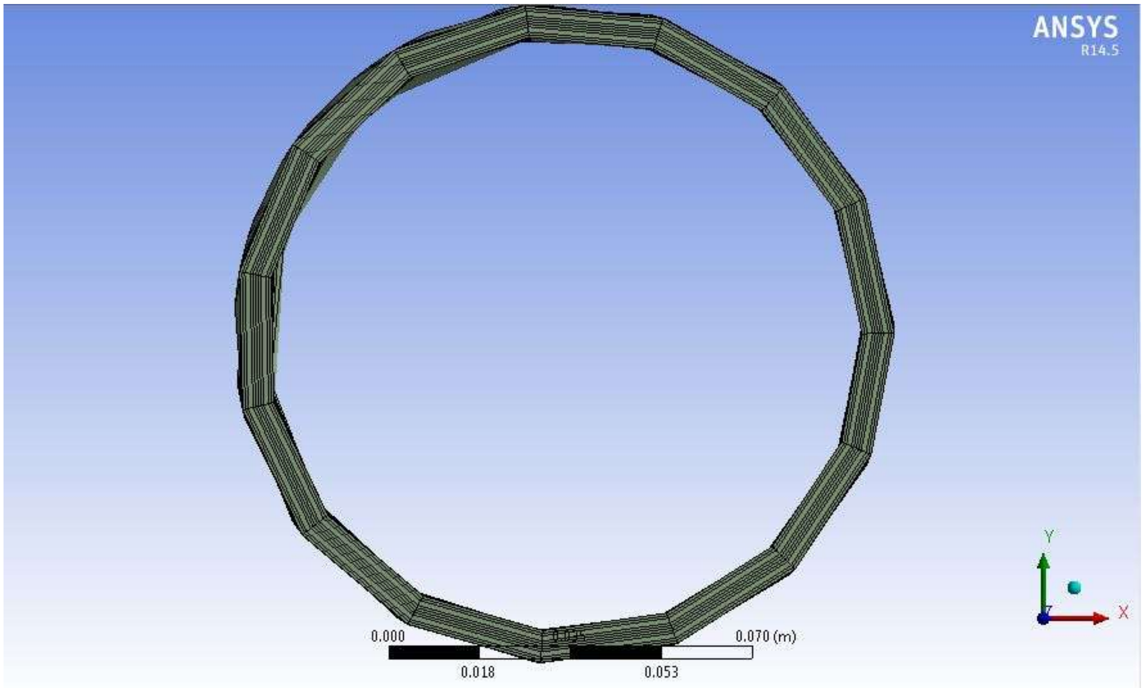


(c) Combined loading

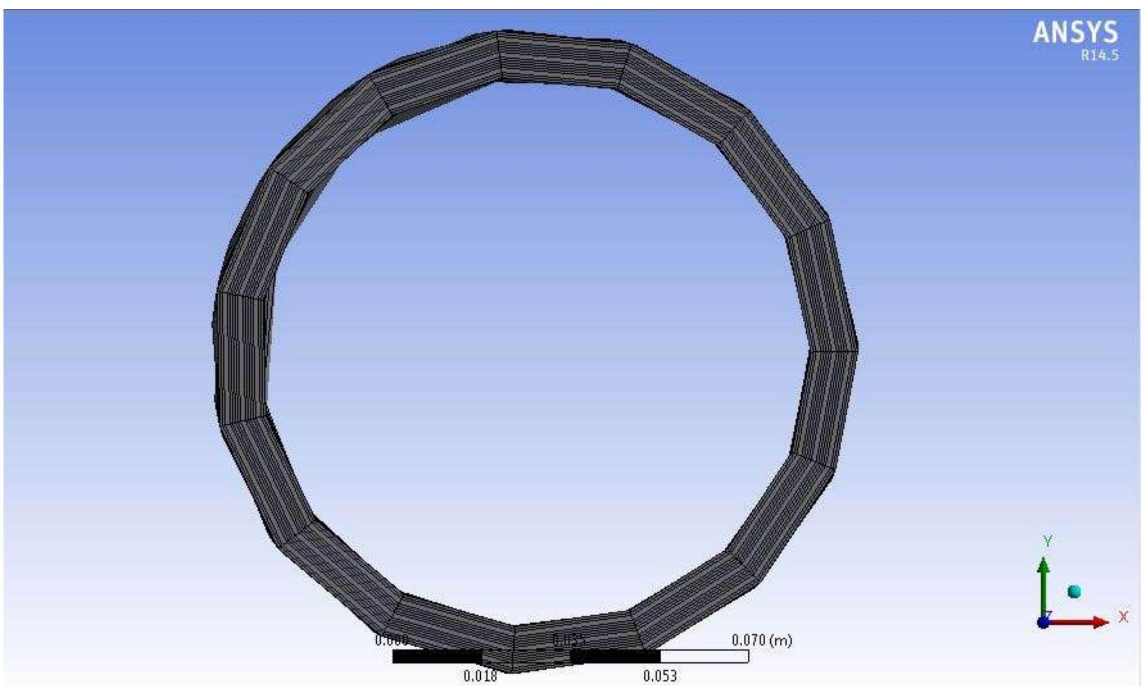
Appendix 3: Types of loadings applied on design model of drill pipe



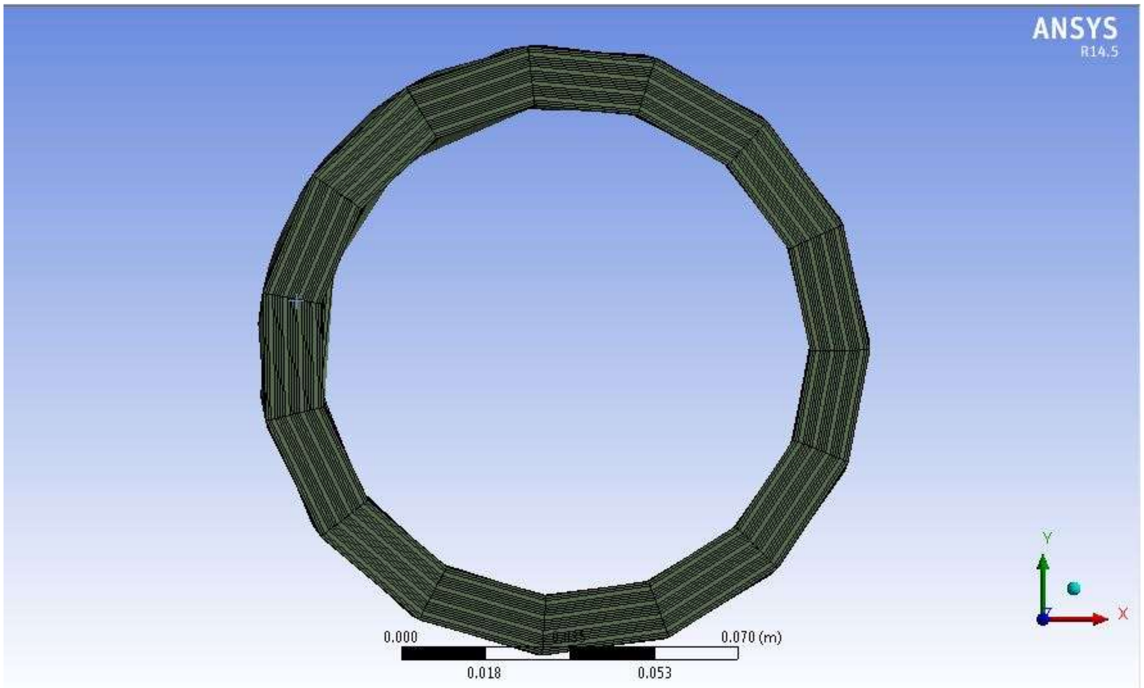
(a) Layer 1



(b) Layer 2



(c) Layer 3



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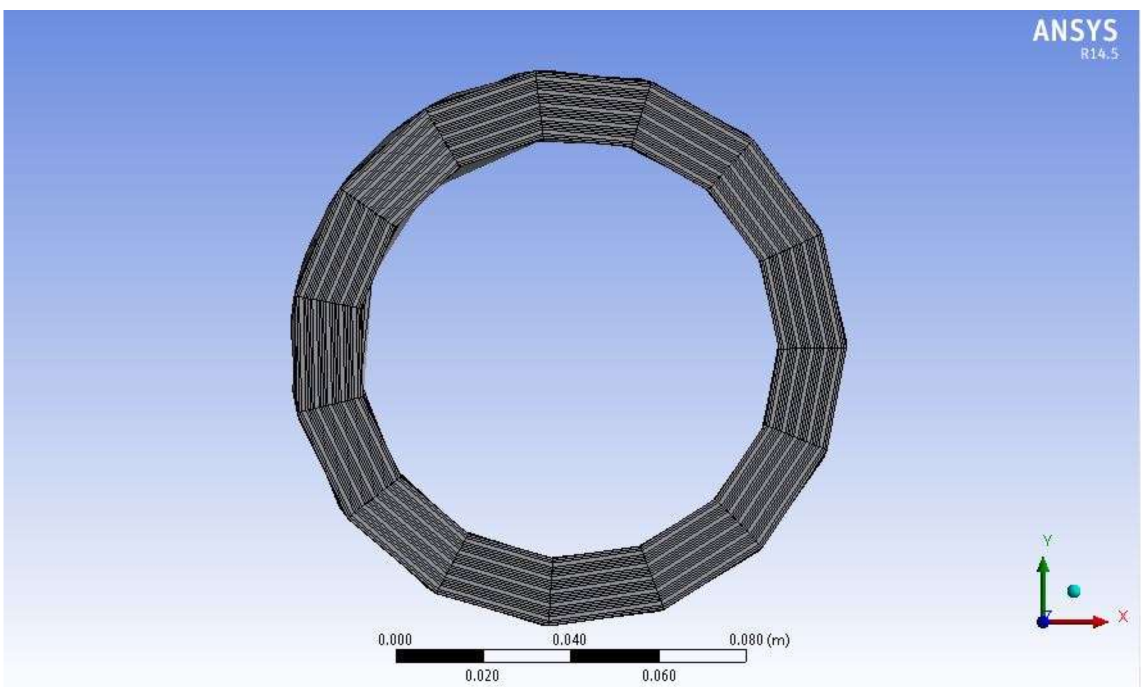
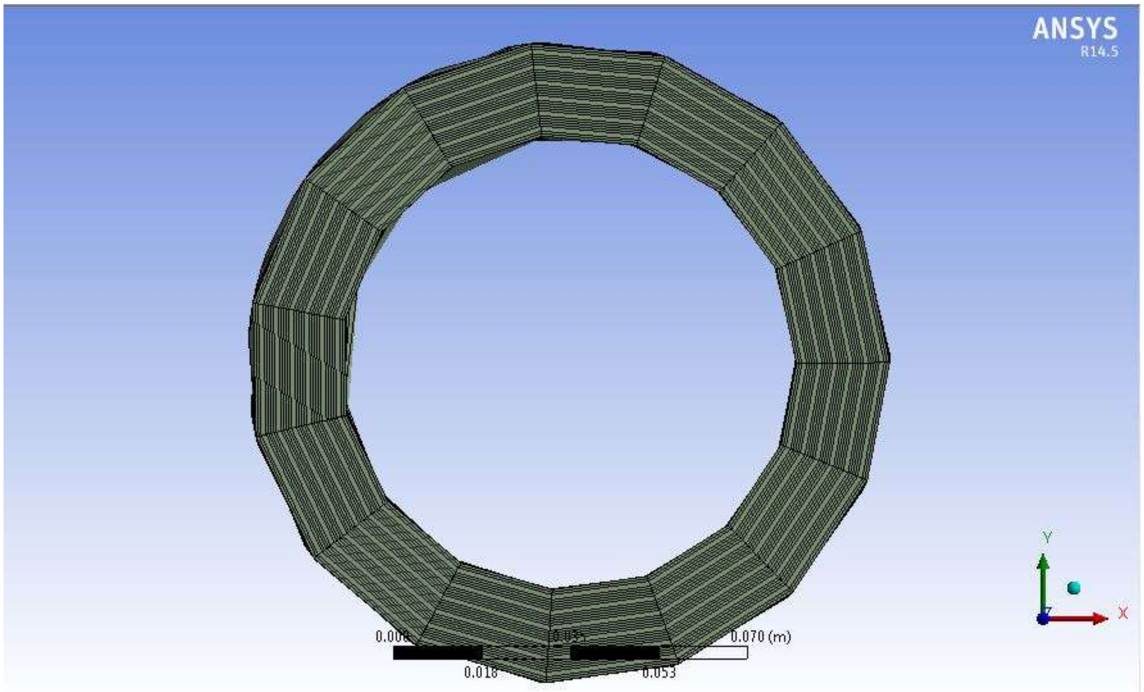
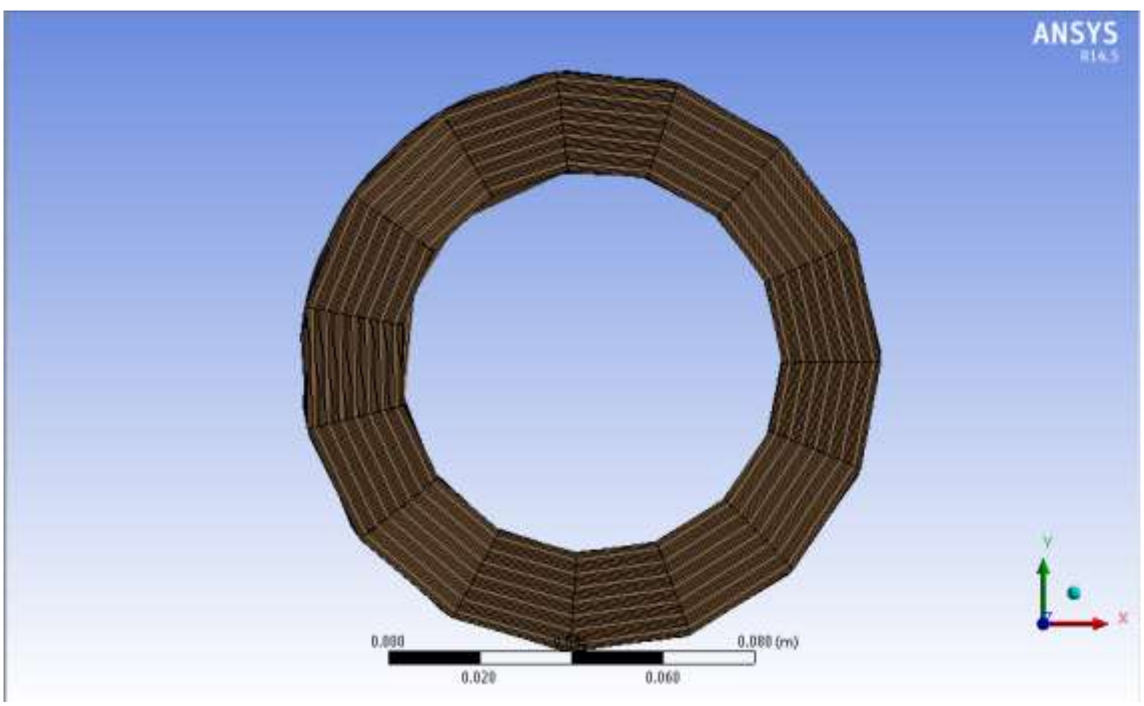


(e) Layer 5

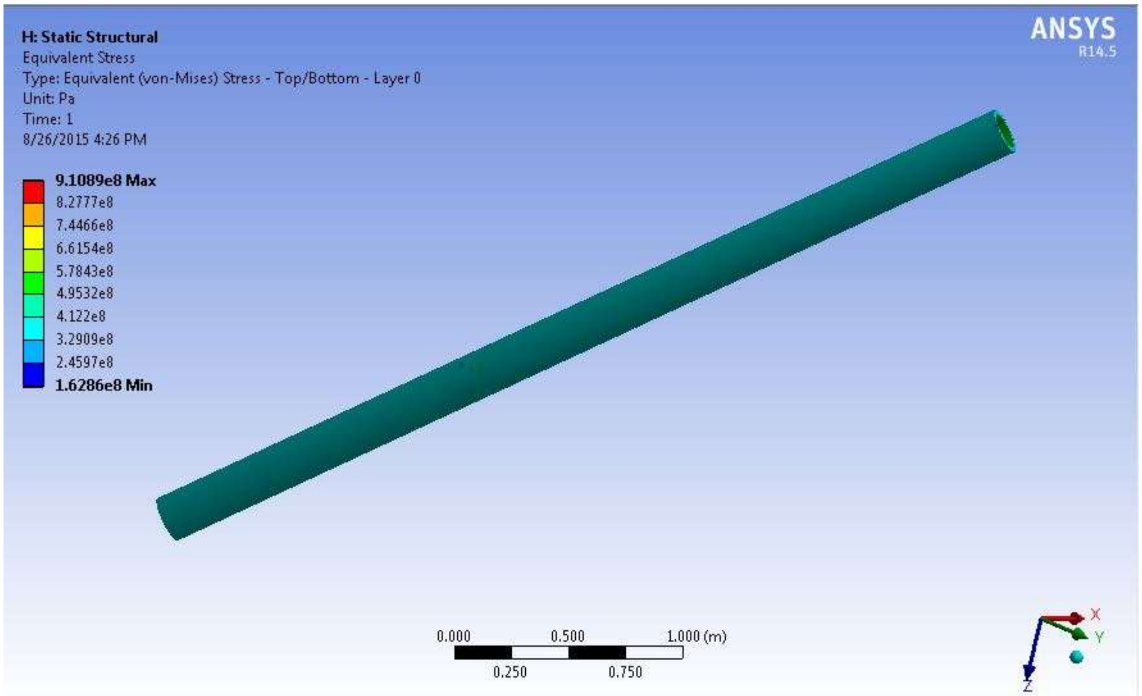


(f) Layer 6

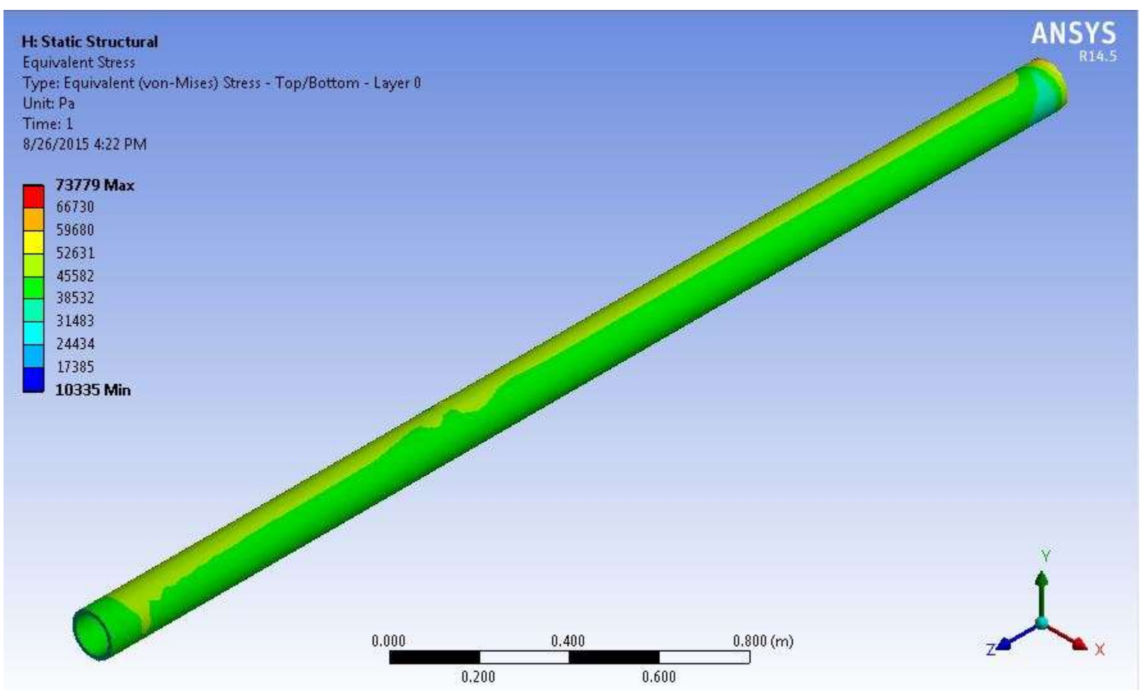


(g) Layer 7

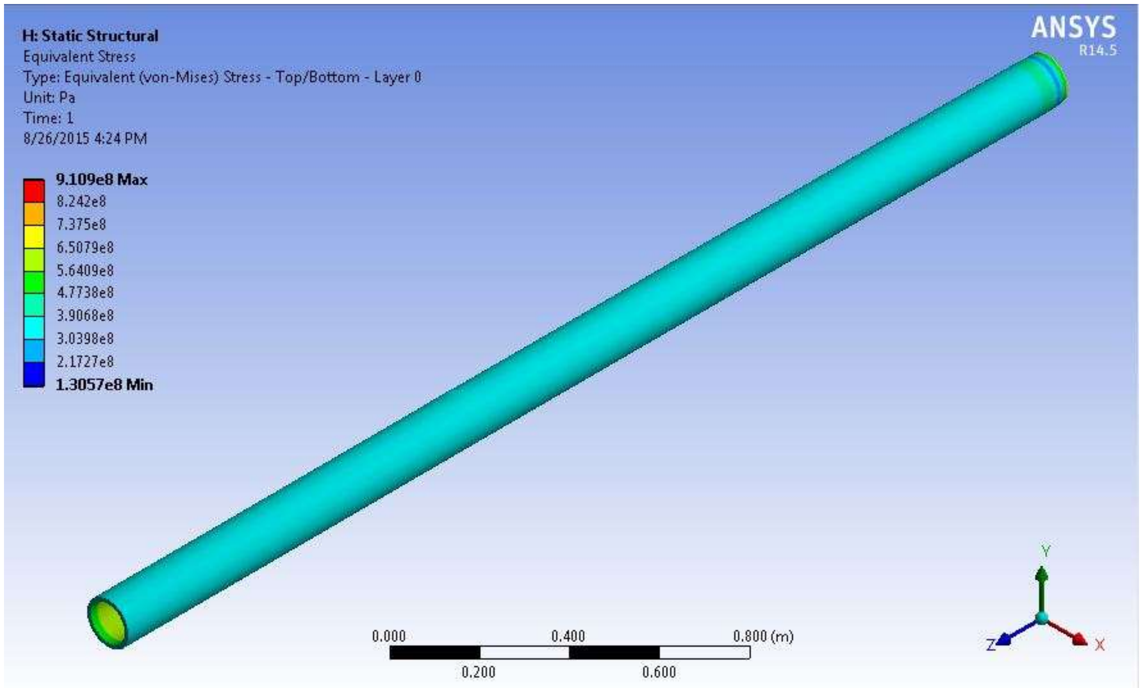
Appendix 4: Number of plies laminated on model of drill pipe



(a) Internal pressure

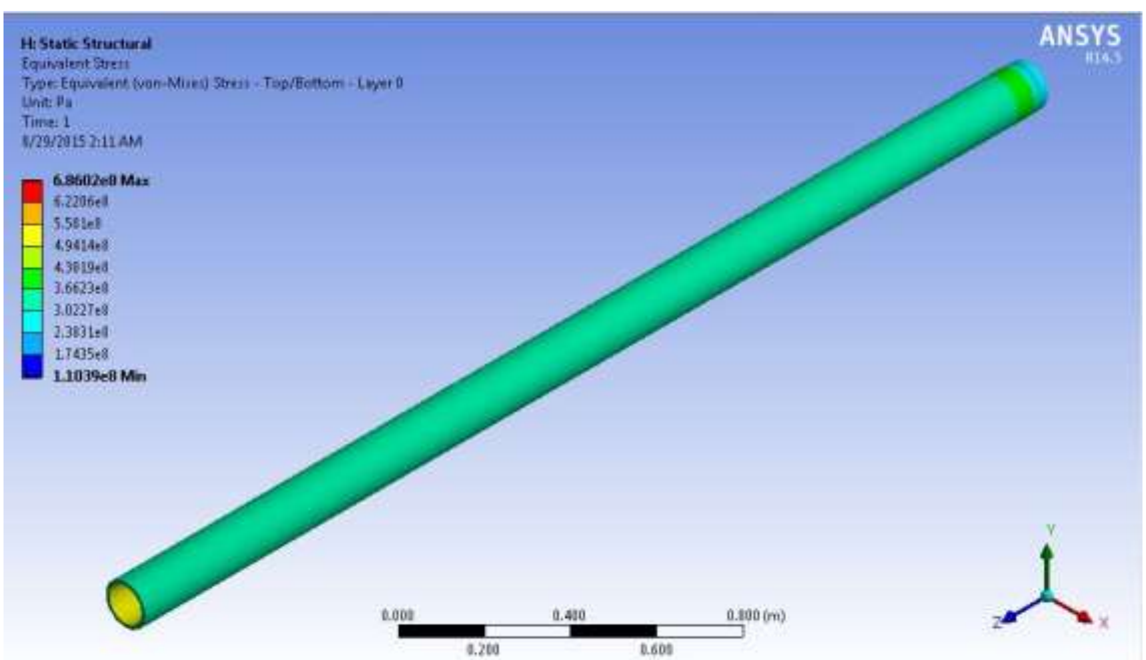


(b) Compressive buckling



(c) Combined loading

Appendix 5: carbon fiber contours result at 55° angle of laminating for 4 layers



Combined loading

Appendix 6: Glass fiber contour result at 55° angle of laminating for 4 layers