Suitability of Multi-Layer Polymeric Coating for Protection of Offshore Pipelines and Structures

Alonge David Shola[1], Tobinson A. Briggs[2]
[1]Offhore Technology Institute, University of Port Harcourt, Nigeria
[2]Department of Mechanical Engineering, University of Port Harcourt, Nigeria

Abstract– **Offshore pipelines or structures are subjected to accidental impact loads, especially impact loads from trawl gear, anchors from the vessel, which can destroy the pipeline or structure. Study shows that polymeric coating solutions, having the ability to absorb energy, which is the major focus of the investigation. This study set to model and simulate multi-layer polymeric coating for the protection of offshore steel X65 pipe. The polymer coating can be applied to the pipes to help in their protection against corrosion along with thermal insulation. Standard design codes, Coatings are conservatively assumed when determining the energy absorbed by structures during impact which is taken to be conservative. However, the energy absorbed can also be overly conservative in the protection of such structure. To this end, modelling and simulation of a common offshore steel pipe are performed, using a polymer composite coating. The primary purpose of this study is to investigate the deformation and protection of a typical polymeric coated pipe by energy absorbed procedure during impact on it. The result shows that pipe with the polymeric coating is more protected compared to the pipeline without composite coating.**

Keywords– **Impact Load, Polymeric Coating, Deformation Analysis and Steel X65 Pipe**

I. INTRODUCTION

Coating systems for offshore risers and flowlines coated externally ensure corrosion protection, insulation ability, which have to be efficient all through the design life. At the same time, it is in-service, usually 25 years. N. Bouchonneau et al. [10], in place of that, the long-term thermal insulation behaviour of the materials cannot be easily predicted due to the effects of the three factors hydrostatic pressure. The thermal gradient between external seawater, internal effluents, and the absorption of water of constitutive materials and in areas susceptible to trawl and drop object there's need for maximum protection. Polymeric coatings are used widely in automobiles, buildings, bridges, and electronic equipment, also in the sector of the oil and gas for functional and corrosion protection purposes. Although there have been significant improvements in terms of coatings technology, there is still a problem existing in the long-term performance regarding polymeric coatings, especially when exposed to harsh environments like temperature, humidity, and other conditions that are aggressive.

As offshore structures and pipelines are subjected to impact loads varying from dropped objects, anchors, and trawl gears. There is a need for optimum protection against corrosion as the structures are exposed to seawater and highly variable condition in addition to other external impacts that can last through almost the design life of the equipment and structures. Organic coatings are usually applied on the surface of the coatings of the metal; we can have several layers on its example, 3-layer Polypropylene (3-LPP) and could be up to 5-Layer Polypropylene. The more the layer, the more expensive it is going to be. Due to this problem, we need to find a solution via modelling that will give optimum polymeric coating combination to provide optimum reliability and protection. This project work considers a model for indentation/impact load that on a major class of steel pipe used offshore, which is X65. We shall consider composite coating to be applied on a pipe, modelling and simulating it to test for energy absorption (Toughness).

This study/research work aims to compare the effect of impact load (indenter) on both pipeline-with-composite material layers and a bare pipeline. This task helps to determine the energy absorption and the stress distribution on both pipelines. The objectives include:

a) Consideration of a combination of polymer coating that is suitable for metal coating on pipelines.
b) Indentation modelling and simulation on offshore steel pipe for both uncovered and covered multiple layer polymeric coating.
c) Comparison of the impact on the coated pipeline, and the uncoated pipeline, in the same impact conditions.

From this research work, a better form of protection of structures exposed to impact load is determined to enable construction companies to make the right decision in protection selection. Offshore pipelines that are laid in the areas where activities like trawling and fishing gear, drop object occurs regularly can be adequately protected from such impacts to help elongate the life span of the pipeline compared to a bare pipe not protected.

The scope of the study covers only for Steel material used predominately offshore and mainly to the X65 steel pipe. The research carried out is limited to modelling and simulation of a particular polymer composite. Cost optimization by varying the thickness of different polymer material is not captured in this study due to time constraints.

The reviewed works have been based on coating of pipe system essentially for corrosion protection, and polymeric coating has helped in this regard and also for protection against trawl gears, fishing activities, anchors, or accidental impact loads that can damage the pipeline or structure. Past works experimented on the multi-layer coating. However, it did not perform a simulation to be an ability to test for the impact of using simulation. This work will focus on modelling and simulation for energy absorption for the analysis of polymeric coating to give suitable protection against corrosion and impacts loads for offshore pipelines and structure. Studies carried out experimentally are limited. However, modelling and simulation make it simpler such that the parameters can be worked upon by varying them to get a better result rather than experimenting again and again.

II. MATERIALS AND METHODS

The material used in the simulation of the model has its distinctive properties, which are stated here. It's simply a model for the analysis of the behaviour of the pipe when subjected to impact load. The materials include:

A) Steel Pipe X65

The steel pipe X65 is a common grade of pipe used in the oil and gas industry with various sizes and types, which most are seamless types having a low cost, high strength, and ductility. The Mechanical Properties of the pipe to be indented is important in this study to determine the suitability of the coated pipe compared to the uncoated pipe. Typically for X65 pipe.

B) Pipe Dimensions

Pipe outer Diameter= 609.6mm
Pipe inner Diameter=17.5 mm
Pipe thickness= 574.6 mm
Pipe length= 1m

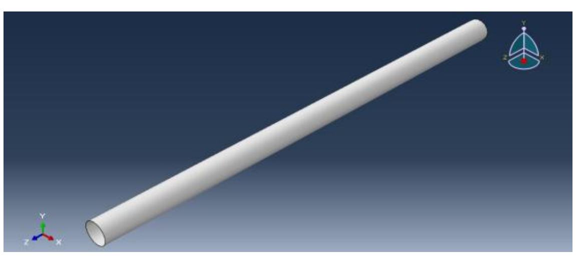


Fig. 1: The figure represents the 3D model view of the pipeline, modelled with Abaqus

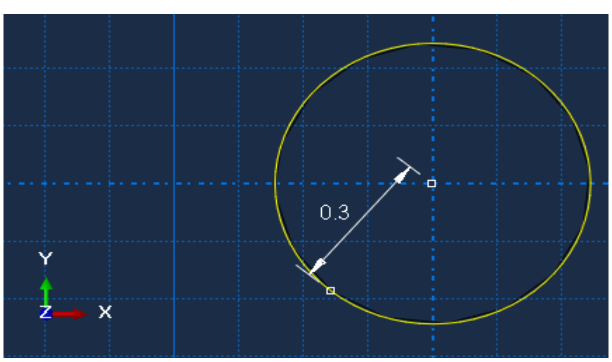


Fig. 2: The figure represents the plan view of the pipeline

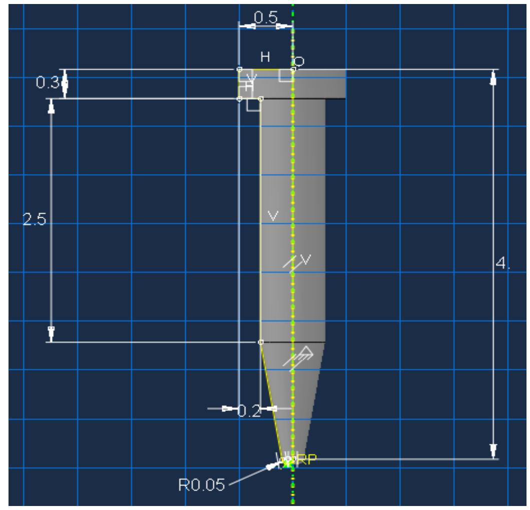


Fig. 3: Front view of indenter (All Dimensions in Centimeters)

1) Coating Materials

For the protection of the pipe against impact loading, a composite was used. Polymers are used for several purposes packaging, textile, buildings, etc. having various densities and strength capabilities.

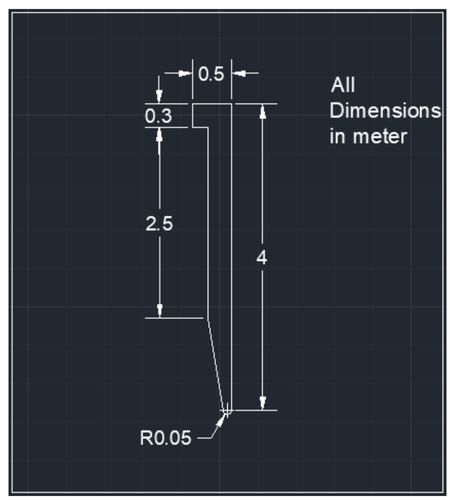


Fig. 4: The sketch represents the dimension of the Indenter, and it was revolved to 360 degrees to form the indenter shape (All Dimensions in Centimeters)

2) High-Density Polyethylene (HDPE)

This polymer belongs to the polyolefins family. They are produced cheap, they also have easy access to their monomers like ethylene and propylene, combining the monomers gives you Polyethylene and Polypropylene. Other groups of the family are medium density polyethene (MDPE) and Low-density polyethene (LDPE).

The advantage of the HDPE over others is that it has superior impacts strength, but at low temperature as most oil and gas pipes are in cold water region offshore, good chemical resistance, excellent stretching capacity, low weight, excellent mechanical strength like tensile and stiffness.

Table I: X65 Pipe Properties (Source: America Petroleum Institute (API) 2004; specification 5L-X65-pipe)

Mechanical Properties			
Pipe Grade Pipe body of seamless and Welded Pipes			**Welded seam Pipes**
	Yield Strength	**Tensile Strength**	**Tensile Strength**
API 5L X65 PSL1 pipe	Mpa (psi)	Mpa (psi)	Mpa (psi)
	minimum	minimum	535 (77600)
	450 (65300)	535 (77600)	

(Source: America Petroleum Institute (API) 2004; specification 5L-X65-pipe)

3) Rubber Coating

Rubber as protection against wear gives optimal protection for the pipe. It has high strength and elasticity, good resistance against abrasion. The advantages are numerous like noise protection, higher lifetime, vibration protection against the impact load to dampen it.

4) Indenter

This model is simply selected for the test and study of impact load on the pipe model itself. It has a radius of 10mm, which will form the indentation on the modelled pipe with a polymer coating on it and compared with an indentation on the bare pipe. Fig. 4 shows the dimension of the indenter used.

5) Methodology

Finite Element Analysis (FEA)

The modelled pipe was subjected to impact loading. The key parameters are the velocity of the indenter and the mass. The analysis was carried out, and it is of crucial value to take into consideration that the shell element size compared to its thickness would not be small.

Dynamic Equilibrium

According to SIMULIA [13] equation of motion for multi degrees of freedom is expressed below as:

$$[P_{ext}(t)] = [P_{ine}(t)] + [P_{dmp}(t)] + [P_{int}(t)] \quad (1)$$

The vector force of inertia can be expressed by mass matrix and the nodal point accelerations.

$$[P_{ine}(t)] = \{M\}[\ddot{D}(t)] \quad (2)$$

The energy dissipation in the system represented by a damping force vector may be expressed by the damping matrix and the nodal point velocities:

$$\{P_{dmp}(t)\} = [C]\{\dot{D}(t)\} \quad (3)$$

Also, the internal force vector can be expressed by the stiffness matrix and the nodal point displacements.

$$\{P_{int}(t)\} = [K]\{D(t)\} \quad (4)$$

Equation (1) which is the equation of motion, may now be written as:

$$[Pext(t)] = [M]\{\ddot{D}(t) + [C]\{\dot{D}(t)\} + [K]\{D(t)\} \quad (5)$$

Using an explicit method to solve the equation of motion above by central differencing. To make the work less tedious, the equation shall be derived from a single degree of freedom. From Taylor's series the two displacements D_{n+1} and D_{n-1} about the time t_n will give:

$$D_{n+1} = D_n + \Delta t\, \dot{D}_n + \frac{\Delta t^2}{2}\ddot{D}_n + \frac{\Delta t^3}{6}\dddot{D}_n + \ldots.. \quad (6)$$

$$D_{n-1} = D_n - \Delta t\, \dot{D}_n - \frac{\Delta t^2}{2}\ddot{D}_n - \frac{\Delta t^3}{6}\dddot{D}_n - \ldots.. \quad (7)$$

Subtracting Eq. (7) from (6) and ignoring other higher-order terms, approximately equation becomes

$$\dot{D}n = \frac{D_{n+1} - D_{n-1}}{2\Delta t} \quad (8)$$

Also, for acceleration adding Eq. (7) and (6) approximately will give:

$$\ddot{D}_n = \frac{D_{n+1} - 2D_n + D_{n-1}}{\Delta t^2} \quad (9)$$

Substituting Equations (8) and (9) into the motion equation and collecting like terms having $Dn+1$ on the left-hand side gives:

For a multi-degree of freedom, it becomes:

$$\left(\frac{1}{\Delta t^2}[M] + \frac{1}{2\Delta t}[C]\right)\{D\}_{n+1} = \{R_{ext}\}_n - \left(\frac{1}{\Delta t^2}[M] + \frac{1}{2\Delta t}[C]\right)\{D\}_{n-1} - \left([k] - \frac{1}{\Delta t^2}[M]\right)D_n \quad (10)$$

A method that can produce solution is the mass matrix because in equation (9) the effective stiffness has to be factorized to obtain displacement except the mass and damping stresses are diagonal. This method is done utilizing the approximations above with the velocity lagging half a step. Using central differencing, the equation of motion becomes:

$$m\ddot{D}_n + c\dot{D}_{n-1/2} + K_{Dn} = P_n \quad (11)$$

Therefore, for a multi-degree of freedom

$$\frac{1}{\Delta t^2}[M]\{D\}_{n+1} = \{R^{ext}\}_n - [K]\{D\}_n + \frac{1}{\Delta t^2}[M](\{D\}_n + \Delta t\{D\}_{n-1/2}) - [C]\{D\}_{n-1/2} \quad (12)$$

The first step is when n=0 and requires some calculations to be done to calculate displacement for n=1, while the velocity for n=-1/2 can be computed using a backward difference approximation.

$$\{\dot{D}\}_{-1/2} = \{D\}_0 - \frac{\Delta t}{2}\{\dot{D}\}_0 \quad (13)$$

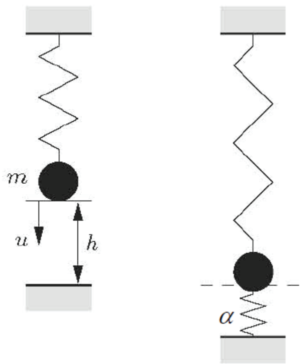


Fig. 5: Penalty Method (Source: K. M. Mathisen [7]

Solving this equation of motion at t_0, the approximate acceleration becomes:

$$\{\ddot{D}\}_0 = [M]^{-1}(R^{ext}{}_{(t)0} - [K]\{D\}_0 - [C]\{\dot{D}\}_0) \quad (14)$$

The two methods of central difference suggested above can only assure us of the first-order accuracy. The matrix of the mass should be diagonal (combined masses must be utilized) to make the work quite easy.

The explicit method of integration is quite stable; therefore, when the stabilized time Δt_s is greater than the increase in time Δt, it means that the solution to the equation is constrained.

$$\Delta ts \leq \frac{2}{\omega_{max}}(\sqrt{1} - \xi^2 - \xi) \quad (15)$$

Where,
ω_{max} is Highest natural frequency
ξ is Damping Ratio

$$\Delta t_s \leq \frac{2}{\omega max} = \frac{Uc}{Cd} \quad (16)$$

where, Le is Characteristic length, C_d= Dilatation wave speed

$$\text{Also, } C_d = \sqrt{\frac{E}{\rho}} \quad (17)$$

E is Modulus of elasticity and *P* is Density.

Many sections for the following equations above is as a study from (K. M. Mathisen 2011).

6) Penalty Method for Contact

K. M. Mathisen [7] provide one of the common methods for contact in FEM software like Abaqus is a penalty method. Solving this equation using an explicit method while applying the penalty method may be useless because the method would leave a greater number of constants unknown.
The penalty method enforces the contact condition by making the potential energy (Πp) of the whole system larger.

$$\Pi^*{}_p = \Pi p + \frac{1}{2}\alpha[C(u)]^2 = \frac{1}{2}ku^2 - mgu + \frac{1}{2}\alpha(u-h)^2 \quad (18)$$

where α is Penalty parameter, m is Mass of body, u is Velocity of contact, "h" is the Height

Find the diagram below for an illustration of a single degree of freedom for a single spring.

To be at equilibrium

$$\left\{\frac{\Pi * p}{\partial u}\right\} = 0 \quad (19)$$

Substituting equation (18) in (19)

$$(k+\alpha)u = mg + \alpha h \quad (20)$$

$$u = \frac{mg + \alpha h}{(k+\alpha)} \quad (21)$$

For the contact condition

$$C(u) = u - h = \frac{mg - kh}{(k+\alpha)} \quad (22)$$

$$\lambda = \alpha C(u) = \frac{\alpha}{(k+\alpha)}(mg - kh) \quad (23)$$

From the Eqn (18) there was no alteration with the real defined parameters as all the constants were the number of unknowns.

The stiffness of the spring will be enormous should the penalty parameter (α) is be adjusted to a large number, as shown in Eqn (23).

Numerical Damage Models

Fracture initiation usually has a higher rank than deformations of enormous plastic, and the gradients of stress and strain are being looked upon attentively around the point of fracture.

Damage mechanism (DM) approach will be used based on fracture damage evolution. These hybrid techniques have proven to be accurate in predicting the response of low-velocity impact polymer composites.

In this study, a damage model is proposed for the high-velocity impact modelling based on the combination of different modelling strategies, i.e. the application of failure, damage mechanics, plasticity etc.

Due to the effect of water, the hydrostatic stress σ_H has been popularly used in pieces of literature concerning ductile fracture which in the triaxiality ratio, maybe enclosed as:

$$\eta = \sigma_* = \frac{\sigma_H}{\sigma_{eq}} \quad (24)$$

where:

η and σ∗ = symbols for the triaxiality ratio
σ_{eq} = equivalent von Mises stress

Energy absorption and Impact Load

The section equations are from the study of K. Sl˚attedalen et al. [13]. Generally, explosions, blasts, and collisions, which are impact problems, decays loads dynamically because of the short time deformation. However, the impact duration can be termed quasi-static if it is about four times the natural time of the structure being impacted. The energy gotten from inertia forces and damping is then negligible, while the stiffness of the structure that is loaded will occupy the impact entirely. The load may be described as those quantities, which include the velocity and the mass and could also be termed as objects striking in the motion's direction concerning the structures that are impacted.

The striking kinetic energy E_k will be absorbed as

dissipated plastic energy E_p and Elastic Energy E_e.

$$E_k = E_e + E_p \quad (25)$$

As kinetic Energy $$E_k = \frac{1}{2}Mv^2 \quad (26)$$

The work executed on the structure by the striker termed as the external work W_{ext} is equal to the area covered under the force-displacement curve.

$$W_{ext} = \int_{U_0}^{U} F(u)du \quad (27)$$

where F is Force of contact
U is Final velocity
U_0 is Initial Velocity

As the pipe's initial velocity approaches zero, the balanced energy becomes:

$$Wext = \Delta Ek = Ee + Ep = Wint \quad (28)$$

Rewriting it becomes:

$$1/2Mv^2 = \int_{U0}^{U} F(u)\,du \quad (29)$$

Analytical Models for the Impact Ability of the Pipe

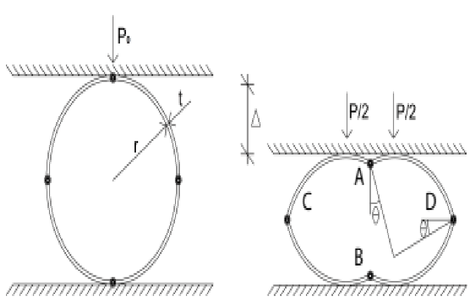
The deformation process for impacted pipes is complex; it is a tedious task deriving an analytical approach calculating the whole force-displacement curve. Therefore, a numerical method shall be used. The analysis is based on a jacket since it's a circular section, and this is related to a hollow/circular pipe.

To derive this method, some significant assumptions were made; that is why it's approximate and not exact. These are:

a) Local Denting and the response of the global bending must be separated.
b) Quasi-static behaviour of the problem was assumed
c) Assuming that the material rigid-perfectly plastic.

The ovality of the pipe can be studied as a simple ring model, assuming the span of the pipe is short relative to the diameter.

The model consists of a pipe undergoing compression. The diagram shows the deformation before and after deformation. Considering plastic hinges at initial contact point A and B and the other contact points C and D as shown below:



(a) Pipe before Deformation (b) Pipe after Deformation

Fig. 6: Rigid, Perfectly Perfect deformation of the pipe [13].

At the end of the impact, the difference in displacement is given as

$$\Delta = 2r.\sin\theta \quad (30)$$

where,
r is Initial radius
ϴ is Rotation of a quarter

The incremental form will be:

$$\delta\Delta = 2r.\delta\theta.\cos\theta \quad (31)$$

The external and internal work that was performed as stated earlier

$$\delta W_{ext} = P\delta\Delta \quad (32)$$

$$\delta W_{int} = 8m_p\delta\theta \quad (33)$$

Where
$m_p = 1/4t^2\sigma_0$
σ_0 is the strength of the material initially yielded.

$$\delta W_{ext} = \delta W_{int} = \frac{8m_p\delta\theta}{\delta\theta} = P = \frac{4m_p\delta\theta}{r\cos\theta} \quad (34)$$

From Eqn. (22), expressing cos θ with sin θ

$$P = \frac{4mp}{r\sqrt{1-\left(\frac{\Delta}{2r}\right)^2}} \quad (35)$$

The initial plastic load P_0 is gotten as $\Delta = 0$ and this equation is only valid for pipe that deforms as a ring and that $\Delta \leq \frac{r}{\sqrt{2}}$.

$$P_0 = \frac{4mp}{r} \quad (36)$$

The section equations is modelled from K. Sl˚attedalen et al. [13].

Model

The methodology is based on the model of the analysis. Since the aim of the analysis to compare a Composite coated pipe with a Pipeline without Composite material as a result of the impact from drop Pipeline object (Indenter) at a constant velocity, the methodology adopted in this research considers the following assumptions.

Assumptions:

d) The same boundary conditions are applied to both the Pipeline-with-Composite materials and Pipeline-without-Composite material
e) The indenter velocity is constant for both cases
f) The time step is also the same
g) The pipeline is assumed to fully restrained at both ends
h) The impact of hydrodynamic forces are neglected
i) The seabed is assumed fixed
j) The pipeline is considered empty

Simulation Using Abaqus

Abaqus may be described as a tool or software that could be utilized for computer-aided-design (CAD) and finite element analysis (FEA). It is typically used for modelling and analyzing mechanical assemblies and getting to see the FEA result.

Abaqus Finite Element Analysis (FEA) program is used for analysis. It requires big displacements and extensive plastic deformation of the polymer coating. Consider an Indenter of mass, M, moving vertically at a velocity of 25m/s, with dimension as shown in Fig. 4, making an impact on a fully restrained 24inches X 17.5mm API 5L X65 12m long-empty pipeline with three layers composite materials (HDPE1, HDPE 2 & Rubber) and a bare pipeline. The thickness of the composite materials is 25mm, 32mm, and 35mm, respectively. The properties of the Indenter, pipeline, and composite materials are outlined in Table II.

Boundary Conditions

For the impact of the indenter on the pipe, some boundaries condition needs to be defined for both pipe and indenter.

Pipe Boundary conditions
Ux=0
Uy=25m/s
Uz=0
No Rotation in X, Y and Z directions

Indenter Boundary conditions
Ux=0
Uy=25m/s
Uz=0
No Rotation in X, Y and Z directions.
In summary, This boundary condition applied to restrict movement in both translation and rotational motion. The pipeline is fully restraint at both ends. The load applied to the Indenter is an impact velocity of 25m/s.

Model Stages
To carry out the simulation successfully, there are stages, this includes:

a) The Load cases
b) Analytical Steps

In this step, the Pipeline is model as A-4-node doubly curved thin or thick shell, reduced integration, hourglass control, finite membrane strain as an element. The properties of the pipeline consist of the Pipeline outer diameter, density, young modulus, pipeline wall thickness, three layers of composite materials of various properties, etc.

After the Pipeline and its composite materials has been modelled, the Impact load (i.e. he Indenter) is then modelled with its properties. A reference point which indicates the point of impact between the pipeline and the indenter is also modelled.

The approach of the model follows this order in Abaqus Software:
Part-Property - Create Section Property - Assign Section Property - Create Analysis Step - Assemble the parts - Applied Load and Boundary conditions - Applied Interaction to the two parts - Analysed Created Job - Generate results.

c) Shell

The Pipeline model is a 3D, Deformation, Shell Element and Extruded with a pipe profile as a cross-section. The depth of extrusion is 12m. The Indenter model is a 3D, Discrete, Rigid, Shell Element and Revolution. The revolution is 360 degree. Fig. 7 shows the pipeline with its composite materials layers.

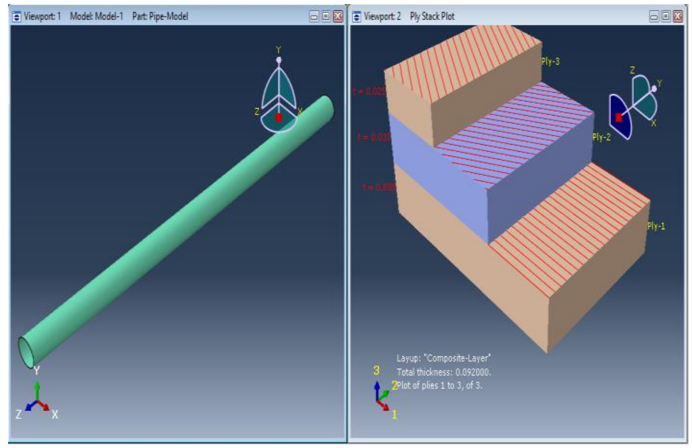


Fig. 7: This figure represents the pipeline with its composite materials layers.

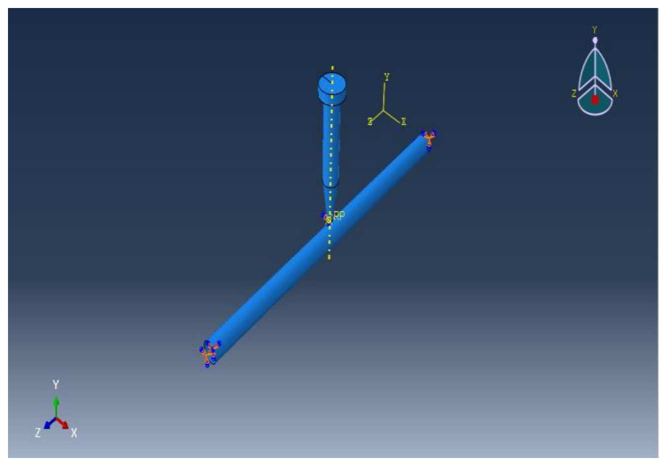


Fig 8: The model showing mid-span of the pipe to be indented and the indenter itself

III. RESULT AND DISCUSSION

The simulation provided us with the result of impact/energy absorption for both polymer composite coated pipe and the uncoated pipe. The analysis is based on Dynamic Explicit in Abaqus software. This helps to determine the stress on the pipeline due to the impact load from the indenter. Thesis energy derived is concerning a time step.

A) Result Comparison

The following figures show the result of the impacts for both the coated and uncoated pipe.

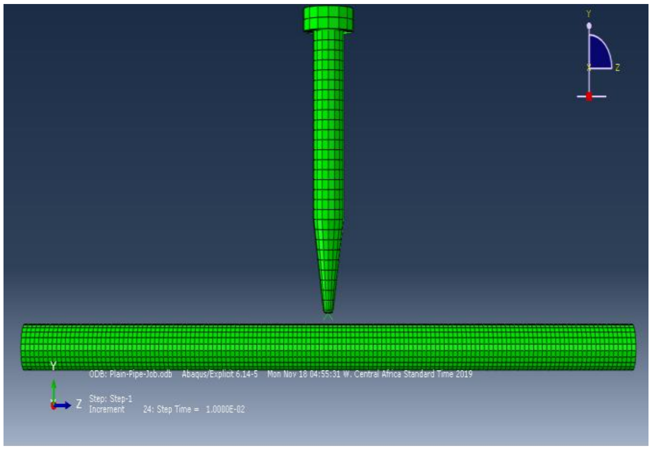


Fig. 9: Before Impact of Indenter

1) Result from Indenter on Composite coated Pipe

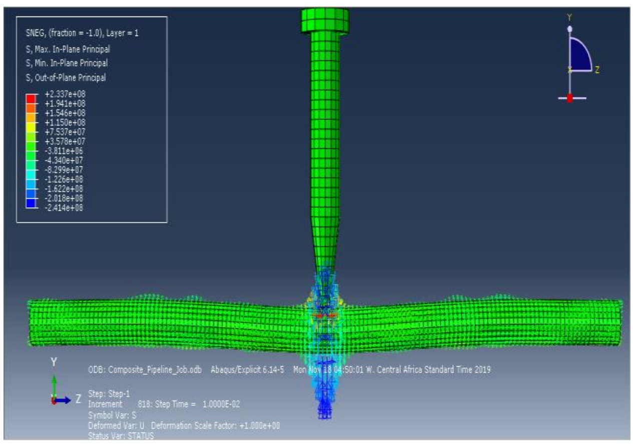


Fig. 10: Deformation Plot for Pipeline-with-Composite Material Layers

Fig. 4 shows the result after the impact of indenter on the coated pipe and the distribution of the impact all over the pipe. The pipe is subjected to vibration due to the impact of the indenter.

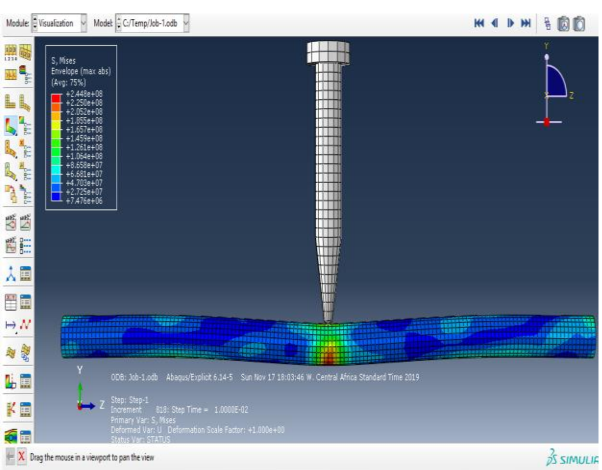


Fig. 11: Plot Contour on Deformed Shape

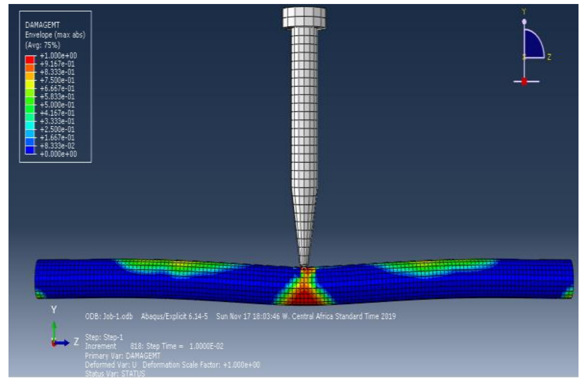


Fig. 12: Analysis Result for the Pipe with a 3 Layer composite Material at 0.01s step time

In this result time step, the indenter impact on the pipeline was absorbed by the composite material coated or applied on the pipeline surface thus preventing the pipeline from being damaged even though the pipeline undergoes some degree of bending with the stress which is within the allowable limit. The stresses in the pipeline is compared to the allowable stress as per ASME B31.8, which is 760MPa and the value here is far less than that to prove that the pipe is overprotected.

Result from Indenter Impact on Uncoated Pipe

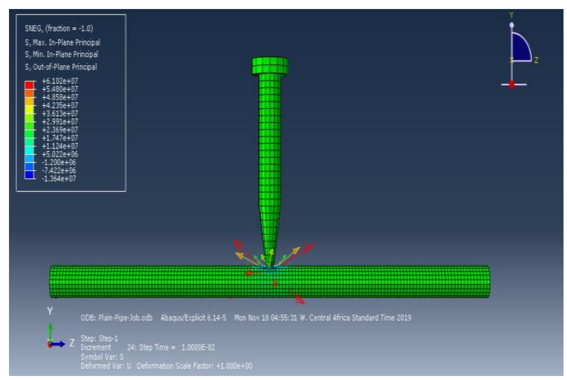


Fig. 13: Deformation Plot for Bare Pipe

Fig. 13 represents deformation on the pipe material as a result of the impact. The pipe has a high value of stress greater than the Maximum allowable, according to ASME b31.8, which is 760MPa. However, the stress, in this case, is greater.

In this result time step, the indenter impact on the pipeline has damaged the pipeline surface. The indenter pierced through the pipeline surface since there is no composite material applied on the pipeline's surface to absorb the impact energy and therefore the pipeline was not protected.

Fig. 17 shows the total energy distribution on the pipeline with its composite materials layer. This indicates that the composite materials have absorbed the energy as a result of the indenter impact on the pipeline. Thus, the composite materials have absorbed maximum energy of 1.66J.

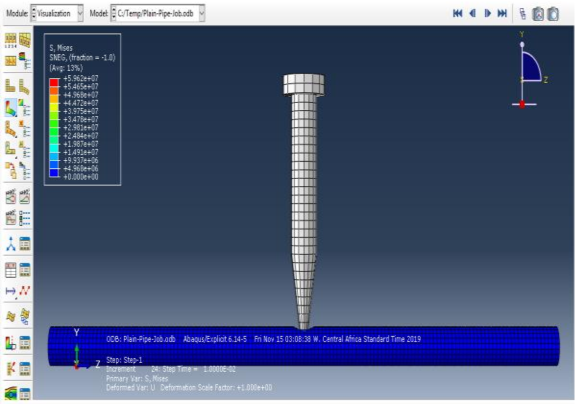


Fig. 14: Plot Contour on Deformed Shape for Bare Pipe

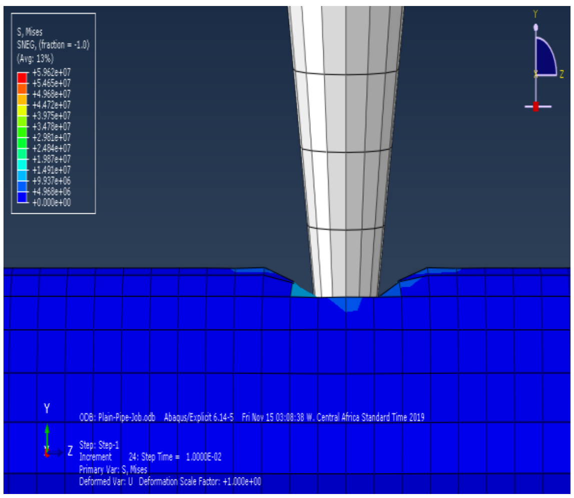


Fig. 15: Result for a PLAIN/BARE pipe at 0.01s step time

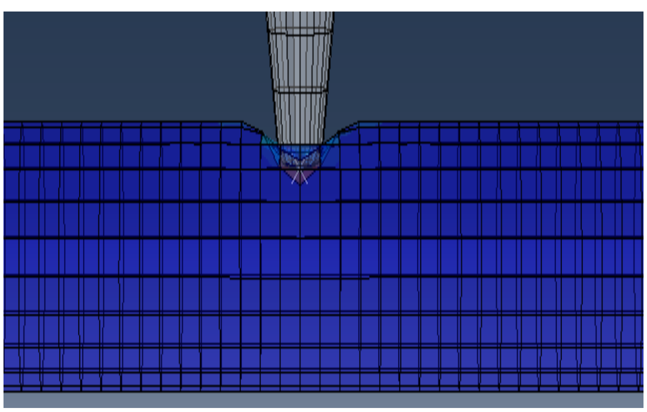


Fig. 16: Analysis Result showing the deformed part of the uncoated pipe

B) Impact Energy Absorption Result

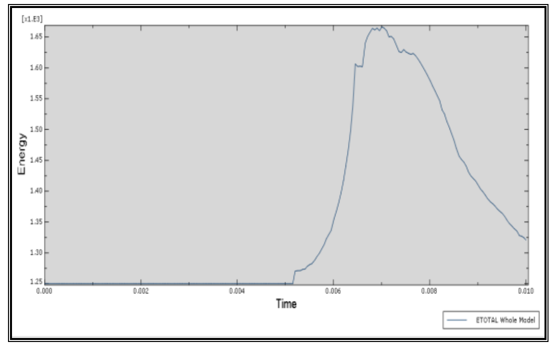


Fig. 17: Energy Distribution for Pipe-with-Composite Material layer

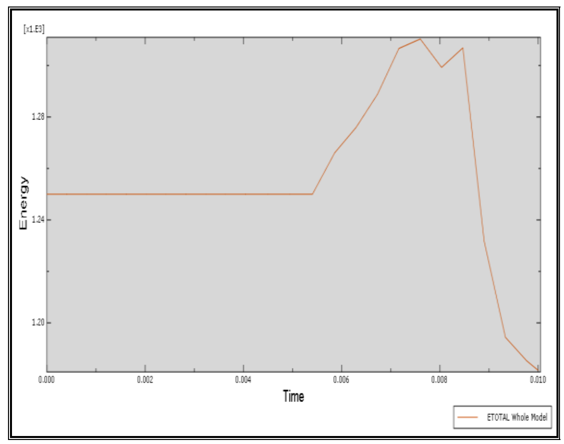
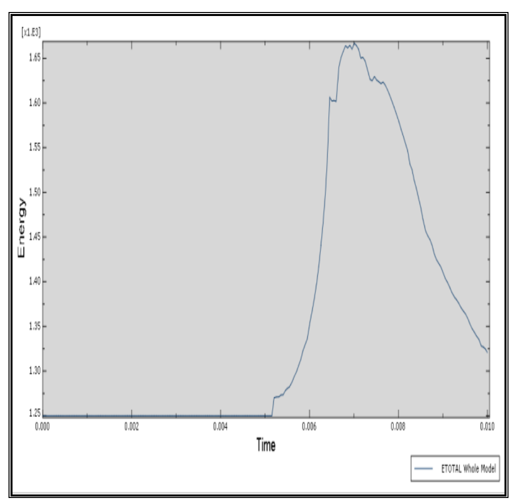


Fig. 18: Energy Distribution for Bare Pipe (Pipe-without-Composite Material layer)

The maximum energy is 1.32J as a result of the indenter impact on the bare pipeline. The bare pipeline has absorbed less energy, the remaining energy has penetrated the pipeline thus damaging the pipeline.



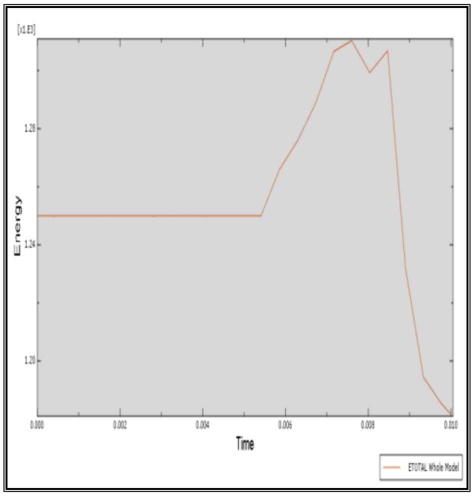


Fig. 19: Showing Comparison of the energy absorption relative time for both coated and uncoated pipe.

C) Result on Displacement due to Impact

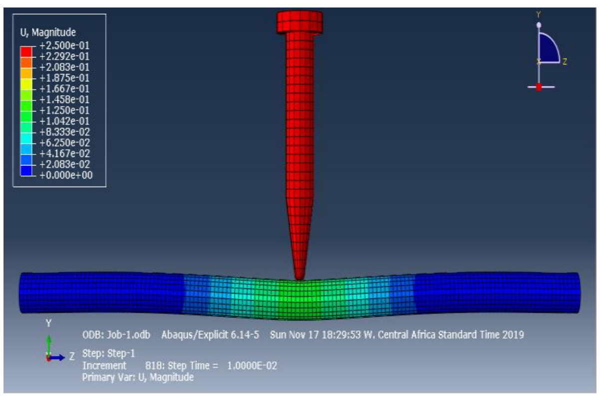


Fig. 20: Displacement for Pipe with-Composite Material layer

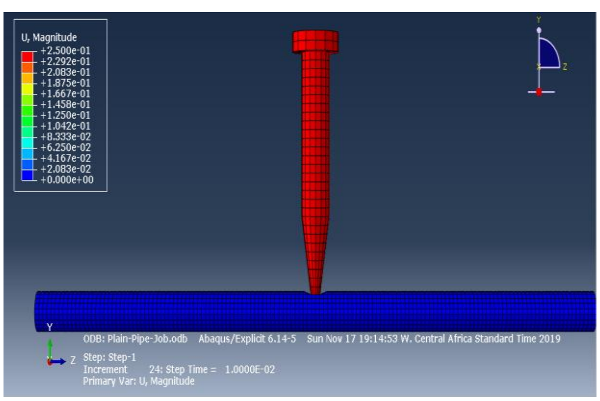


Fig. 21: Displacement for Pipe without Polymer coating

The Fig. 20 and Fig. 21 showed that the same displacement has been generated since the indenter velocity is constant for both cases. However, Fig. 19 indicated that the pipe was only subjected to bending but did not deform the pipe but the other case in Fig. 20 with the same velocity and displacement and it showed the pipe was deformed.

IV. CONCLUSION AND RECOMMENDATION

Conclusion

From the analysis carried out for both Pipeline-with-composite material layers and bare pipeline (or pipeline-without composite material layers), it is observed that more energy is absorbed by the presence of composite materials and the stresses transferred to the pipeline are within the allowable limit. In contrast, for the pipeline without composite material, less energy is absorbed, thus leading to pipeline damaged.

On the whole, it can be deduced that pipeline lined with composite materials layers are better protected against impact load compared to the bare pipeline.

Recommendation

This modelling was only based on a particular composite, and we would recommend further work to be done by varying the composite material subjecting them to same load conditions to be able to optimize and know a good composite combination that will give the best result for energy absorption of coated pipe. By also considering the cost to know the optima material to be used by the also varying thickness of the composite. Also, the impact of hydrodynamic forces is not considered; further work can consider this.

Contribution to Knowledge

The Oil and gas industry are concerned about the protection of their equipment and Facility to last long for the design life and to prevent it from explosion due to the nature of the fluid that has been transported. The pipeline, which is used to transport fluid in the industry requires maximum protection against impact/drop object. The study has provided a headway of protection via simulation of a layer of composite polymer on the pipe's surface. The benefit of this is to help engineers play their way around the material property and see the result via simulation rather than experimenting on an experiment to test if the material is suitable for protection.

Table II: Properties of composite Material, Coated pipe and Indenter

Properties			**Mechanical Elasticity-Engineering Constant**								
Parameters	Density (kg/m^3)	Possion Ratio	E1	E2	E3	Nu12	Nu13	Nu23	G12	G13	G23
HDPE1	950	-	4.56E+10	8.2E+09	8.2E+09	0.278	0.278	0.365	5.83E+09	5.83E+09	3E+09
HDPE1	950	-	4.56E+10	8.2E+09	8.2E+09	0.278	0.278	0.365	5.83E+09	5.83E+09	3E+09
Rubber	1030	-	4.56E+10	8.2E+09	8.2E+09	0.278	0.278	0.365	5.83E+09	5.83E+09	3E+09
Pipeline	7850	0.3					207000000				
Indenter	7850	0.3					207000000				

Table III: Composite Material Damage Data

Hasine Damage data for Composite Materials						
Composite Materials	Logitudinal Tensile Strength	Logitudinal Compressive Strength	Transverse Tensile Strength	Transverse Compressive Strength	Logitudinal Shear Strength	Transverse Shear Strength
HDPE1	566670000	241380000	20690000	82960000	65260000	46000000
HDPE1	566670000	241380000	20690000	82960000	65260000	46000000
Rubber	566670000	241380000	20690000	82960000	65260000	46000000

Table IV: Composite Material Damage Fracture Data

Hasine Damage Revolution data for Composite Materials				
Composite Materials	Logitudinal Tensile Fracture Energy	Logitudinal Compressive Fracture Energy	Transverse Tensile Fracture Energy	Transverse Compressive Fracture Energy
HDPE1	2691680	5431050	69830	1244400
HDPE1	2691680	5431050	69830	1244400
Rubber	2691680	5431050	69830	1244400

REFERENCES

[1]. Manes (2009), "The Behaviour of an Offshore Steel Pipeline Subjected to Bending and Stretching. Structural Impact Laboratory, Departement of Structural Engineering, Norwegian University of Science and Technology, Politecnico di Milano, Department of Mechanical Engineering" API 5L2 (1994) "Internal Coating of Line Pipe for Non-Corrosive Gas Transmission Service."

[2]. Boye Hansen A., Jackson a. (2005), 'High-performance polypropylene thermal insulation for high temperature and deep-water applications", 16th International Conference on Pipeline Protection, Paphos, Cyprus.

[3]. Smith, (2004) "Coatings for Corrosion Protection: Offshore Oil and Gas Operation Facilities, Marine Pipeline and Ship Structures"

[4]. Bud Senkowski, P.E. (2016) "Meeting Demands of Gas Exploration: The Evolution of Pipeline Coatings" https://ktauniversity.com/evolution-pipeline-coatings/

[5]. Jackson, A. Jackson, P. Wan, E. and Hegdal J.P (2009) "A Novel Thermal Insulation System for Bonded Subsea Single Pipe Wet Insulation Applications"

[6]. J. Fornes and S. Gabrielsen (2011). "Impact Against Offshore Pipelines. MSc Thesis, Structural Impact Laboratory, Departement of Structural Engineering, Norwegian University
of Science and Technology"

[7]. K. M. Mathisen (2011), "Lecture Notes TKT4197 Nonlinear Finite Element Analysis. Department of Structural Engineering, Norwegian University of Science and Technology.

[8]. M. Kristoffersen, (2014) "Impact Against X65 Offshore Pipes. PhD thesis, Norwegian University of Science and Technology.

[9]. M.Polanco-Loria (2013) "Experimental Investigation of Indentation Problem on Steel Pipes with Polymeric Coating. Internal Report, Statoil"

[10]. N. Bouchonneau, Ifremer, IFP, Franche-Comté U.; V. Sauvant-Moynot and F. Grosjean, IFP; D. Choqueuse, Ifremer; and E. Poncet and D. Perreux, Franche-Comté U (2007) "Thermal Insulation Material for Subsea Pipelines: Benefits of Instrumented Full-Scale Testing To Predict the Long-Term ThermomechanicalBehaviour" This paper was prepared for presentation at the 2007 Offshore Technology Conference held in Houston, Texas, U.S.A.

[11]. Ole Vestrum, Martin Kristoffersen, Mario A. Polanco-Loria, Håvar Ilstad, Magnus Langseth, Tore Børvik (2018) "Quasi-static and dynamic indentation of offshore pipelines with and without multi-layer polymeric coating".

[12]. Ray A. Dickie and F. Louis Floyd (1986) "Polymeric Materials for Corrosion Control: An Overview" Ford Motor Company, Dearborn, MI 48121, Glidden Coatings and Resins Division, SCM Corporation, 16651 Sprague Road, Strongsville, OH 44136.

[13]. Sl˚attedalen, K., and Ørmen, A., (2010). "Impact against offshore pipelines – Experiments and numerical simulations". Master'sthesis, Norwegian University of Scienceand Technology.

[14]. SIMULIA (2014) "Abaqus Analysis User's Guide, 12.2.3. 6.13 Edition"

[15]. Soreide, T. H. and Amdahl, J., 1982, 'Deformation characteristics of Tubular members with reference to impact loads from collision and dropped objects', Norwegian Maritime Research, Vol. 10, No.2, /3/.

[16]. The Properties of Steel Grade X65 (2015) "http://www.ehow.com/list_7492075_properties-steel-grade-x65.html".

[17]. U. R Evans, (1972). "An Introduction to Metallic Corrosion", 2nd edition, Edward Arnold: London.

[18]. Williams J G (1984)" Fracture Mechanics of Polymers. Horwood, Chichester, UK"

Alonge David Shola. He has a degree in Mechanical Engineering at the Federal University of Minna, Niger State and he has a master's degree in Subsea Engineering at the Offshore Technology Institute, University of Port Harcourt. He is a result driven Engineer, involved in several Oil and Gas Pipeline Design and Installation, Subsea components projects.

Dr T. A. Briggs obtained his Doctoral degree (PhD) in Mechanical Engineering University of Nigeria and a Postgraduate Certificate in Advanced Studies in Academic Practice from the University of Newcastle. Dr Tobinson Briggs has published some research papers in reputable learned journals both here and abroad. He has a high sense of research curiosities with a tremendous intellectual drive. He was a pioneer Head of Department of Mechatronic Engineering and formal Acting Director of Intellectual Property Technology Transfer Office (IPTTO). Currently, He is acting director of Offshore of Technology Institute, and member of academic board ACE-CEFOR, University of Port Harcourt.