Analysis of shell failure of a semi-trailer tanker used for hauling petroleum products

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Article Info

Abstract

Failures of heavy-duty vehicles during load hauling are major concern in road transportation. This is due to the magnitudes of accidents that sometimes result from the failures with loss of lives, destruction of goods or spillage with treat to environment, and road blockages. The failures are particularly detestable to the vehicle owners owing to the much loss they can incur including litigations they can face and compensations they can be obliged to make to affected innocent victims. In this paper, shell failure analysis of a semi-trailer tanker owned by an oil marketing company which resulted in much loss of its full-tank carried oil has been investigated. The information provided can be useful for forestalling recurrent failure problems with the company's fleet of semi-trailers which had caused the company substantial losses in its annals. The shell was first examined visually to assess the nature and magnitude of the failure and where it occurred. Maintenance records of the vehicle was surveyed and collected samples from critical locations of the shell was analyzed with respect to chemical composition, metallographic structure, and corrosion behaviors. Visual inspections indicated that the shell failed by small brittle crack perforation along the seam of a previous weld repair. Surveys showed no clear standard maintenance records of the semi-trailer. Chemical analysis showed steel material of different composition at the failure location compared to the as-made shell carbon steel. Metallographic analyses showed that the failure location was heterogeneous compared to the as-made shell steel. Corrosion analyses showed greater corrosion rates at the failure location which presumably raised the location stresses amid dynamic effects from bad road conditions and caused the shell to crack-perforate along the weld seam of the location.

1. Introduction

A component, machine, process, or system is considered to fail when it has deteriorated to the point at which it is unsafe or only marginally capable of performing its intended function. The consequence of failure can be tragic and expensive. There are several cases of failure resulting in loss of life and property. These cases are highly undesirable. Failure analysis is the process of collecting and analyzing data to determine the physical root causes of failure and how to prevent it from recurring [1, 2].

The common root causes of system failure include natural phenomenon, human factors, technological errors, and lack of proper maintenance [3]. Material corrosion and/or fatigue have frequently been attributed to the natural causes of structural failures. Carbon steel is the most commonly and widely used and important structural material, but it is a corrodible material of serious concern. Failures of carbon steel structures as results of low corrosion resistance amid

fatigue have been alarming. Corrosion-originated failures of catastrophic consequence have been found in annals of engineering technology where carbon steel has been used as a construction material such as storage tanks, boilers, road vehicles, aircrafts, buildings, bridges, oil rigs, pipelines, metallic containers for toxic chemicals etc. The Federal Highway Administration of United States reported an estimated $500 Billion corrosion costs each year to the country's businesses alone which is up to 6% of the nation's GDP. The National Association of Corrosion Engineers (NACE)-an international organization which focuses on developing corrosion prevention and control standards attributes more than 20% of that cost to the transportation and infrastructure industries [4, 5].

The critical causes of corrosion of road vehicles is due to road debris, sand, gravel and, especially deicing materials which sandblast vehicle underbodies. This action leaves chips in the protective coatings of the vehicles and predisposes the underlying substrate and other exposed parts to corrosive atmospheric moisture and severe temperatures. The presence of corrosive atmospheric chemicals particularly pollutants further contribute to breakdown or deteriorate the exposed areas. Exposed areas of the rear frames, gussets, rear under ride guards, threshold plates, front aprons, upper couplers, front under structure, suspension and axle assembly, and main frame assembly are typically affected by environmental chemicals and sand-blasting. Therefore, as a vehicle is frequently driven over long-distances carrying heavy loads, its structural components can experience excessive stress due to corrosion and/or fatigue and fail. Unexpected structural failure of moving vehicle can occur due to various forms of corrosion such as stress corrosion cracking, corrosion fatigue, and pitting or their various combinations in synergism with improper distribution of carried weight and structural vibrations under bad road conditions [4, 5, 6].

Vehicular failure can lead to accident with loss of lives and the vehicle. Failures of heavy-duty vehicles during load hauling is major concern in road transportation due to the magnitudes of accidents that sometimes result threat with loss of lives, destruction of goods or spillage with treat to environment, and road blockages. These failures are particularly detestable to the vehicle owners owing to the much loss they can incur including litigations they can face and compensations they can be obliged to make to affected innocent victims. In most developing countries such as Nigeria, there is low level of adherence to driving regulations and majority of roads are single-lane and characterized by deplorable condition. Driving heavy duty vehicles that carry heavy loads under such road scenarios is therefore a very critical issue that requires proactive failure prevention of the vehicles all the time by the vehicle owners, road safety workers, government legislations, and the vehicle drivers to avoid disasters [4, 5].

The semi-trailer is a heavy duty road vehicle that is designed and fabricated to specification and used for transporting goods for business. It is a trailer having wheels at the back but supported at the front by a towing vehicle [6, 7]. Semi-trailers are used in many countries to haul different types of goods including petroleum products. The capacities of most petroleum-hauling semi-trailer tanks can accommodate from 14,000litres to 100,000litres of the products. The tank shell of semi-trailers is typically made from mild steel of 4mm thickness and equipped with inside baffles of 4mm thickness designed to permit easy flow of fuel inside the tank and prevent the product vibration during operation [3]. Nigeria's economy is about 95% petroleum-dependent. Petroleum hauling is a top lucrative transportation business in Nigeria and about 80% of the petroleum haulage in the country is done on roads. Semi-trailer tankers form the bulk of heavy duty road vehicles for transporting petroleum products from depots to various locations of the country [8, 9]. It is however lamentable that many of these trailers are very old but frequently employed in carrying much quantity of the inflammable petroleum products without adequate maintenance schedule services such as corrosion monitoring, inspections and repairs. Maintenance of these trailers is critical for their longevities and optimal performances. Proper maintenances of the vehicles ought to be done in accordance to their manufacturers' specifications in conjunction with regulations of reputable relevant authorities. Lack of compliance to requisite maintenance

standards for vehicles is seen to be the major origin of their corrosion deteriorations which lead to various levels of unpredictable failures of the vehicles [9, 10, 11].

There are a number of main and subsidiary oil marketing companies in Nigeria with fleets of semi-trailers that are used for hauling petroleum products in the country. Failure of such vehicles during the hauling process can result in product spillage, fire hazards and other treats to environment, road blockages, and a multiple accident with loss of lives. Some of the companies might have incurred substantial losses from failures of their semi-trailers in their annals [7, 9, 10]. Positive research inputs on preventing or minimizing failures of the companies' semi-trailers can therefore be contributive to optimal petroleum-hauling and profile of the companies and road safety in Nigeria. The aim of this paper is to present a conducted shell failure analysis of a semi-trailer owned and used by one of the subsidiary companies for hauling petroleum products in Nigeria. The objectives of the study include:

i. To find out whether corrosion was the root cause of the shell failure or else some other factors including deliberate human actions were the root cause.

ii. To determine if any, corrective actions that can be used by the companies for forestalling such structural failures among their fleets of oil-hauling semi-trailers.

2. Methodology

2.1 Description of the Shell Failure

Based on narrated information by the driver of the semi-trailer in question and other field surveys, the semi-trailer was owned by a subsidiary oil marketing company in Nigeria. The shell failure of the vehicle occurred at night around 10.00 pm along Kaduna-Kachia road at about 30km away from the town of Kachia on 16/09/2016 while it was in motion. The vehicle was transporting full load capacity of 40,000 liters of gasoline along a single-lane road en route to Nasarawa state in Nigeria and cruising at a speed of about 60km/hour when the failure occurred. The road condition on which the trailer was moving was fair in some sections but characterized by bumps, potholes, narrowness, bad turns, dustiness, and on-going constructions or repairs with short diversions in some sections. Due to the shell failure, the carried gasoline in the shell started pouring. A few minutes after that, the trailer driver perceived the smell of the pouring gasoline and quickly parked the vehicle off the road. He and his only companion on the trailer came down from the vehicle and used various tools and means to stop the outflow of fuel from the tank but to no avail. It was not long from there when a lorry travelling in the opposite direction on the same road arrived at the scene where the semi-trailer was parked. The driver of the trailer tried to stop the lorry driver for assistance. The driver of the lorry was initially not willing but after sensing the truth of what was happening, parked his lorry at a safe distance away from where the trailer was parked. The lorry driver came down with some of his passengers and tools and assisted in stopping the outflow of gasoline from the tank but still to no avail. Road signs were mounted on the roads to signify drivers of other traveling vehicles of the danger at the spot. At that juncture, the owner of the semi-trailer was phone-informed by the trailer driver of what was happening. After being helplessly desperate to stop the outflow of the gasoline in vain for nearly an hour, the flow stopped itself. By this time more than 70% of the gasoline had leaked away into road side gullies and on the road itself where the failure occurred. The outflow had stopped because the fuel level in the tank had fallen below the perforation point on the tank. Structural adhesives (araldite) and thick cello tapes were later got from Kachia and used to seal the perforated shell. The trailer was thereto driven back to its park in Kaduna around 13.00pm hours the next day on 17/09/2016.The remaining fuel in its tank was evacuated and the trailer was kept in its park for one week. After that, the trailer was taken to Arewa Metal Containers Limited Kaduna (ARMECO) where it was last repaired before it had the shell failure for further repairs.

2.2 Background Information and Condition of the Semi-Trailer at the Time of Failure

The trailer in question is one of the fleet of semi-trailers that operate under the management of a big oil marketing company for hauling petroleum products from depots in Nigeria to various parts of the country. The trailer was said to be over 15 years old and had a total mileage of over 300,000km in its usage life at the time of the failure. The trailer was built by Doepker industries in Canada and purchased second hand in April 2005 among 10 other semi-trailers of the same capacity and make from UAC limited at total cost of 40 Million Naira by a subsidiary company of the main marketing company. Further collected information showed that the trailer driver had contractual agreement with the subsidiary company for management of his assigned trailer in terms of repairs. The subsidiary company also assigned a mechanic to the driver for working with him for effecting both minor and major repairs on the trailer. The trailer used to have minor failures like tire deflations, electrical and engine problems but did not have any failure in which accidents or loss of its hauled products occurred. The shell failure was the first failure type from the trailer that resulted in loss of its hauled petroleum products. Maintenance of the trailer was the responsibility of both the driver and the mechanic. It was said that the duo used to service their trailer each time they were to travel out with it, but nobody was sure whether the services were detailed with proper inspections of wear and corrosion of the trailer with standard tools or facilities and according the vehicle manufacturer's stipulations. The shell of the trailer was weld-repaired by arc welding sometime eight years ago at ARMECO before the failure occurred.

2.3 Visual Examination of the Shell

Visual examination of the failed semi-trailer shell was conducted at ARMECO where the trailer was parked awaiting repair of the shell. The examination showed that the trailer shell was made of steel material and had a faintly visible quasi-transverse brittle crack perforation of about 25 cm lengths where it was previously arc-welded to seal a previous perforation at the spot and repainted. The paint however got worn out at the spot and before the shell failure in question occurred around the same spot where it was sealed. Pictures were then taken with a Nikon 990 digital camera through a Nikon Stereoscopic microscope at a magnification of 20.Plate I is the picture of the point on the shell where the trailer was repaired, repainted but rather deteriorated and perforated and outpoured fuel from the perforation marred the trailer body. Plate II on the other hand is the surface appearance of the weld-repair failure location on the trailer.

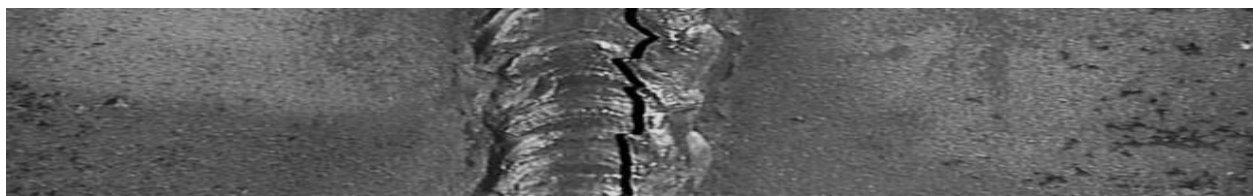PlateI: Point on the semi-trailer shell before it was lastarc-weld-repaired but later deteriorated and failed.

Plate II: A magnified view of the actual weld-repair failure location

2.4 Collection of Materials for Laboratory Tests

The material make of the shell was obtained from the semi-trailer itself at ARMECO where it was parked by mechanically sawing out pieces from the shell at and away from the failure locations.

2.5 Analyses of the Shell-Make Materials

The qualities of the original metal used in constructing the shell and the material at the failure location of the shell were analyzed through chemical composition, laboratory corrosion tests, and metallographic inspections.

2.5.1 Materials used for the analyses

The materials used in the analyses were; samples of the shell make material, gasoline, diesel, and concentrated sulphuric acid (H_2SO_4).

Samples of the shell make material were cut out using facilities at ARMECO, Kaduna. 10 liters of gasoline and 10 liters of diesel were sourced from Conoil Plc. About three liters of concentrated sulphuric acid was gotten from ARMECO Ltd. Plate III shows the component sample of the shell make material that was cut off at away location from the failure location, while Plate IV shows the component of the shell make material that was cut at the failure location.

The equipment for the laboratory study were; PDA Shimadzu 7000 metal analyzer located at Defence Industries Corporation of Nigeria (DICON); Kaduna, a grinding machine, an engine lathe (located at ARMECO Limited, Kaduna), mechanical cutting machine-schavi sc1060/T (located at ARMECO), punching machine-ficep st-super with serial No 15521 (located at ARMECO), metallurgical microscope with serial No. D33021 (located at DICON), shaping machine (with serial No klopp KE4 45908 (located at ARMECO), hand-held venire caliper, weighing balance of Mettler model AE100 (located at ARMECO), and metallurgical scanning electron microscope located at Department of Mechanical Engineering, Federal University of Technology, Minna, Nigeria.

Plate III: A component of the shell make material that was cut at away location from where failure occurred

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Plate IV: The A component of the shell make material that was cut at the location where failure occurred

2.5.2 Chemical composition

The chemical compositions of the cut components away and at the failure locations of the shell shown in plates III and IV were analyzed using the Shimadzu-model-PDA-7000 optical emission spectrometer metal analyzer at the Research and Development Unit of the Defence Industries Corporation of Nigeria (DICON). Three samples of about 15mm by 10mm by 1.5mm solid dimensions, suitable for accommodation on the sample stand of the analyzer were sawn out of each component cut at and away from the failure location of the shell. The samples were each

separately loaded on the sample stand of the analyzer and the equipment was switched on. This created an arc or spark discharge that resulted in vaporization of material from the surface of the samples. The atoms and ions contained in the atomic vapour were excited into emission radiation. The emitted radiation passed to the spectrometer optics via an optical fibre, where it was dispersed into its distinct spectral components that were each the characteristic of chemical element of the material samples. These spectral components were automatically and appropriately analyzed by the integral computer accessory of the unit into percentage elemental weight quantities with the results printed out by the printer unit. The respective elemental weight compositions for each of the three-set samples were averaged to get the average elemental weight composition of the shell make at and away location from the failure location. This was done in principles used by Guma and Daniel [12] in accordance with the manual of the analyzer.

2.5.3   Corrosion tests

The cutting machine was used to cut each of the two cut components from the semi-trailer shell shown in plates III and IV into 50 similar solid pieces of about 10mm length (L) by 10mm width (w) by 1.5mm thickness (t) to produce the coupon types. The rough surfaces of the cut coupons were smoothened by slowly grinding them with the grinding machine. For the same surface exposure of the coupons to the prepared test media for comparability of results, grease and natural corrosion products formed on the coupons and machining burrs on them were removed by wire brushing. The coupons were also polished manually to similar surface finishes using abrasive papers of grits 60 and 120. Thereto, the coupons were cleaned with acetone, rinsed in distilled water, dried in air just before immersing them in the prepared corrosive test media. The cleaning process was done in accordance to the ASTM G-1 Standard Practice for Preparing, Cleaning, and Evaluating Metallic Corrosion Test Specimens [12, 13]. The cleaned coupons were measured with a venire caliper to determine their dimensions and surface areas to the nearest $0.0001mm^2$. Plate VI shows some of the coupons before cutting them to similar size while VII shows some of the polish-prepared coupons.

Plate VI: Some of the coupons before cutting them to similar size

Plate VII: Some of the polished coupons

The test media were preparedin the laboratory by separately admixing 0, 5, 10, 15 and 25 % of concentrated sulphuric acid (H_2SO_4) by weight (Wt) with the procured gasoline in separate glass containers to accelerate corrosion to various levels for fast results and better appreciation of

corrosion behavior trends of the coupons. This was also similarly done with the procured diesel. The weight determinations were achieved using the Mettler weight balance.

Five coupons of each component type were weighed to the nearest 0.001mg using the very accurate Mettler balance, tong-held and immersed in each prepared medium in separate plastic containers with labels indicating the levels of gasoline or diesel acidic contents therein. The containers were left open-ended with their contents in the laboratory at ambient temperature undisturbed for various durations of 120, 360, 720, 960, and 1200 hours. Thereto, the coupons were sequentially removed and rinsed to remove residual test solution and any loose corrosion products on them, re-cleaned with detergent using bristle brush under running tap water, rinsed in distilled water, dried with a lint-free towel, and reweighted in line with the ASTM G-1 method [12, 13, 14]. The respective change in weight (weight loss) of each coupon during its immersion period was used to determine its corrosion penetration rate (CPR). The CPR of each coupon for specified exposure duration in each medium was evaluated according to [12, 14];

$$CPR = \frac{87.6W}{DAT} \quad \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where: W = weight loss in milligram of the coupon, D = density of the steel coupons (7.75 g/cm^{3}), A = evaluated average exposed surface area of all the coupons in square centimeters before exposing them to the medium, and T = exposure time in hours [12, 14].

The average surface area of the solid plate coupons was evaluated after cleaning them before exposure to the media as;

$$A = 2(lw + tl + tw)\dots\dots\dots\dots\dots (2)$$

Where, 'l' was their average legnths = 9.998mm, 'w' was their average determined widths = 9.992mm, 't' was their average determined thicknesses = 1.498mm; from which 'A' was evaluated to be 259.690072 mm^2 = 2.59690072cm^2.

2.5.4 Micro-structural examination of the collected shell material

Samples cut from the shell make at and away from the failure location were prepared to suitable loadable sizes on the specimen stand of the electron microscope (SEM). Exposed and unexposed samples to the prepared corrosive test media were thereto individually mounted on the slotted plate of the scanning microscope stereo holder. Microscopic examination of the samples was undertaken using the Hard Core DIY scanning electron microscope with an inbuilt camera that automatically photographically recorded the resulting microstructures or surface morphologies of the samples with magnification of 200.

3. Results and Discussion

3.1 Results

The collated results from laboratory tests of cut materials from the failed semi-trailer shell are presented as follows:

3.1.1 Chemical composition

The average elemental weight chemical composition of the shell make samples that were gotten at a remote location from the failure point is presented in Table 1 while that of the samples that were gotten at the failure location is presented in Table 2.

Table 1: Analyzed average elemental weight chemical composition of the shell make samples that were gotten at away location from the failure location.

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Fe
Content [%]	0.184	0.088	0.378	0.018	0.001	0.001	0.0015	0.003	0.009	99.3165

Table 2: Analyzed average elemental weight chemical composition of the shell make samples that were gotten at the location where failure occurred

Element	C	Zn	Mn	Al	Ti	Cr	Cu	Fe
Content [%]	0.109	0.031	0.629	0.1422	0.017	0.008	0.104	98.9598

Low carbon steel is the type of steel that contains less than 0.3% carbon [14]. From Tables 1 and 2, it can therefore be seen that the elemental weight compositions of the shell make at and away from the failure location were all of low carbon steels of very different compositions. This might have been due to the inability of the earlier weld-repair work at the failure location to create original steel make material of the shell threat.

3.1.2 Corrosion test

Results of corrosion weight losses of coupons after immersing them for various durations of 120-1200 hours in separately prepared gasoline and diesel media containing different concentrations of 0-25% by weight H_2SO_4 are presented in Figs. 1 to 5. Results of the determined corrosion rates from the weight losses presented in Figs. 1 to 5 are respectively presented in Figs. 6 to 10. In all cases;

ALG = Coupons prepared with steel sample got at away location from the shell failure location and immersed in gasoline medium containing specified concentration level of concentrated H_2SO_4.

ALD = Coupons prepared with steel sample got at away location from the shell failure location and immersed in diesel medium containing specified concentration level of concentrated H_2SO_4.

ALAG = Coupons prepared with steel sample got at the failure location of the shell and immersed in gasoline medium containing specified concentration level of concentrated H_2SO_4.

ALAD = Coupons prepared with steel sample got at the failure location of the shell and immersed diesel medium containing specified concentration level of concentrated H_2SO_4.
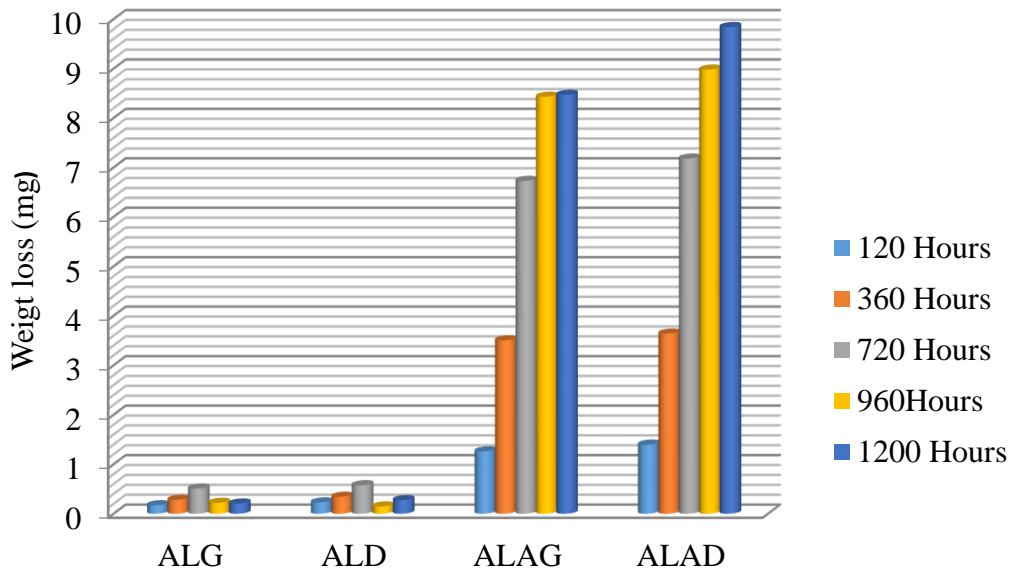
Fig. 1: Weight losses of coupons (mg) after imerssing them for various durations of 120-1200 hours in as-received gasoline and diesel media
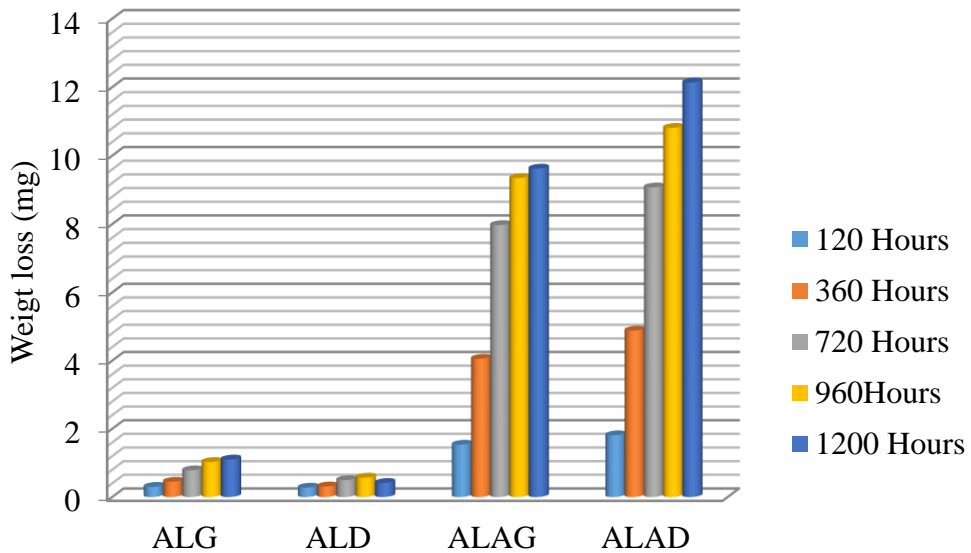

Fig. 2: Weight losses of coupons (mg) after imerssing them for various durations of 120- 1200 hours in gasoline and diesel media contaiinin 5% by Wt of concentrated H_2SO_4
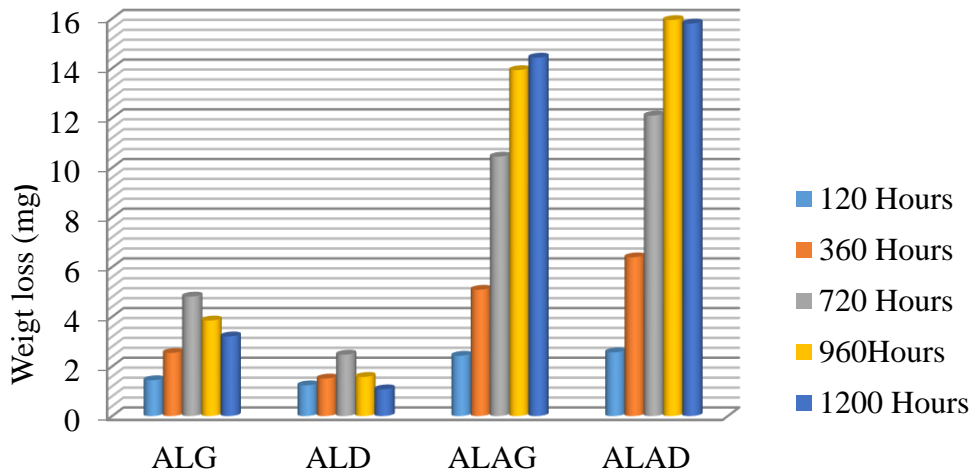
Fig. 3: Weight losses of coupons (mg) after imerssing them for various durations of 120-1200 hours in gasoline and diesel media containing 10% by Wt of concentrated H_2SO_4
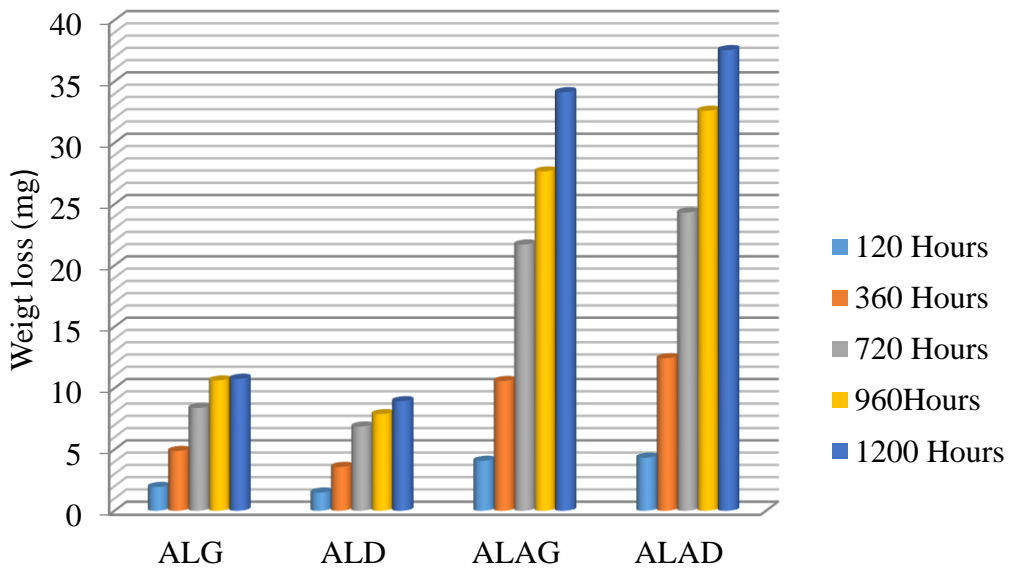

Fig. 4: Weight losses of coupons (mg) after imerssing them for various durations of 120- 1200 hours in gasoline and diesel media containing 15% by Wt of concentated H_2SO_4.
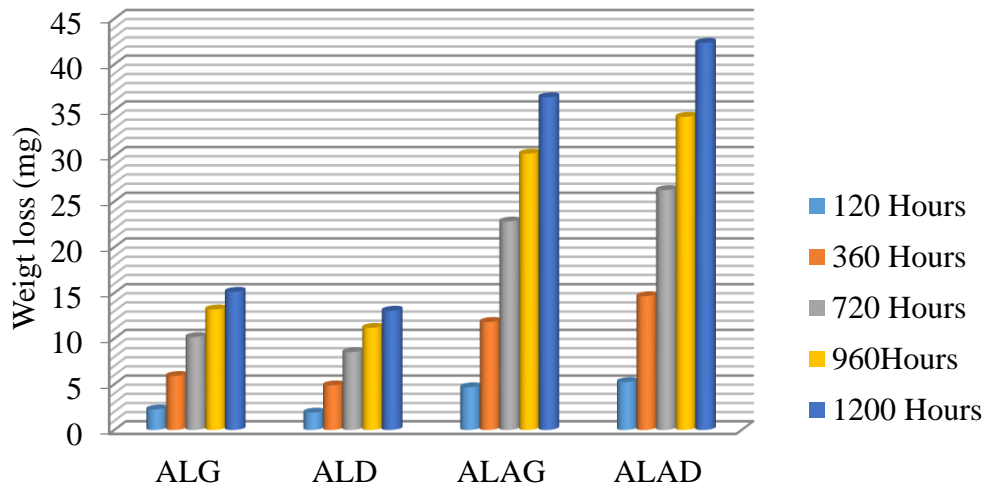
Fig. 5: Weight losses of coupons (mg) after imerssing them for various durations of 120-1200 hours in gasoline and diesel media containin 25% by Wt concentrated H_2SO_4
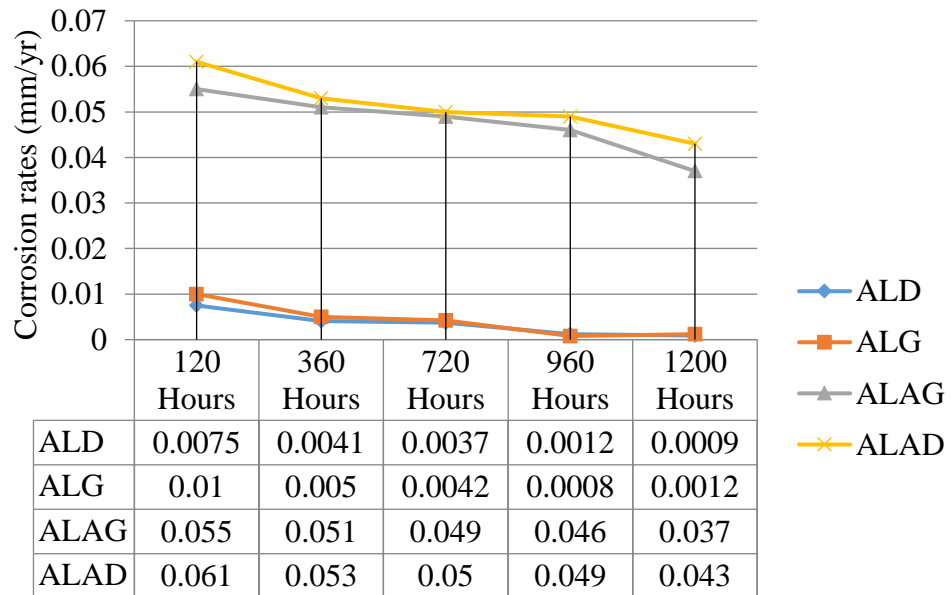

	120 Hours	360 Hours	720 Hours	960 Hours	1200 Hours
ALD	0.0075	0.0041	0.0037	0.0012	0.0009
ALG	0.01	0.005	0.0042	0.0008	0.0012
ALAG	0.055	0.051	0.049	0.046	0.037
ALAD	0.061	0.053	0.05	0.049	0.043

Fig. 6: Corrosion rates of samples after immersing them for the specified durations (Hours) in as-received gasoline and diesel media

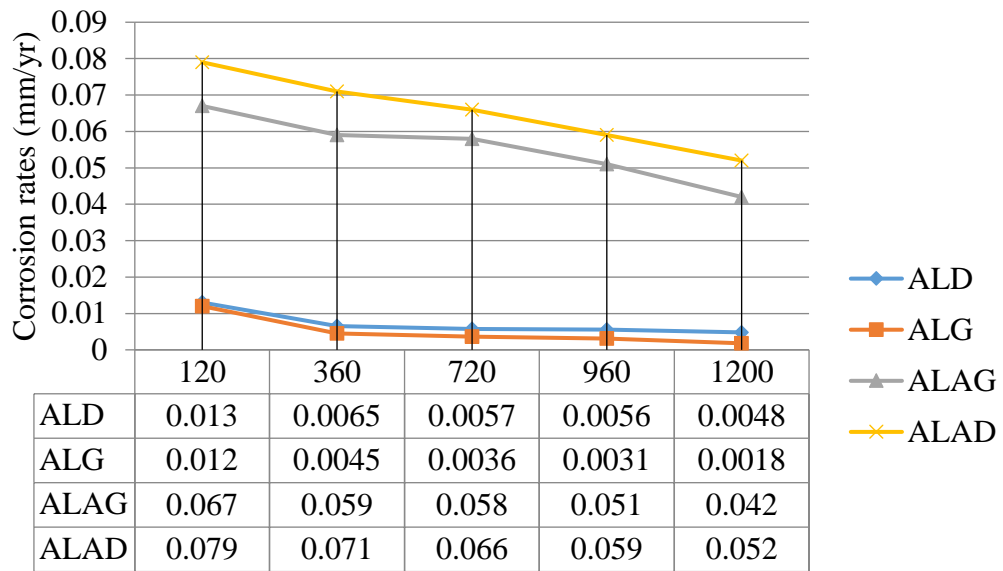|	120	360	720	960	1200
ALD	0.013	0.0065	0.0057	0.0056	0.0048
ALG	0.012	0.0045	0.0036	0.0031	0.0018
ALAG	0.067	0.059	0.058	0.051	0.042
ALAD	0.079	0.071	0.066	0.059	0.052

Fig. 7: Corrosion rates of samples after immersing them for the specified durations (Hours) in gasoline and diesel media containing 5% by Wt of concentrated H_2SO_4

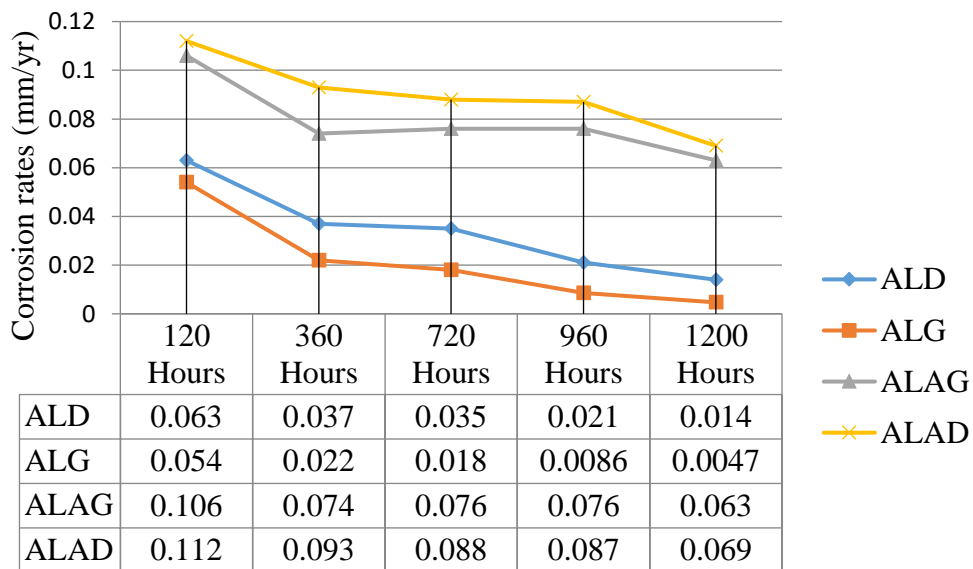|	120 Hours	360 Hours	720 Hours	960 Hours	1200 Hours
ALD	0.063	0.037	0.035	0.021	0.014
ALG	0.054	0.022	0.018	0.0086	0.0047
ALAG	0.106	0.074	0.076	0.076	0.063
ALAD	0.112	0.093	0.088	0.087	0.069

Fig. 8: Corrosion rates of the samples after immersing them for the specified durations (Hours) in gasoline and diesel media containing 10% by Wt of concentrated H_2SO_4
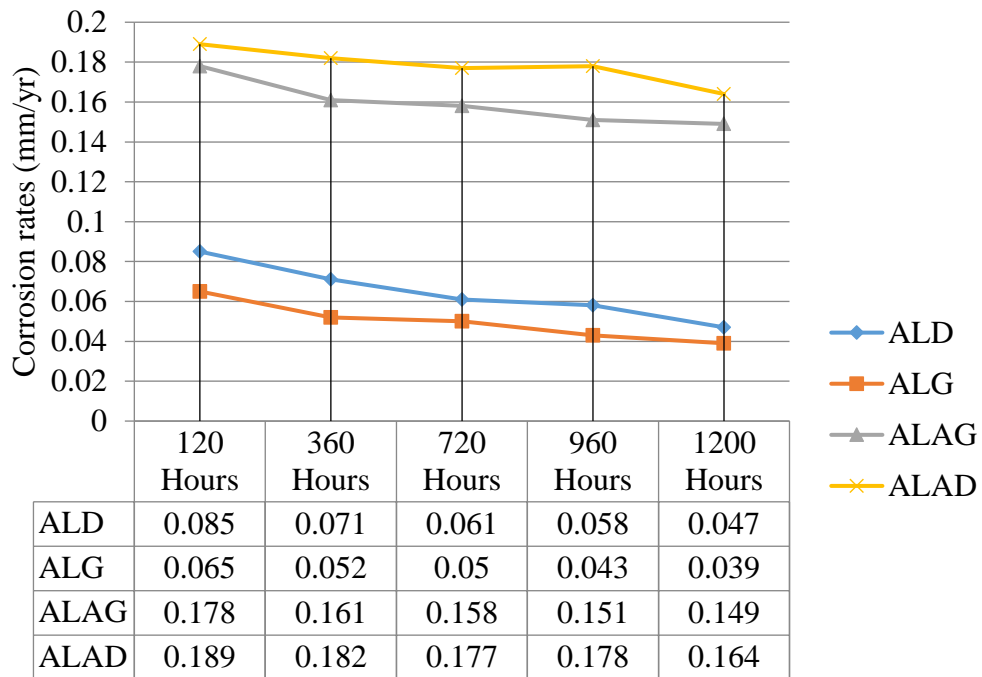
	120 Hours	360 Hours	720 Hours	960 Hours	1200 Hours
ALD	0.085	0.071	0.061	0.058	0.047
ALG	0.065	0.052	0.05	0.043	0.039
ALAG	0.178	0.161	0.158	0.151	0.149
ALAD	0.189	0.182	0.177	0.178	0.164

Fig. 9: Corrosion rates of samples after immersingr them for the specified durations (Hours) in gasoline and diesel media containing 20% by Wt of concentrated H_2SO_4

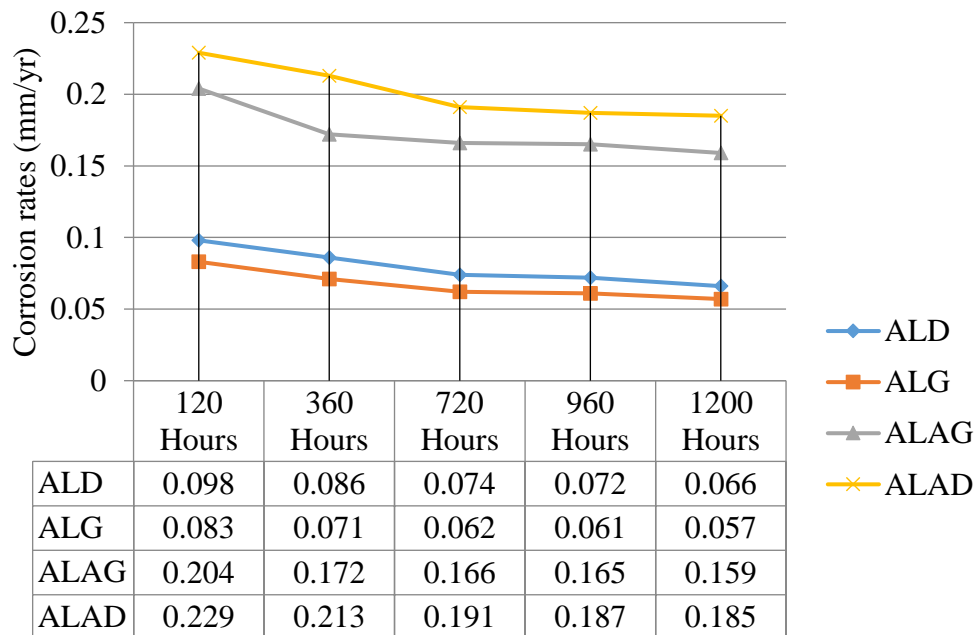|	120 Hours	360 Hours	720 Hours	960 Hours	1200 Hours
ALD	0.098	0.086	0.074	0.072	0.066
ALG	0.083	0.071	0.062	0.061	0.057
ALAG	0.204	0.172	0.166	0.165	0.159
ALAD	0.229	0.213	0.191	0.187	0.185

Fig. 10: Corrosion rates of samples after immersing them for specified durations (Hours) in gasoline and diesel media containing 25% by Wt of concentrated H_2SO_4

In Fig. 1 to 5, it can be seen that corrosion weight losses and rates of samples prepared from the shell make component gotten at and away from the failure location of the shell exhibited different values for the same exposure durations of 120 to 1200 hours in each of the prepared media. In all cases the corrosion weight losses increase with the exposure duration and ranged from 0.172 to 9.87mg as can be observed from Fig.1 to 5 while the corrosion rates ranged from 0.0075 to 0.061mm/yr as can be observed in Fig. 6 to 10. In all cases, Fig. 1-5 and 6-10 indicate that the corrosion weight losses and rates of prepared samples with the shell make component got at the failure location are higher than those of samples from the shell make component got at away location from the failure location under the same respective gasoline or diesel media and exposure durations. The corrosion weight losses and rates therefore clearly support the chemical analysis that the shell make material at its failure location was very different from the original mild steel used in constructing the shell.

According to atmospheric corrosivity categorization by ISO 9223 1992 from the point of view of corrosiveness to carbon steel as the base material; corrosion rates of 0 up to 1.3mm/yr arevery low, corrosion rates of more than 1.3mm/yr up to 25mm/yr are low, corrosion rates of more than 25mm/yr up to 50mm/yr are medium, corrosion rates of more than 50mm/yr up to 80mm/yr are high, and corrosion rates of more than 80mm/yr up to 200mm/yr are very high [15]. From these categorizations and the results presented in Figs. 6, it is evident that the as-received gasoline and diesel media per se had negligible effects on corrosion rates on all the shell make steel samples. The diesel media however exhibited greater corresponding losses and rates than the gasoline media under the same concentrations of H_2SO_4 and exposure durations of the samples as can be seen from Figs. 1-10.These clearly indicate that petroleum products per se which are hauled by the semi-trailer have negligible effects on corrosion of the shell make steel. Therefore environmental exposure corrosive factors from the atmosphere, soil, and humans coupled with dynamic effects from bad road conditions are seen to have been responsible for some forms of corrosion that caused the shell to fail by cracking.

3.1.3 Microstructures and surface morphology

The microstructures or surface morphologies of the as-received and corroded samples prepared from the failed semi-trailer shell components are presented in Plates VIII to XV.
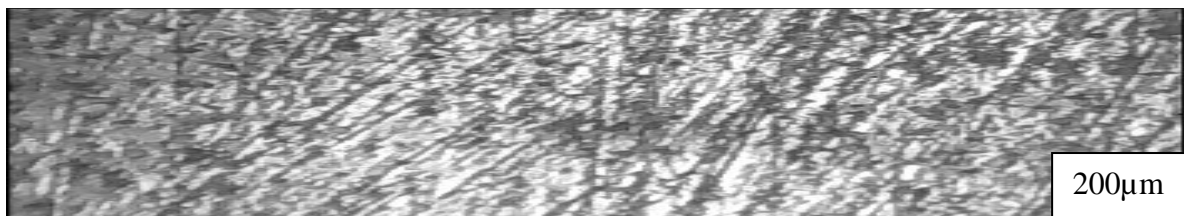

Plate VIII: SEM microstructure a sample got at away location from where the shell failure occurred
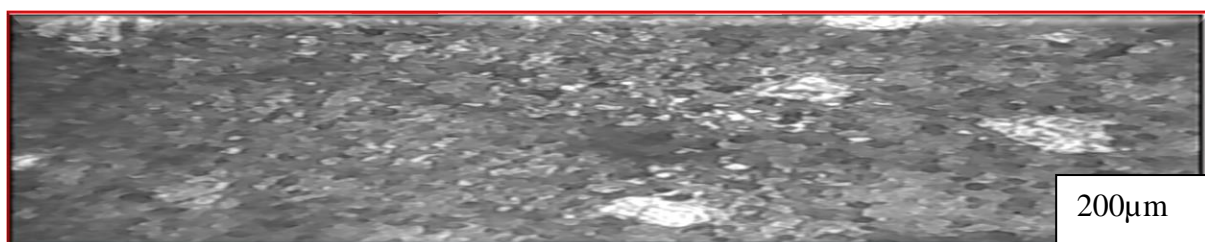

Plate IX: SEM micro-structure of a sample from the failure location of the semi-trailer shell

Plate X: SEM surface morphology of a sample from the failure location after it was immersed continuously for 1200 hours in as-received gasoline media

Plate XI: SEM surface morphology of asample from the failure location after it   was immersed continuously for 1200 hours in the as-received diesel media
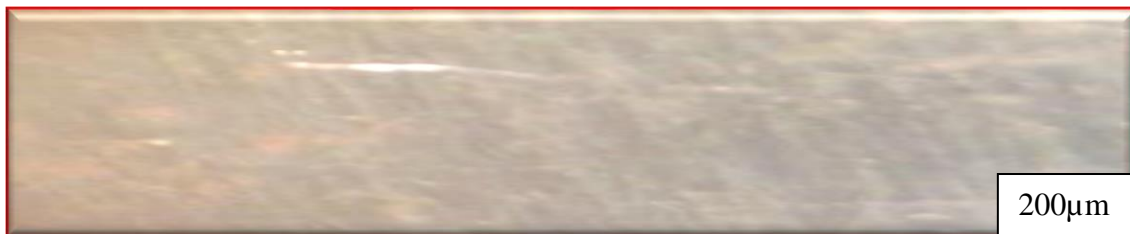

Plate XII: SEM surface morphology of a sample from steel got on the semi-trailer shell at the shell failure location after it was immersed continuously for 1200 hours in the as-received gasoline media

Plate XIII: SEM surface morphology of sample from steel got on the semi-trailer shell adjacent the shell failure location after it was immersed continuously for 1200 hours in the as-received diesel media

Plate XIV: SEM surface morphology of a sample from the failure location after it was immersed continuously for 1200 hours in as-received gasoline media that contained 25% Wt of concentrated H_2SO_4

200μm

Plate XV: SEM surface morphology of a sample from the failure location after it was immersed continuously for 1200 hours in a diesel media containing 25% Wt of concentrated H_2SO_4

In Plates VIII to XV, it can also be observed that the metallographies and surface morphologies of samples prepared with the steel make materials gotten at and away from the shell failure location were very different. Plate VIII shows a more consistent microstructure than plate IX which is heterogeneous. It is notable that for a material to perform optimally in corrosion behavior and strength, it needs among other requirements to be homogeneous. Lack of homogeneity in the shell make low carbon steel around the failure location as indicated by Plates IX was seen to have aggravated corrosion rates at the location. Inimical forms of corrosion such as galvanic corrosion, selective removal of some metallic ions, corrosion fatigue, and stress corrosion cracking might have been responsible for failure of the shell [16, 17]. Plates X to XV also show different surface morphological characteristics of the exposed coupons in the prepared media. This agrees with the earlier discussion that corrosion behavior of the shell make material at and away from the failure locations are different.

In all and all, collated field and test information vividly indicated that the shell failed following an improper weld-repair work on it which created a debased material location with wide differences in metallography and chemical composition, and increased corrosion rates and weight losses by comparison to the as-made shell mild steel. These presumably raised the location stresses amid dynamic effects from frequent bad road conditions, and caused the shell to crack along the weld seam of the previous repair work.

To forestall future occurrence of this and other related failures, it is suggested that companies that use semi-trailers for hauling petroleum products in Nigeria beef up timely and proper corrosion monitoring, inspection, servicing, and repairs of their semi trailers and other related vehicles by employing the services of competent, committed and dedicated personnel with correct working tools or facilities in line with stipulated or standard maintenance practices for the vehicles.

4. Conclusion
There are main and subsidiary petroleum marketing companies in Nigeria. These companies have fleets of oil-hauling semi-trailers under their managements that operate under peculiar road and other environmental exposure conditions. Analyses of shell failure of a semi-trailer tanker owned by one of the subsidiary oil marketing companies which resulted in substantial loss of the trailer's full-tank carried oil have been conducted by visual examination, maintenance background survey; as well as chemical composition, metallographic inspections, and gravimetric laboratory corrosion behaviors of materials collected at critical locations from the shell-make. Collated information from the analyses vividly indicated that the shell failed following a substandard weld-repair work on it which created a debased material location that aggravated corrosion thereat and presumably raised the location stresses amid dynamic effects from frequent bad road conditions and caused the shell to crack along the weld seam. To forestall future occurrence of this and other types of

failures, the work suggests that the oil marketing companies should beef up scheduled corrosion inspection, and timely servicing and repairs of their semi-trailers and other vehicles under their managements by employing the services of competent, committed and dedicated workmen with correct working facilities in line with stipulated or standard maintenance practices for the vehicles.

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