TECHNO-ECONOMIC STUDY OF ALUMINIUM ALLOY AND STEEL AS MATERIALS FOR DECKHOUSES OF OFFSHORE SUPPORT VESSELS

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ABSTRACT

Aluminium alloy is a relatively more expensive material than steel although its weight is one-third of the steel. Thus the use of steel as a structure adds additional weight by 60%; and when used as deckhouses would raise the GM and scarifying the stability of the offshore support vessel. This paper reviews the merit and demerit of Aluminium alloy and steel focusing on fabrication and assembly, and maintainability cost typical of a 60.0m offshore support vessel operating between Kemaman port and offshore oil rigs in the South China Sea. Mathematical equation was used to calculate the weight of the materials used to construct the deckhouses. Also, net present value and payback period calculations were performed to indicate the economic benefit between the two materials. The initial construction cost for Aluminium and Steel are USD 45506 and USD 6808 respectively involving 23.5 metric ton for Aluminium and 67.0 metric tons for steel. In term of investment, offshore support vessels using Aluminium have shorter payback period of 7.9 years and 8.4 years for steel inclusive of the costs of maintenance and operation. This exercise indicates Aluminium alloy is more economical than steel as construction material for deckhouse of offshore support vessel due to its light weight, lower maintenance and increase earning capacity (more cargo).

Keywords: Aluminum alloy, cost-benefit analysis, deckhouse, offshore support vessel, payback period

NOMENCLATURE

AAC	Average annual cost
B	Benefit
C	Cost
CBA	Cost benefit
CF	Cash flow
DCF	Discount cash flow
DP	Dynamic positioning
EU	Europian Union
G	Grafity
HAZ	Heat effected zone
HSLA	High strength low alloy
IRR	Internal rate of return
LOA	Length overall
MIG	Metal inert gas
MSET	Marine System Engineering Terengganu
NPV	Net present value
OSV	Offshore support vessel
PV	Present value
TIG	Tungsten inert gas
US	United States

1. INTRODUCTION

The demand in the offshore support vessel (OSV) market in Asia Pacific will continue to grow, driven by deepwater exploration and production activities. The Offshore Support Vessels undertake production support, diving support, supply duties for personnel and materials, anchor handling, towing, mooring, rig moving, emergency response or rescue and fire fighting operations.

Various approaches have been utilized including lighter weight materials for equipments and deckhouse structure of OSV. According to John et al. [1] aluminum alloy has been used for many years for the deckhouse structure and it might be useful to briefly trace the history of its introduction to the fleet. In the early 1950, in an attempt to reduce deckhouse weight by 35 – 40% [1]. The use of aluminum alloy as a structural material for deckhouses goes back to the 1890s and Aluminum alloy continued to be the standard deckhouse material because its use reduced topside weight by one half [2]. Aluminum alloy has been used for then deckhouse structure of US Navy combatant and amphibious ships for more than 70 years [3]. However, aluminum alloy began to be adopted worldwide for fabrication of the superstructure of passenger ships, a practice that continues today [3].

The steel used in ship construction was mild steel with 0.15 - 0.23% carbon content [4]. Beside that the use of high tensile steel in bottom and deck can reduce weight by 5 - 7%. The most commonly used aluminium alloys for marine applications were 5000 and 6000 seriess, which have magnesium as their primary alloying element [2, 5]. The 5000 series alloys have generally shown to have excellent resistance to corrosion, there was concern that material is becoming sensitized over

time to intergranular corrosion and stress-corrosion cracking, particularly when subjected to higher service temperatures on exposed decks [5]. Besiedes that, most aluminium alloys require low maintenance because of their good corrosion resistance. Therefore, aluminium is an excellent candidate for all applications where the benefit of freedom from initial protection and maintenance yields a commercial benefit. Aluminium is lighter than mild steel (approximate weight: Aluminium 2.723 ton/m³, Mild steel 7.84 ton/m³) and with an Aluminium structure it has been suggested that up to 60 per cent of the weight of a steel structure may be saved. Aluminium alloy also has excellent strength to weight ratio making it ideal for use in situations where high strength and low weight are required [6].
The properties required of a good shipbuilding steel is reasonable cost [4]. The use of the Aluminium alloy was higher initial cost, this have been estimated at 8 to 10 times the price of the steel on a tonnage basic [7]. Aluminium alloy was a more expensive material than most alternative structural materials. Cost was major consideration when decide to build deckhouse on offshore support vessel. And weight of the steel was heavier than Aluminium alloy**.** The weight of steel causes deckhouse not suitable to build on the offshore support vessel. Aluminium alloy was about one-third the weight of steel for an equivalent volume of material. The use of steel in a structure can result in addition of 60% of the weight of an equivalent aluminium alloy structure. This addition in weight, particularly in the upper regions of the structure, can lower the stability of the ship.
The study was aim to determined which material is more suitable to build the deckhouse on offshore support vessel. For this purpose three parametres were considered in this study. First, to identify weight difference between using Aluminium alloy and Steel for deckhouse and that cause this ship gains more carrying cargo. Second, to estimate the costs using Aluminium alloy and Steel for deckhouse. Third, to calculate the profit that the ship gains while carrying more cargo. It is usual to apply discounted cash flow methods to establish a net present value for the comparison of different design options. A compound interest rate is used to determine the 'present' value of money to be spent in later years. The net present value (NPV) must be positive if an option is acceptable. The task of the ship builder is to evaluate the various The ship was build by MSET shipbuilding Corporation Sdn Bhd in May 2009 Kuala Terengganu. The ship is 60.0 m length, used for undertake production support, supply duties for personnel and materials to the oil platform. The ship was equipped with all facilities for 20 crews. The speed of the ship is 13.0 knots. The ship is shailing from Kemaman Port to Esso Platform. The distance between Kemaman Port and Esso Platform is about 124.3 miles. Kemaman Port is a major seaport located on the east coast of Malaysia in the state of Terengganu and is an important LNG shipment port. The dimensions of the ship are given in the Table 1

options in economic terms to see which gives the best overall result, recognizing both cost and operational performance.

2. METHODOLOGY

One excisting offshore support vessel was used in this study. Figure 1 is shows the methods used to determined the best material for deckhouse construction. Interview method also used to get more data and information about deckhouse from the shipyard. Mathematical models and equations were used to compute the weight and cost difference between using aluminium alloy and steel for deckhouse. Net present value, cost-benefit analysis (CBA), and payback period were used to analyse the fersibility of the desigen obtions in this study further namely.

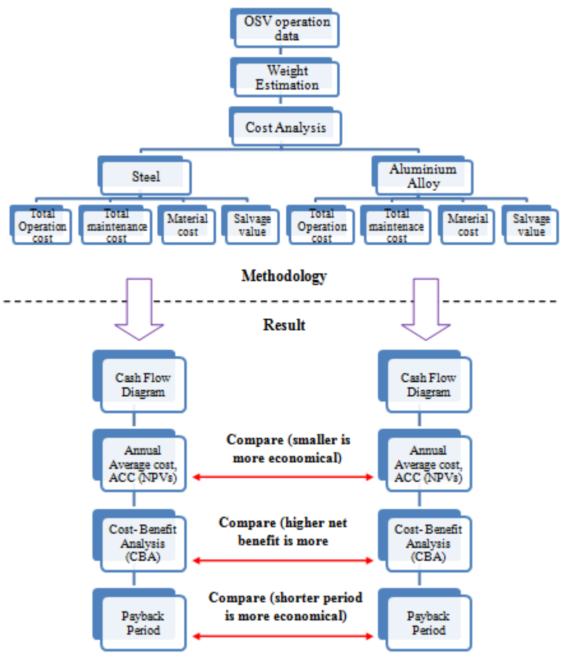

Figure 1. Methodology Flow Chart

Table 1. Principal Dimension for Offshore Support Vessel

Length overall	60.00m	Main Engine:	2714bhp ×2
Length waterline	58.74m	Main generator:	260kW ×2
Beam	16.00m	Auxiliary Generator:	99kW
Depth	6.00m	Deck space:	390m² (Approx.)
Draft	5.10m	Deck loading:	5 ton/m²
DWT	1650ton	Speed:	13.0knots

In this study the weight of deckhouse was taken from bridge deck and navigation bridge deck. The construction of deckhouse was form by steel frames, bracket, and plate. The total weight calculation for bridge deck and navigation bridge deck is given in Table 2.

Table 2. The total weight for bridge deck and navigation bridge deck

No.	**Bridge deck**		**Navigation bridge deck**	
	Description	Weight (kg)	Description	Weight (kg)
1.	Starboard side bulkhead	3274.4510	A - A	1642.6490
2.	Port side bulkhead	3274.4510	B - B	2768.9010
3.	A – A	2251.4940	FR 57	83.939
4.	B - B	3836.3540	FR 58	1786.121
5.	C - C	1334.6810	FR 59	169.632
6.	D - D	1098.4250	FR 60	177.938
7.	FR 55	599.368	FR 61	103.341
8.	FR 56	2471.2000	FR 62	265.358
9.	FR 57	131.2060	FR 63	177.938
10.	FR 58	809.3160	FR 64	2259.3870
11.	FR 59	161.6080	FR 65	147.566
12.	FR 60	161.6080	FR 66	641.8040
13.	FR 61	161.6080	FR 67	606.3170
14.	FR 62	161.6080	FR 68	212.563
15.	FR 63	901.0640	FR 69	223.823
16.	FR 64	131.2060	FR 70	1033.7800
17.	FR 65	772.9540	FR 71	546.636
18.	FR 66	131.2060	FR 72	188.917
19.	FR 67	131.2060	FR 73	321.153
20.	FR 68	131.2060	FR 74	188.917
21.	FR 69	131.2060	FR 75	129.413
22.	FR 70	131.2060	C view	2814.7539
23.	FR 71	654.8160	D view	2445.3200
24.	FR 72	329.4260	E view	1085.3760
25.	FR 73	128.7666	F view	545.8200
26.	FR 74	126.3258	G view	489.2725
27.	FR 75	123.8864	H view	545.8200
28.	FR 76	121.4456	Profile @ 5.2 off C.L	1380.1780
29.	FR 77	119.0060	Upper base of bridge	6512.3600
30.	FR 78	116.5652		
31.	FR 79	111.4272		
32.	Front bulkhead	2316.739		
33.	F view	463.7950		
34.	Upper base of bridge	10726.5540		
	Total	**37527.3848**	**Total**	**29494.9934**

2.1 STEEL DECKHOUSE

The ship has been builded mostly using grade A ABS steel. Density of grade A ABS steel is 7850 kg/m³.

Total weight of deckhouse (steel) = Weight of bridge deck + Weight of navigation deck = 37527.3848kg + 29494.9934 kg = 67022.3782 × 0.001 tonnes = 67.02 tonnes

2.2 ALUMINIUM DECKHOUSE

The 5083 grade of Aluminium alloy is mostly used for ship construction and density of 5083 grade of Aluminium alloy is 2660 kg/m³. According to Loscombe [8] Aluminium alloy is exhibing 65% of the total weight of steel version. Therefore,
Total weight of deckhouse (Aluminium alloy) = Total weight of deckhouse (steel) × 35% = 67.02 ton × 0.35 = 23.457 tonnes

The weight of deckhouse using aluminium alloy is 23.457 tonnes whereas the weight of deckhouse using steel is 67.02 tonnes. Net weight gain of the ship using Aluminium alloy deckhouse is 43.563 tonnes. Therefore, the ship using Aluminium alloy deckhouse can carry more cargo compared with using steel deckhouse.

2.3 COST

The investment cost, material cost, labour cost, maintenance cost and overhead cost of offshore support vessel were estimated based on market prices. The labour cost of Aluminium alloy ship is higher because Aluminium alloy welding needed special skill workers. The price of aluminium alloy was USD 1940 per ton whereas price of steel was USD 400 per ton. Overhead costs include a wide variety of costs incurred in the operation of the shipyard which are not directly chargeable to particular ship contracts. They include such items as interests on bank loans, rates and taxes, insurance, electricity, telephone and postage and others. The overhead cost is normally 80% of the labour cost [9]. The maintenance cost is cost for maintenance and repair of the ship. In this study, maintenannce cost for steel was considered as 15% of total material cost per year. In addition, the total maintenance cost of Steel was assumed increasing 3% each year. Meanwhile, maintenannce cost for Aluminium alloy was 2% of total material cost per year. In addition, the total maintenance cost of Aluminium alloy was assumed increasing 1% each year [9].

Besides that, operation cost and salvage value also were estimated. Operation cost included fuel cost and lube oil cost. It depends on specific fuel consumption rate, normal brake horse power of engine, duration of trip and current fuel price. The specific fuel consumption rate depends on the engine that used by the ship. Salvage value is the return cost when sell the ship. The salvage value depends on the market. It was assumed that the salvage value of the offshore support vessel is decreasing by 5% each year. The service life of the ship was considered as 20 years. The estimated cost componentens and overall cost are given in Table 3.

Table 3. Cost estimation

Item	**Componentens**	**Cost (USD)**	
		Aluminium alloy	**Steel**
Investment cost	Ship cost(not include the deckhouse cost, labour cost and overhead cost)	- 17 million (assume)	- 17 million (assume)
	Material cost (Deckhouse cost)	- 45506.58	- 26808
	Labour cost	- 213652.8	- 175122
	Overhead cost	- 170922.24	- 140097.6
Total investment cost		- 17430081.62	- 17342027.60
Maintenance cost		- 910.12	- 4021.20
Operation cost (1st year)	Fuel oil cost	- 1518775.47	- 1518775.47
	Lube oil cost	- 3659.64	- 3659.64
Salvage value		+ 6577304.09	+ 6544076.59

Note: + debit (profit), - credit (expenditure)

2.4 INCOME OF SHIP

The following parameters were assumed for the income calculation of the ship. For a trip between port and platform 4 days are needed include loading and unloading. The operation days in a year is 300. Average freight rate is USD 0.35 per ton / mile.

Income per year of deckhouse using Steel = USD 0.35 per ton /mile × 1200 tonnes × 124.3 miles × (300/4) = USD 3915450

Net gain weight for AL deckhouse = 67.02 ton - 23.457 ton = 43.563 ton
Income per year of using Aluminium = USD 0.35 per/miles × (1200 + 43.563) ton × 124.3miles × (300/4) = USD 4057580.84

3. RESULT AND DISCUSSION

3.1 CASH FLOW DIAGRAM OF STEEL AND ALUMINIUM DECKHOUSES

Figures 2 and 3 show the cash flow diagrams for steel and Aluminium alloy deckhouse ships respectivly. The positive direction shows the profit and negative direction shows the expenditure.

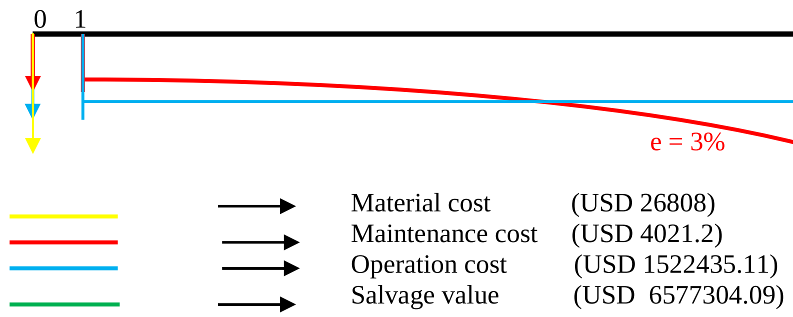

Figure 2. Cash flow diagram for Steel

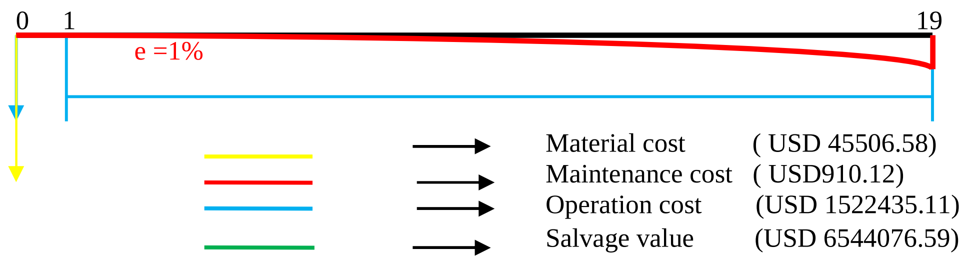

Figure 3. Cash flow diagram for Aluminium alloy

3.2 ANNUAL AVERAGE COST

To calculate the profit that the ship gains, it is usual to apply discounted cash flow methods to establish a net present value for the comparison of different design options. A compound interest rate is used to determine the 'present' value of money to be spent in later years. The net present value (NPV) must be positive if an option is acceptable. The differences in Annual Average Cost (AAC) between Steel and Aluminium alloy deckhouse ship operation was used to analyzed the fesibility. The following equations were used to calculate AAC.

NPV (Net Present Value) = $\sum$ - PV (maintenance cost) – PV (operation cost) + PV (salvage value) (1)

PV (maintenance cost) $= D\left[\frac{\left(\frac{1+e}{1+i}\right)^n - 1}{e-i}\right]$ (2)

PV (operation cost) $= p\left[\frac{(1+i)^n - 1}{i(1-i)^n}\right]$ (3)

PV (Salvage Value) $= \mathbf{P}(1+i)^{-n}$ (4)

ACC (NPV) $= NPV\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$ (5)

wher *PV* is present value, *D* is maitenance cost for 1st year, *e* is % of maintenance cost each year, i is interest rate, n is life time in years, *p* is operation cost and ***P*** is salvage value.

AAC (NPV) of deckhouse using Steel:
$= \text{USD } 39429459.27\left[\frac{0.02\,(1+0.02)^{20}}{(1+0.02)^{20}-1}\right]$
= USD2411611.54

AAC (NPV) of Aluminium deckhouse :
$= \text{USD } 39277476.31\left[\frac{0.02\,(1+0.02)^{20}}{(1+0.02)^{20}-1}\right]$
= USD 2402315.85

The result reveled that the annual average cost of Steel deckhouse ship was higher thanthe annual average cost of Aluminium alloy deckhouse ship. Therefore, Aluminium alloy deckhouse ship is more economical.

3.3 COST BENEFIT ANALYSIS

A cost benefit analysis finds, quantifies, and adds all the positive factors. These were the benefits. Then it identifies, quantifies, and subtracts all the negatives, the costs. The difference between the two indicates whether the planned action is advisable. Overall cost-benefit analysis is presente in Table 4.

Table 4. Overall cost-benefit analysis

Description	Aluminium alloy (USD)	Steel (USD)
Income Investment per year	4057580.84	3915450.00
Total benefit	4057580.84	3915450.00
Maintenance cost	910.12	4021.20
Construction cost for deckhouse	45506.58	26808.00
Operation cost per year	1522435.11	1522435.11
Total cost	1568851.81	1553264.31
Net benefit	**2488729.03**	**2362185.69**

Comparison of cost-benefit analysis of Aluminium alloy and Steel deckhouse ship is given in Figure 4. The net benefit of the Aluminium alloy deukhouse ship is higher than net benefit of the Steel deukhouse ship and difference between them is USD 126543.34. The results shown that the Aluminium alloy deckhouse ship has maximum net benefit. If we used steel for deckhouse, the lost of the profit wsa USD 126543.34 compared with Aluminium alloy deckhouse. Therefore, deckhouse using Aluminium alloy is more profitable for offshore support vessel.

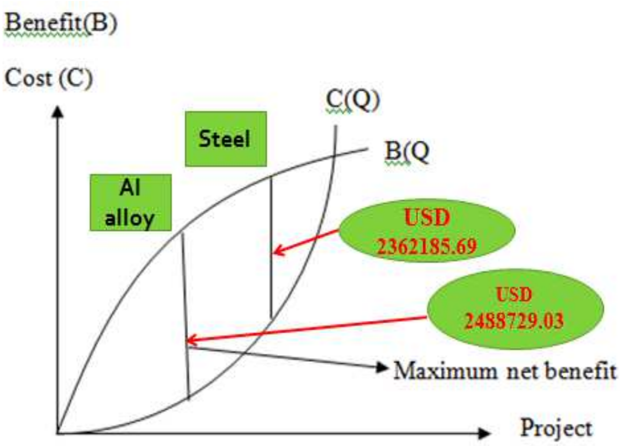

Figure 4. Comparison of cost-benefit analysis of Aluminium alloy and Steel deckhouse ship

3.4 PAYBACK OERIOD

Payback period is the amount of time required to recover the initial investment in a project.

Cash inflow of deckhouse using Steel:
Income - maintenance cost - operation cost - crew cost
USD 3915450 - USD 4021.2 - USD1522435.11 - USD 332268
USD 2056725.69

Payback Period: $\frac{USD\ 17342027.60}{USD\ 2056725.69}$
= 8.4319 years
= 8 years 5 months

Cash inflow of deckhouse using Aluminium:
Income - maintenance cost - operation cost - crew cost
USD 4057580.84 - USD910.12 - USD1522435.11 - USD 332268
USD 2201967.61

Payback Period:
$\frac{USD\ 17430081.62}{USD\ 2201967.61}$
= 7.9157 years
= 7 years 11 months

These results show that the payback period of Aluminium alloy deckhouse was shorter than Steel deckhouse. Therefore, Aluminium alloy deckhouse is more economical for offshore support vessel.

4. CONCLUSION AND RECOMMENDATION

The research results are conforming that the Aluminium alloy is more suitable for building deckhouse on offshore support vessel since it has lighter weight than steel, permit the vessel to carry more cargo, less annual average cost, maximum net benefit and shorter payback period. Therefore, Aluminium alloy deckhouse ship is more economical.

Further, the performance Of the deckhouse using others materials such as composite (lightweight and better dimensional stability than steel elements) must be studied in future and a prototype of OSV develeped to evaluate the performance.

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