Design Synthesis for weight and cost reduction through Material optimization for H-1301 Discharge in IFSS

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ABSTRACT

With the current rise in military activities in all the realms of the security forces, the demand for higher and more innovative safety standards has increased substantially over past decade in India. As a consequence, a system was required to be developed that could instantly and effectively suppress and cut-off the most fatal cause in battlefield that is Fire. Hence a system was developed for the same cause named Instant Fire Detection and Suppression System. Manufacturing of fire extinguisher cylinders encompasses several cold working processes for which materials play a crucial role as they are important for economic fortune moreover they are at center of property and innovation. So in order to select optimum material used for manufacturing major challenge is to reduce the cost of manufacturing. The whole research process is to discuss possible methods to increase the efficiency of the system by further decreasing the weight and to find further application in other combat vehicles (especially aero planes) besides tanks. A thorough study on materials have been done for a lightweight fire extinguisher shell along with its manufacturing technique. This study concludes that Aluminium 7075-T6 is the perfect option for manufacturing of lightweight fire extinguishers for IFSS.

Keyword : - *Lightweight, Fire-Extinguisher, fire, suppress, instant-detection*

1. INTRODUCTION

All manufacturing processes have to deal with materials as they are basic elements for any product. Environmental performance of products are at center of materials. Reducing a product's environmental impact through material use-reduction commitments and material resource efficiency are examples of industry-led responses to support wider sustainable business strategies. Material selection is necessary for every product and involvement of designer is necessary any product. Design practitioners achieve these tactics by reducing environmental impact through material selection, Environment Friendly design practices and application. Despite an evolving culture of sustainability in industry, there are limited methods or processes to support the management and synthesis of material knowledge to progress the material innovation in a design development process.
For manufacturing high quality products at comparative low cost requires thorough knowledge of large number of factors which includes manufacturing processes, material properties, design considerations etc. all these complex interactions are essential for converting material into desired forms. Today wide range of materials and processes are available and task of selecting optimum material while minimizing cost and weight is a hindering challenge. Therefore to meet these challenges designer are required to have in depth knowledge of material and their properties along with processes which are associated with manufacturing technology [1]. As no two materials are identical to one another so the most optimum choice of material is decided by a smart combination of economic factors and

material properties which compels most favourable solution. For Selecting optimum material a thorough and detailed scientific approach is required and following major challenges need to be satisfied:

a) Fundamental properties: The correct combination of mechanical, chemical and physical properties are required to meet basic operating condition of component.
b) Manufacturing properties: This property plays an important role as material needs to mouldable into desired shape with ease in process like casting, forming, machining etc.
c) Economic factor: overall economics of material is taken in account right from cost of material to availability, cost of manufacturing and recycling aspect of material

Instant Fire Detection & Suppression System (IFSS) is a microcontroller based fire detection and suppression system for armoured vehicles. This equipment is used to automatically detect fire and suppression of fire is carried out in two ways either automatically or by pressing manual override switch which is present in crew as well as in engine compartment of the tank [2].

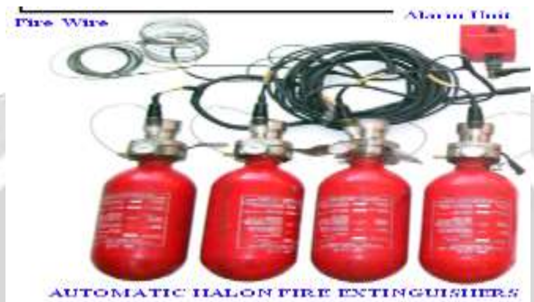

Fig. 1 Instant Fire Detection and Suppression System for AFVn

The components of IFSS system are:

- IR sensors: These sensors detect the fire in crew compartment and send the conformation signal of fire to main control unit (MCU). The MCU further takes the necessary action.
- Fire Wire: It is a flexible heat detecting wire, having one or more elements joined in series by means of various connector accessories. Its logic is designed for detection “over heat”, “fire”, “open circuit”, & “short circuit” condition.
- The system has features of continuous health monitoring of Detector units, Alarm & Flasher unit, Fire wire & Fire Extinguishers associated with it.

The existing fire extinguisher cylinder used in IFSS is made up of Si-Mn steel 32G2SF1 and has a tare weight of 6.41 Kg. these cylinders contain 3.5 Kg of halon gas. So after charging the cylinder, the total weight of the cylinder becomes 12-13 Kg (including weight of assembly valves) which is considered to be quite a huge load for any safety equipment reducing the weight of product can lead to easy accessibility.

Thus the objective of our research is to reduce the tare weight of the cylinder by substituting the existing material with a suitable low weight and high strength characteristic materials with minimum change in dimensions.

2. STATEMENT OF PROBLEM

A better and more lightweight system is required to make it much more portable and useable in lightweight vehicles and aircrafts as lightweight equipment are more manoeuvrable than heavier alternatives also they are easy to use and are tend to be more safer than heavier ones [3].

Currently used lightweight fire extinguisher, consists of

- Steel (ST12) for cylindrical hull
- Thickness around 1.4 to 2 mm.
- Inside coating of epoxy or polyester to prevent corrosion
- Outside protective coating of paint.

Hence a thorough study of multiple materials is required in order to come up with a material that is optimum in terms of strength, processibility, cost and most importantly weight.

The following materials are unsuitable for manufacturing when taking into consideration the requirement for manufacturing fire extinguisher cylinder:

- Ceramics or glasses: due to their porous and brittle nature.
- Magnetic materials: magnetic behaviour is highly undesirable.

- Fibres, particulates or foams: As they are not watertight and leakage of Halon is lethal.
- Expensive material like tungsten: As aim of study is to reduce current cost.

Thus keeping in mind all the above unsuitable materials, the aim of this study is to provide thorough in depth research of most suitable and optimum materials which can be used to replace the current material used in manufacturing modern fire extinguisher.

3. LITERATURE REVIEW

For selecting new material a detail knowledge of material selection process as well as design aspects of product is required. Many researchers have tried to provide a simple yet efficient solution for material selection process based upon requirement of designer. S. Prendeville [4] talks about material selection and design for sustainable material innovation. Thus educating how material selection for environment friendly design needs consideration of factors over and above the technical properties of materials. Research also dealt with how material system as a method helps to communicate material selection as influenced by internal and external business factors. Furthermore identifying opportunities to allow for an exploratory approach to materials within a business's design portfolio is essential to cultivate material knowledge. For example, through trialling new materials on less crucial projects or on minor parts management can create room for knowledge generation through experimentation.

Steven E. Hodges [5] talked about how medical and environmental concerns necessitated changes in armoured vehicles including changes to the crew-bay AFES. The study concluded how a major change in the AFES was the switch from Halon 1301 to a Halon-alternate suppression agent such as a blend of HFC-227ea and sodium-bicarbonate based dry chemical. This study gave an idea about how weight reduction parameters can be worked upon gases or liquid agents being filled in the cylinder of fire extinguisher

In study done by J. Jia-ming [6] it was shown how release characteristics of the gas extinguishing agent depend upon different filling conditions through rigorous jet test platform. The calculation model of jetting gas extinguishing agent from gas extinguisher vessel was constructed with AMESim and the jet performance of gas extinguishing agent was simulated by using the two-phase flow model. The study concluded that for different filling pressure, outlet pressure showed rapid decline with jetting time.

From literature review one can conclude that for a particular filling pressure thickness of cylinder is determined and is designed considering the factor of safety. Larger thickness correspond to increase in overall weight which is not desired, Especially in case when this system is being used in aircrafts, where added weight increases the amount fuel consumption and reduces its flight time. Also provided an idea about how replacing the current used agent can provide additional benefits. Overall it can be seen that weight of cylinder is very crucial parameter while considering the safety of equipment.

4. RESEARCH METHODOLOGY

When selection a material four factors are to be kept in mind Availability, Mechanical properties, Cost and Manufacturing considerations. Thus keeping these factors in mind the main objective of this decision making process is optimization.

A. Specifications Of The Existing Cylinder

- Material: Silicon Manganese steel STH 70 (acc. to IS 7285)
- Tare Weight: 6.41 Kg
- Weight of Halon Gas: 3.5 Kg
- Total Weight: 12-13 Kg (including weight of assembly valves)
- Water capacity: 3.6 litres
- Bottom: convex
- Hydrostatic Test Pressure: 240 Kgf/cm^2
- Working Test Pressure: 140 Kgf/cm^2
- Yield Stress: 4700 Kgf/cm^2

Material currently being used in modern fire extinguisher is really cheap when compared to other material but along with it has some cons like heavy weight. Total assembly of fire extinguisher cylinder weighs around 12-13 kg which is very bulky considering the fact that they are safety equipment.

B. Optimization Statements and Constraints

To further proceed with study there is need to understand the design and manufacturing constraint of fire extinguisher cylinder like when manufacturing hull series of processes are followed. Firstly the two bodies of hull are drawn from steel coils after that parts are welded together to create a filling opening a hole is cut out form top and finally the finished hull is welded with thread on which a metallic tap made of brass or chrome is screwed on. For nozzle usually plastic is used whereas the hose of hull is made of rubber. Most common types of hull are cylindrical as this form easy to construct as well as very sturdy. As our aim is material optimization no change in design is suggested, all the calculation are based on this design only.

Environmental issues and sustainability are of greater concern of society these days while when considering the view point of consumer they will favor low cost and low weight as it most beneficial to them. So designer has to keep both society and consumer in mind while choosing the material with optimum properties which meet the safety standards and material characteristics desirable from both point of view. So keeping in mind all these point important factors are

- Recyclable materials
- Low energy cost
- Low CO_2 Emission
- Availability of material
- Water required
- Reduced Environmental cost

Sustainability also plays important role while deciding material as these days major concern of environment is to sustain material. Sustainability standards are continuously being revised for improving effect on environment. Also it's been proven beneficial for better environment quality and good for natural resources. So for choosing a sustainable product different set of rules and guidelines are there which has impact on both society and environment. The challenge is to design such a devices that it complies with all regulations and satisfies previously mentioned characteristics.

C. Suggested Materials

Keeping in mind all the design philosophies mentioned above, the following materials mentioned in Table 1 were chosen for the study and a comparison is drawn in tabular format via Density, Ultimate Tensile strength and Tensile Yield strength to further help in selecting the optimum material for replacement in modern fire extinguisher cylinder.

Materials	**Density (g/cm^3)**	**Ultimate Tensile Strength (MPa)**	**Tensile Yield Strength (MPa)**
Aluminium 5- series alloy	2.68	193	89.6
Aluminium 6-Series alloy	2.7	110-310	-
Aluminium 7 Series alloy	2.81	572	503
Inconel 718 alloy	8.9	1375	1100
Inconel 612 alloy	8.44	880	460
Inconel 625 alloy	8.36	710	340
Titanium Grade-5 Alloy	4.43	950	880
Titanium Grade-4 Alloy	4.51	550	480
Titanium 6246 Alloy	4.51	1212	1120
Maraging Steel Grade-250 Alloy	8.2	1800	-
Maraging Steel Grade-300 Alloy	8.2	2030	1990
Maraging Steel Grade-350 Alloy	8.2	2420	2000
AerMAT 340 Steel	7.86	2683	2070
SuperINVAR32-5- Low Expansion Alloys	8.15	483	276

Table 1. Properties of Suggested Materials

D. Optimization and Design Calculation

The nominal diameter (outside diameter in millimeters rounded is to the nearest integer) of the fire extinguisher is specified in **IS: 2844-1964** in case of shells manufactured from flat sheet. The following diameters (in mm) should be preferably used in the case of cylindrical pipe shell: *159, 219, 267, 324, 368, 419, 457, 508, 558.8, 609.6, 660.4, 711.2, 762, 812.8, 863.6, 914.4 and 1016*. The shell thickness (t_s) can be calculated from the equation below based on the maximum allowable stress and corrected for joint efficiency:

$$t_c = pD_s / (2fJ - p) \qquad (1)$$

Where,
t_c=*shell thickness of cylinder*
p= *design pressure*
D_s= *Shell ID*
f=*Maximum allowable stress of the material of construction*
J=*Joint efficiency (usually varies from 0.7 to 0.9)*
Minimum corrosion allowance as specified by IS: 4503 should kept in consideration when deciding minimum shell thickness in accordance with normal shell diameter.

Similarly the equation for thickness of hemispherical end covers is given by:

$$t_h = pR_s / (2fJ - 0.2p) \qquad (2)$$

Where,
t_h=*shell thickness of hemisphere*
p= *design pressure*
R_s= *Shell IR*
f=*Maximum allowable stress of the material of construction*
J=*Joint efficiency (usually varies from 0.7 to 0.9)*
In all the calculations we have assumed the cylinder is a thin cylinder i.e. the ratio of its diameter to its thickness shouldn't be less than 1/15. Also a seamless cylinder is considered with no weld beads, hence Joint efficiency = 1.

In the analysis of thin walled cylinders subjected to internal pressures it is assumed that the radial plans remains radial and the wall thickness does not change due to internal pressure. Although the internal pressure acting on the wall causes a local compressive stresses (equal to pressure) but its value is negligibly small as compared to other stresses & hence the state of stress of an element of a thin walled pressure is considered a biaxial one. Further in the analysis of them walled cylinders, the weight of the fluid is considered negligible.
For all cases factor of safety is considered 4 and formula for inner volume of cylinder is given as:

$$V= \pi/4(600-D_i)\, D_i^2 + \pi/6(D_i)^3 \qquad (3)$$

Where, D_i = *Internal Dia. Of the shell*

Therefore, mass of metal used is given by formula:

$$Mass = Volume*Density \qquad (4)$$

5. NUMERICAL ILLUSTRATION

Materials	T_c **(mm)**	T_h **(mm)**	**Volume (m^3)**	**Mass (Kg)**	**% Difference**	**Price (USD/ton)**
Silico-Manganese Steel (Currently used Material)	4.92	2.35	8.08×10^{-4}	6.2	-	584.4
Aluminium 5- series alloy	28.32	11.306	7.26×10^{-3}	19..5	-214.51%	2350
Aluminium 6-Series alloy	11.767	5.31	2.063×10^{-3}	5.5	11.29%	2500
Aluminium 7 Series alloy	8.2	3.82	1.39×10^{-3}	3.9	37.09%	10604.99
Inconel 718 alloy	3.24	1.57	5.23×10^{-4}	4.6	25.80%	8421.65

Inconel 612 alloy	5.17	2.47	8.52×10^{-4}	7.19	-15.96%	10604.99
Titanium Grade-5 Alloy	4.77	2.28	7.03×10^{-4}	3.11	49.83%	23196.72
Titanium 6246 Alloy	3.69	1.78	5.98×10^{-4}	2.69	56.61%	27215.55
Maraging Steel Grade-350 Alloy	1.81	0.9	2.88×10^{-4}	2.36	61.93%	53015.89
AerMAT 340 Steel	1.633	0.805	2.12×10^{-4}	1.66	73.22%	87055.66

During this study, through different research papers and by expert opinions we have identified some of the key Materials which can be used to replace the current material which is Silico-Manganese Steel. So first step is collection of data of various material through primary market research and analyse it and summarize it. After detailed study and analysis of numerous Materials suggest above optimization and design calculation were performed and results are tabulated in Table 2

Table 2. Result Table of Weight Optimization

6. RESULT AND ANALYSIS

From Table 2. It is evident that AerMAT340 is the perfect option for manufacturing of lightweight fire extinguishers for IFSS. The Weight Reduction with AerMAT340 is 73.3%. Followed by materials like Maraging Steel Grade-350 Alloy, Titanium 6246 Alloy, Titanium Grade-5 Alloy, Aluminium 7- series alloy, Inconel 718 alloy, Aluminium 6-Series alloy which showed good percentage of weight reduction, furthermore material like Aluminium 5- series alloy and Inconel 612 alloy exhibited reverse characteristic by showing increase in weight when compared to current material Silico-Manganese Steel.

Also when considering the cost reduction aspect Aluminium 5- series alloy is cheapest material for manufacturing while AerMAT340 being the most expensive material. Silico-Manganese Steel currently used material is even cheaper than Aluminium 5-series alloy. On the basis of these results, it easy to find replacement of current material also it can be concluded that the optimized material will be meeting the functional and design aspects of the original material and with an additional benefit of weight saving.

7. CONCLUSION

Optimization was performed to reduce weight and manufacturing cost of modern fire extinguisher cylinder. From the above study, we can clearly see that from all the metals and alloys considered, Aluminium 7075-T6 gives the maximum weight reduction along with being economical itself.

The weight reduction achieved is 40%, which could have been improved a lot (upto 75%) but keeping the product economical is also a major responsibility of the designer.

7075 aluminium alloy is an aluminium alloy, with zinc as the primary alloying element. It is strong, with a strength comparable to many steels, and has good fatigue strength and average machinability. It has lower resistance to corrosion than many other aluminium alloys, but has significantly better corrosion resistance than the 2000 alloys. Its relatively high cost limits its use.

7075 has been sold under various trade names including Zicral, Ergal, and Fortal Constructal.

Some 7000 series alloys sold under brand names for making moulds include Alumec 79, Alumec 89, Contal, Certal, Alumould, and Hokotol.

AerMET340 offers the best fit for manufacturing of cylinder if weight reduction upholds most priority AerMAT alloy is not corrosion resistant, so it must be sealed if used in a moist environment. AerMAT is a registered trademark of Carpenter Technology Corporation. Applications include armour, fasteners, airplane landing gear, ordnance, jet engine shafts, structural members, and drive shafts

Silico Manganese Steel can be used for manufacturing of cylinder if cost factor upholds priority being cheapest of all, offers large reduction of cost. But this adversely increases the weight, this factor play a vital role depending on use of cylinder in aerial vehicle.

Concluding the above report, Aluminium 7075-T6 gives fit for manufacturing of cylinder considering normal operating condition where factor of weight and price plays equally important role in determining the constraints.

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