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DESIGN AND FAILURE ANALYSIS OF VAULTING POLE

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ABSTRACT

Composites materials are made by combining two materials where one of the materials is reinforcement (fiber) and the other material is a matrix (resin). The combination of the fiber and matrix provide characteristics superior to either of the materials alone.In the advanced technology, design requirements are becoming more and more diversify to achieve needs of human being.This paper is concerned how to manufacture pole vaulting using composite material. The polevault is a sport where the successful competitor must combine a high level of athletic prowess with the development of unerring and fluid technique. Glass/ epoxy composite material and filament winding manufacturing process are selected using subjective rating and logic methods. Then after, the following design parameters have done:

- Thicknesses of the laminates
- Type of stacking sequences
- Global and local strains and stresses of each lamina, etc.
- Finally, the design is checked using Tsai-wu failure analysis theory whether the design is safe or not.

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The pole vault is undeniably one of the most exciting track and field events. It combines the incredible speed of a sprinter, the explosive energy of a high jumper and the breathtaking grace of a gymnast into one magnificent event. The aim of pole vault is to use a pole to jump over a crossbar which is set at heights of over six meters at world-class level.

I. INTRODUCTION

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The pole vault is undeniably one of the most exciting track and field events. It combines the incredible speed of a sprinter, the explosive energy of a high jumper and the breathtaking grace of a gymnast into one magnificent event. The aim of pole vault is to use a pole to jump over a crossbar which is set at heights of over six meters at world-class level. Pole vault is the only track and field event in which competitors are allowed the aid of a tool to help them reach their goal. Thus, having more than one component, it is likely the most technically complicated event. Originally, the purpose of pole vault was to cross the canals and ditches filled with water in Europe. Of course it followed that men would compete to see who was able to cross the widest canal. This period of pole vault for distance is considered primitive history for the event. No records were ever kept, and competitions were mainly local and unorganized (The History of Vault, 2004).

Pole vault for height began in the early 1900s in college athletics. Still primitive, the athletes jumped on a grass fields, landing on grass too. They sharpened their poles at one end to ensure a secure plant. Bamboo became the pole of choice based on its strength and light weight. Following WWII metal poles were used, because the metals were becoming lighter and stronger, and were much more reliable than bamboo. Soon, fiberglass poles began showing up on the scene. This brings us to the present era of pole vault. (Vault Techniques, 2004). It is apparent that the heights reached in pole vault are based upon both the athletic prowess of the vaulter, and the materials of the poles. It is perhaps the only event in which the world record may be easier to break from one year to the next.

The objective of the study is to:
Select the appropriate material and manufacturing process for the successful functioning of vaulting pole

- To calculate the load acting on the vaulting pole
- Show the economical and functional merits of composite materials.

The study will investigate evidences from internet, books journals and magazines. Materials selection based on the functional requirements of the vaulting pole should be conducted. The results of design analysis will be summarized with tables. By comparing different fabrication methods of composite materials, proper manufacturing method will be suggested.

II. MATERIALS AND METHODS

Composite Materials

When two or more materials are mixed together, the resulting composite material very often has physical properties that are very different than the properties of the used composites.
Many technical textile products appear like textile composite materials that consist of two or more materials of different nature, joined together by adhesion or cohesion (through a third material).

Their typical ways of appearing are:

- stratified composites (spread or assembled surfaces, lamé)
- matrix composites (e.g. bonded fiber fabric joined with a binding agent)

As far as structure is concerned, apart from spread textiles (textile supports, plastic surface or substrate), plastic substances with a textile content (plastic support, external coat made of textile material) deserve consideration. Components are bound together usually by adhesion (it’s a typical method for binding products).

Materials used in fibrous reinforcements

Materials used to produce particularly resistant to traction and to plastic collapsing filaments, are both polymeric and inorganic. Among traditional materials more commonly used there are polyamides, polyesters, meta aramidic fibers and glass fibers, whereas among high performances materials recently developed there are paraaramidic fibers, carbon fibers, high polyethylene modulus fibers and poly-eter-eter –ketone (PEEK) ones. These materials are different for their elastic and environment resistance characteristics and for their plastic collapsing.

Glass fibers

Thanks to their traction and tearing resistance, their high modulus and dimensional stability, glass fibers have been used for many years to produce fabrics and reinforcement materials for composites. They are gotten through warm spinning method of glasses made in a suitable way (usually, alumino- borate –silicate) according to the use and the environment where it will be used. To obtain composites with good characteristics under stress, the break stretching of the fiber (3 and 6% in many composites) must be less and the rigidity must be more of those of the matrix. The transfer of matrix efforts to the fiber is bettered with the help of chemical coverings.

These doubling agents can better very much the mechanic characteristics of the resulting composite.

Carbon fibers

Carbon fibers are thin filaments made of elementary carbon with structures that vary from those of the amorphous carbon to those of the crystalline graphite. These fibers own very variable chemical and physical properties: as far as the elasticity or rigidity modules are concerned, e.g., they change from about 35 Gpa, that is the half of that of glass fibers or of aluminium, to 700 Gpa, more than three times that of steel. As the carbon density is low, the specific rigidity is very high.

Carbon fibers keep electric, thermal and chemical characteristics of carbon and they are often used as reinforcement in rigid polymeric composites. Usually, mechanical resistance and deformability don't increase at the same rate as the rigidity increases. In specific applications where both high resistance and high rigidity are needed, fibrous reinforcements must be chosen, where these two characteristics are balanced. With the current production technologies, the greater resistance is gotten for fibers that have rigidity between 210 and 300 Gpa.

Polyamides
One of the first polymeric materials produced has been the Nylon filament, a polyamide gotten through poly-condensation of diamines and dicarboxil acids that can be linear or contain aromatic groups up to 85% of weight (if contents of aromatics in the repetitive structure are higher than85%, we talk about aramids). Nylon has a big affinity for water and its resistance to ultraviolet radiations is not high but, if protected with a suitable covering, can reach an acceptable environment resistance. However, because of its low elasticity module (about 5 GPa), of its tendency to plastic collapsing under laden and of the dimensional variations caused by water absorbing (fibers stretching in humid places and fiber shortening in dry places), this material gives problems in applications where fabric preliminary tension and dimensional stability are critical. The resistance of this fiber varies between 500 and 700 MPa, but, like the elastic module, it is significantly reduced if there is absorbed humidity.

Polyester
Polyester fibers are gotten through spinning of an aromatic polymer gotten through polycondensation of terephthalic acid and of a dial cool (glycols). The most used polyester is polyethylene terephthalic (PET). The oriented fibers structure is similar to that of polyamides. Polyester contains an aromatic ring that makes it less flexible than polyamide macromolecules. PET fibers are in fact characterized by a higher elastic module, about 18 Gpa, and by break resistance like that of Nylon.

Hybrids
With this word we mean connections of different kinds of fibers finalized to the balancing of some characteristics or weaknesses of individual materials. Frequent examples are those where carbon fibers and more ductile glass fibers are weaved together. In the same way, in order to better the resistance to impact, hybrids with aramidic and glass fibers or aramidic and carbon ones are used. Possible kinds of connections, however, are many and they can be aimed to specific laden and environment conditions.

Generally, Composites are becoming an essential part of today's materials because they offer advantages such as low weight, corrosion resistance, high fatigue strength, faster assembly, etc. Composites are used as materials ranging from making aircraft structures to golf clubs, electronic packaging to medical equipment, and space vehicles to home building. Composites are generating curiosity and interest in students all over the world. They are seeing everyday applications of composite materials in the commercial market, and job opportunities are also increasing in this field.

Combining two or more materials together to make a composite is more work than just using traditional monolithic metals such as steel and aluminum. The traditional dominance of steel and aluminum industrial and product design has long past. Increasingly, companies are exploiting the benefits of advanced composite material systems to improve competitiveness. These benefits include Design freedom, High strength to weight ratios, Structural efficiency, Corrosion resistance, Low maintenance, Long life, Acoustic, thermal and electrical insulation.
The combination results in a material that maximizes specific performance properties. The constituents do not dissolve or merge completely and therefore normally exhibit an interface

Vaulting pole
The pole vault is a sport where the successful competitor must combine a high level of athletic prowess with the development of unerring and fluid technique. Pole vaulting also involves a consideration of the advanced

technologies used to construct the pole; the physical characteristics of the pole will be critical to the generation of the lift necessary to take the athlete over the bar.

As with many of the disciplines that are predominately in the public eye only during Olympic competition, the pole vault is a relatively simple event. The vaulters must clear a bar, positioned above a landing mat, using a long pole with which to propel them upward for leverage to assist in the clearing of the bar. The event commences with a run up along a track. The athlete runs as fast as possible, holding the long pole. The pole is thrust into a pre-positioned box on the track surface, and the athlete converts the forward motion along the track into vertical lift. The pole provides considerable flexion, as it absorbs and then releases the energy of the athlete generated by the approach as the pole is straightened. As the vaulter nears the bar, the pole is used for balance as the vaulter angles his or her body across the bar, falling onto the landing mats below.

The object of the pole vault is to clear the greatest height possible; this object may also be stated as how to best optimize the energy of the athlete created by the run up and the planting of the pole prior to take off. The technology of the pole has been central to the progression of vaulters in achieving greater heights in the past 100 years. As a physical proposition, the greater the amount of energy that can be released from the pole as it is flexed by the athlete on the path up toward the bar, the further the athlete will be able to travel.

In 1896, the Olympic champion used a pole constructed of bamboo; he jumped 10 ft 6 in (3.2 m). The master of vault in the early era was Dutch Warmer dam. He was the first man to ever clear 15 feet, which was done using a bamboo pole.

With aluminum poles in the early 1950s, vaulters could achieve heights of 15 ft 6 in (4.7 m), due in part to the more flexible nature of the aluminum construction, one that absorbed greater amounts of energy when struck into the ground by the vaulter, and which then released the stored energy to the body of the vaulter as the pole uncoiled. In 1994, Sergey Bubka of Russia set a pole vault world record of 20 ft 1.75 in (6.15 m), using a pole constructed of a carbon fiber/fiberglass composite, materials that are both lighter and possessed of a greater coefficient of restitution than the aluminum model.

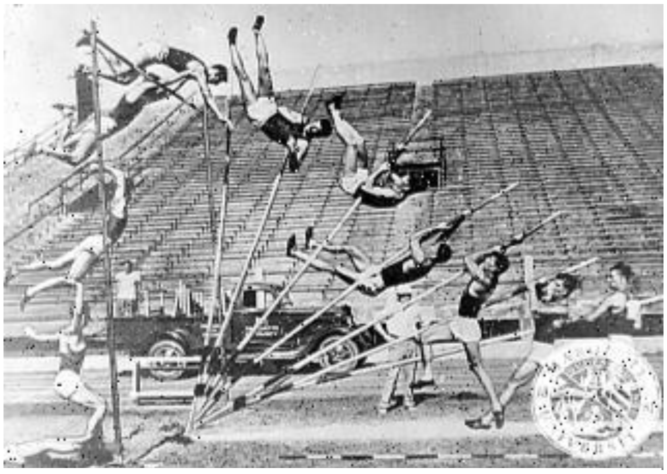

Figure 1 Dutch Warmer dam jumping with bamboo pole

For safety reasons, the poles are rated for use by athletes of a minimum weight to prevent a larger than rated athlete falling as a result of a pole that snaps under an excess weight. Vaulters use as light a pole as possible to ensure that they carry as little weight as possible on the run up, permitting the fastest approach possible, and the corresponding greatest amount of energy to be directed into the pole.

How long can a pole be?

There are no rules on pole length only practical applications. A very short pole would obviously defeat the purpose of using a pole. The longer a pole is, the more awkward it becomes to carry. This is due to weight, leverage, angular inertia (swing or drop - rotational resistance), and air resistance (how about carrying any 17' stick around on a windy day!). Grip height and corresponding pole length is a function of the athlete's physical qualities; standing/reach height and running speed, technical abilities; skill running, planting, and taking off the ground, the stiffness of the pole, and psychological disposition. Further consideration by a wise athlete is efficiency, i.e. the return on the grip height – noting more or higher is not always better.

The longest pole that anyone could recall made for use is 5 meters (18'0.5"). These poles may be bent by over 120° without breaking, and are able to store an amount of elastic strain energy that is equivalent to about one half of the vaulter's run-up kinetic energy (Arampatzis et al. 1999; Gros& Kunkel 1988, 1990).

Vaulting Pole Characteristics

Glass-fiber composites are light and stiff and have a much greater failure strain than that of bamboo (Haake, 2000). Carbon fiber-composites generally have a higher stiffness and this can be a limitation since the vaulter has less time to swing and rotate before the pole unbends. Carbon fiberlaminae also have a higher strength and a typical laminate of carbon fibers in epoxy at 50 % volume fraction would have a strength of 1000 MPa compared with 700 MPa for a similar laminate of polyester and glass fibers (Harris, 1999) Most vaulters still use glass-fiber poles and considerable experience is necessary to use carbon-fiber poles. A pole with too low a stiffness straightens incompletely and the vaulter does not achieve a great height. A pole which is too stiff straightens too quickly and the vaulter reaches peak height too early.

A long pole has low stiffness

- Stiffness to low – not enough support
- Stiffness too high – may cause "bounce back"

A short pole may have sufficient stiffness for support but may not be able to achieve height
We can measure the stiffness by looking at the amount of deflection, *D*, generated by applying agiven load, *F*, at the mid-point:
$D=FL3/48EI$
$I=\pi/64(do4 -di4)$
The Young's Modulus, E, of the composite is controlled by the proportion of fibers and the way in which they are arranged in the matrix, i.e. the angles between the fibers and the axis of the pole θ.

III. DESIGN PROCEDURE

Selection of manufacturing process

Before selecting raw materials for composite manufacturing, it is mandatory to determine the appropriate manufacturing techniques. Because, the material we select prior to manufacturing technique may not be processed by the available method, which leads to wastage of time, labor, and money. Therefore, unlike to conventional materials such as metals, selection of manufacturing technique precedes material selection.

Composite fabrication processes include:

1. **Prepare lay-up** is expensive but produces the highest-quality parts.Prepare parts are usuallycured in an autoclave to maximize part quality.
2. **Filament winding** is a process capable of making parts that are bodies of revolution or nearbodies of revolution. Filament winding can be conducted by using either prepare roving or wet winding.
3. **Wet lay-up** along with low-temperature curing resins, is capable of making very largestructures. It is an excellent process for low-volume large parts. Wet laid-up parts can be cured with or without a vacuum bag.
4. **Spray-up** is another process capable of making very large part size. Due to the randomdiscontinuous nature of the fibers, the mechanical properties are lower than parts made by continuous fiber prepare or Wet lay-up.

5. **Liquid-**molding processes use a dry perform that is placed in a Matched-die tool, liquid resinis injected and the part is cured in the mold. The resin can be injected under pressure or pulled through the perform with a vacuum.
6. **Compression molding** is another matched-die process that uses either SMCs or BMCs that isloaded as a predetermined charge. Heat and pressure form and cure the part to the required shape
7. **Injection molding** is a high-volume process capable of making millions of parts per year. Athermoplastic or thermo set resin reinforced with short fibers is injected into precision mold under high pressures, where it either cools (thermoplastic) or cures (thermo set).
8. **Pultrusion**is a continuous process for making structural shapes of constant cross-section.Roving is normally pulled through a resin bath and into a heated die where the part cures as it travels through the die. It is then pulled to the desired length and cut with a mechanical saw.

Selection of Manufacturing Process Using Digital Logical Method

Selection criteria for determining the appropriate manufacturing process of pole vaulting are:

1) Production rate
2) shape
3) cost
4) size
5) flexibility
6) suitability

Using digital logic method, the total number of possible decisions, N, is given by:

$$N = \frac{n(n-1)}{2}$$

Where, n = number of parameters under consideration (6)

$$N = \frac{6(6-1)}{2} = 15$$

Table 1. Allocation of weighting factor

Factors	Production rate	Cost	flexibility	Size	Shape	suitability
Weighing factor	2.5	2.5	4	1	2	3
Weighting Factor (%)	.17	.17	.26	.017	.13	.2

Manufacturing process selection and Decision

Table 2.comparison of manufacturing process for pole vaulting using normalized out comes

Process	Factors	Product iron rate	Cost	Flexibility	Size	Shape	Suitability	Average r*w	Rank
Filament winding	Rating (r)	70	70	80	70	100	100	13.13	1
	Weight Factor (w)	0.17	0.17	0.26	.017	0.13	0.2		
	r*w	11.9	11.9	20.8	1.19	13	20		
Putruaion	Rating (r)	80	60	70	70	100	20	10.03	2
	Weight Factor (w)	0.17	0.17	0.26	0.017	0.13	0.2		
	r*w	13.6	10.2	18.2	1.19	13	4		
Hand lay up	Rating (r)	40	40	80	60	60	20	7.87	4
	Weight Factor (w)	0.17	0.17	0.26	0.017	0.13	0.2		

	r*w	6.8	6.8	20.8	1.02	7.8	4		
RTM	Rating (r)	60	60	60	60	60	20	8.13	3
	Weight Factor (w)	0.17	0.17	0.26	0.017	0.13	0.2		
	r*w	10.2	10.2	15.6	1.02	7.8	4		

From the above analysis, we conclude that filament winding Processing is more appropriate than other manufacturing methods.

IV. FILAMENT WINDING

Filament winding is a process for fabricating composite materials in which continuous fibers, either previously impregnated with a matrix material or impregnated during winding, are wound onto a rotating mandrel in a precise, predetermined pattern. In the process, the fibers are inter-weave to form regular laminate, which derives more strength from the fiber than in any other composite technology. High-speed, precise placing of the reinforcement in pre-determinate pattern is the basis of the filament winding process. Filament winding is a process for fabricating composite materials in which continuous fibers, either previously impregnated with a matrix material or impregnated during winding, are wound onto a rotating mandrel in a precise, predetermined pattern. In the process, the fibers are inter-weave to form regular laminate, which derives more strength from the fiber than in any other composite technology. High-speed, precise placing of the reinforcement in pre-determinate pattern is the basis of the filament winding process. During the past twenty years, the filament winding industry has gone through a resurgence based on recently developed high strength fibers, toughened resins, and computerized winding equipment. Mikrosam's experts team, with more than thirty years of experience, are deeply involved in the field of research and development of composite materials and designing & manufacturing state of the art filament winding machines. Modern and advanced equipment and control & software solutions keep our customers up to date with the most current and competitive technologies in the fast growing composites industry.

Filament winding machine parts

The Mandrel –varies in length and diameter like the poles. Fiberglass is wound on to themandrel. The bigger mandrel diameter the lower the wall thickness to get a given stiffness. As the poles get longer and stiffer (lower flex number or higher weight rating) the larger the mandrel. Most elite vaulters will specify a certain length, flex rating and possibly mandrel size.

Spiral Wraps –narrow spiral-bound strips of fiberglass are applied to the mandrel. The numberof glass and how they are wrapped all impact pole properties.

Full Body Wraps –typically a rectangular piece that is the full length of the pole and is designedto achieve a certain number of complete wraps around the pole’s circumference when rolled on (with heated rollers). The number of wraps varies with manufacturer.

The Sail Piece –a section of fiberglass of varying length –may be up to the full length andshaped like a sail or trapezoid. The location, size and shape of these sail pieces have a major impact on how and where the pole bends when used. This varies between pole models and manufacturers.

Curing –the pole is ‘cooked’ to get the resin to flow and cure. The temperature, steam and pressure all impact the quality of the final product. **Pre-bend –**once cooled the pole gets a small pre-bend if required.

Proof-test –the pole is bent beyond normal vaulting conditions. Further testing performed if needed.

Flex testing –loaded centrally in bending and flex recorded.
Tape –colored tape, decals, and manufacturers weight-rating applied**.**

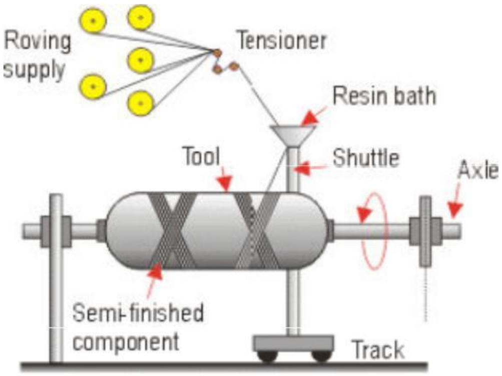

Figure 2 Filament winding machine part

V. RESULT AND DISCUSSION

Material Selection

With growing awareness and customer needs, ignorance of opportunities offered by advanced material systems such as composite materials can cause decreased competitiveness and can lead to loss of market. With the increase in customer demand for higher performance and quality, competition among companies has increased. To capture the global market and be at the cutting edge of the technology, companies are utilizing new and advanced materials for increased performance. In light of global needs and environmental awareness, lightweight materials are gaining importance in various industry sectors.

There are two major reasons for selection processes are:

1. To redesign an existing product for better performance, lower cost, increased reliability, decreased weight, etc.
2. To select a material for a new product or application.

In either case, mere material substitution is not sufficient. The product must be redesigned for the selected material to utilize the maximum benefits of the material’s properties and processing characteristics. When a composite material is substituted for a steel or aluminum product, the part needs to be redesigned to obtain the cost and weight benefits.

Based on the requirements of an application, possible materials and manufacturing processes that meet minimum or maximum requirements of the application are determined. Materials and manufacturing processes are discussed simultaneously because they go hand in hand with composite material systems.
Candidate composite materials, which are selected for comparison with respect to functional requirements of the vaulting pole, are:

- S-glass /epoxy
- Carbon/Epoxy
- Kevlar/ Epoxy

In manufacturing of pole vaulting the following main properties have to be considered as stated in the literature review. Here are the factors with their **Weighting factor** according to the importance of the properties.

Longitudinal strength/stiffness (MPa) - (0.3) Failure
strain (%) - (0.2)
Modulus of elasticity- GPa - (0.05) Cost -
(0.1)
Flexibility - (0.35)

Table 3. Failure strain (%)

Material	Failure Strain (%)	Rating
S-glass/Epoxy	2.6	80
Carbon/Epoxy	0.6	50
Kevlar/Epoxy	2.8	100

Table 4.Modulus of elasticity- GPa

Material	Modulus of Elasticity-GPa	Rating
S-glass/Epoxy	4.9	100
Carbon/Epoxy	7.2	80
Kevlar/Epoxy	2.2	65

Table 5. Cost

Material	Cost	Rating
S-glass/Epoxy	High cost	80
Carbon/Epoxy	Moderately	90
Kevlar/Epoxy	Very High Cost	70

Table 6. Bending capacity

Material	Flexibility	Rating
S-glass/Epoxy	High	100
Carbon/Epoxy	Low	65
Kevlar/Epoxy	Medium	80

Table 7 Resulting out come

Material	*Cost*		*Longitudinal Strength/Stiffness (MPa)*		*Modulus of Elasticity (GPa)*		*Flexibility*		*Failure Strain (%)*	
	M	*W*	*M*	*M*W*	*M*	*M*W*	*M*	*M*W*	*M*	*M*W*
S-glass/Epoxy	*80*	*0.1*	*100*	*100*0.3*	*100*	*100*0.05*	*100*	*100*0.35*	*80*	*80*0.2*
Carbon/Epoxy	*90*	*0.1*	*90*	*90*0.3*	*80*	*80*0.05*	*65*	*65*0.35*	*50*	*50*0.2*
Kevlar/Epoxy	*70*	*0.1*	*80*	*80*0.3*	*65*	*65*0.05*	*80*	*80*0.05*	*100*	*100*0.2*

Table 8. Final Result

Material	*Cost*	*Longitudinal Strength/Stiffness (MPa)*	*Modulus of Elasticity (GPa)*	*Flexibility*	*Failure Strain (%)*	*Total*	*Rank*
S-glass/Epoxy	*8*	*30*	*5*	*35*	*16*	*100*	*1*
Carbon/Epoxy	*9*	*27*	*4*	*22*	*10*	*73*	*3*
Kevlar/Epoxy	*7*	*24*	*3*	*28*	*20*	*81*	*2*

From the above table we can conclude that S-glass /epoxy is the best material to manufacture vaultingpole.

Economical Analysis

The cost of manufacturing a product is different for different manufacturing processes. For a given pole vaulting, there is usually one process that will produce the best results and be least expensive. The designer must select this "optimum process" among the methods available. The optimum may be defined as the one that will give the lowest total cost of the part produced.

To estimate the cost one has to consider both fixed and variable costs. Fixed costs are equipment usage, supervisory, inspection. Administrative expenses are added as 150 to 200% of direct labor costs. This is normal industrial costs.

Labor cost: labor cost is a function of equipment, labor and time required for various activities in casting production

Material cost: The material cost involves both direct and indirect materials. Direct materialsappear in the final product whereas indirect materials are essential for production but are not included in the final product In the economical analysis of the composite manufacturing process of the output for the particular product is determined by analysis of the cost of material of the object with which is used to make the pole vaulting. The procedure is starting by determining the bill of material of geometry of the component of the equipment that makes it.
The length and width of lamina used for making the pole vaulting are:
Thickness of laminate used =0.167mm
Length used=5m
Width =94.25mm
No of laminate**= 10**
Laminate density =2000kg/m3
Volume of the lamina =5m* 0.09425m*0.000167m
= $7.54*10^{-5}m^3$
Density* volume =mass
$7.54*10^{-5}m^3$*2000kg/m3 *10laminate= 0.6kg
1kg resin =80 birr
1kg fiber =65birr
1. Mass of resin = 0.37 * mass of composite
2. Mass of fiber = 0.63* mass of composite Resin
(0.37*0.6kg)=0.222kg
0.222kg *80birr/kg=17.76birr
Fiber (0.63* 0.6kg) = 0.38*65=24.57birr
Total=17.76birr +24.57birr =43birr
10%*43birr +43birr =47.3 birr

VI. CONCLUSION AND RECOMMENDATION

1) The design of vaulting pole requires not only a knowledge of mechanics, biomechanics and the characteristics of the individual athlete but also of materials properties and manufacturing conditions.
2) Modern glass fiber vaulting poles are complex structures in which the multiple layers and components provide flexibility and energy storage whilst ensuring bending stiffness.
3) Fiber bundles and the relative orientation of the layers not only give stiffness and strength but they can help arrest incipient failures.
4) Generally, safe vaulting poles are made of s- glass/epoxy material using filament winding process.
5) A design which is light in weight compact in size, cheap in cost and portable, is smartly attracted by consumers due to economical, functional and durable advantages.

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