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DESIGN FOR PRODUCING FIBERGLASS FABRIC IN A LUNAR ENVIRONMENT

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Abstract

The purpose of this project was to design a method of producing a fabric material on the lunar surface from readily available glass fibers. Various methods for forming fabrics were analyzed to determine which methods were appropriate for the lunar conditions. A nonwoven process was determined to be the most suitable process for making a fabric material out of fiberglass under these conditions. Various resins were considered for adhering the fibers. A single thermoplastic resin (AURUM) was found to be the only applicable resin. The end product of the process was determined to be suitable for use as a roadway surfacing material, canopy material, reflective material, or packaging material. A cost analysis of the lunar process versus shipping the end-product from the Earth suggests that the lunar formation is highly feasible. A design for a lunar, nonwoven process was determined and included in the following document.

Problem Statement

The purpose of this research project was to create a method of producing a fabric on the lunar surface. The fabric had to have a minimum width of half a meter, be composed of readily available fiberglass fibers, and be useful in a number of applications on the lunar surface.

The process to make the fabric was to be operational while fully exposed to the lunar environment. Any beneficial efects of the lunar environment (such as microgravity) were to be incorporated into the design.

Because of the limited amount of power available on the moon, a power constraint was established. The maximum power available for the total process had to be no more than five kilowatts.

To make the process economically feasible, a constraint was placed on the use of non-lunar materials. Any Earth materials necessary had to be kept to a minimal weight.

The final requirement of the process was that the cost of producing a required mass of the end product (in a given amount of time) be less than the cost of shipping the same mass of product from the Earth.

Resin

The resin used for this project is a super heat-resistant thermoplastic polyimide, Aurum, developed by Mitsui Toatsu Chemicals, Inc. Aurum was chosen because of its thermoplastic properties in addition to outstanding heat resistance, cold resistance, and mechanical/electrical properties, which are suitable for use in a variety of applications in the aerospace industry. The resin melt temperature is approximately 390-415° C. The glass fibers are assumed to have the resin in powder form already applied to them during the sizing process. This powdered resin acts both as a lubricant and a binder for the glass fibers. Because Aurum is a thermoplastic resin, it does not need to be cured but simply melted. As soon as the resin melts, it will bond to the fibers uniformly throughout the fiber mat to produce a fabric with a strength of 1156 kPa. The resin itself has a strength of approximately 136 kPa. One advantage of this type of polyimide resin is that it does not boil or foam when melted in a vacuum. The

final product is 15% resin by weight. After melting, the binder is allowed to cool by radiation and conduction.
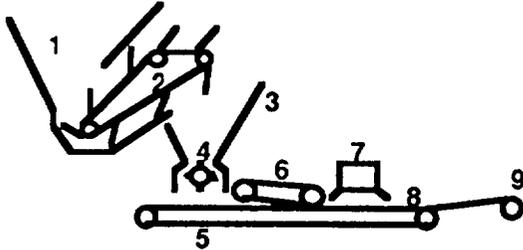

Fig. 1 Schematic of process

1. Main bin
2. Paddle conveyor
3. Secondary bin
4. Feed roller
5. Main conveyor
6. Compression conveyor
7. Infrared heating
8. Cooling area of main conveyor
9. Take-up roll

Machine Components

Main Bin

Fiber that is to be used in this process is going to be in staple form and thus must be stored in large batches. A large storage container is needed to hold these fibers. This main bin will act as the storage container and provide surge protection for the rest of the system. The fiber will enter the bin from the production process through the large 3 m x 3 m opening in the top and be funneled to a smaller opening of 1.5 m x 0.75 m which leads to the paddle conveyor. The fiber will then leave the main bin via the paddle conveyor from the bottom portion of the bin.

The main bin will be made of aluminum due to the metal's low density but relatively high strength. Since the gravitational force on the moon is roughly 1/6 that of the Earth, the bin will not be subjected to high

forces. Therefore, the walls of the bin do not have to be very thick and will need little support.

Paddle Conveyor

The paddle conveyor consists of an aluminum frame, aluminum rollers, bearings, and a belt made of a thin sheet of an aluminum-copper alloy with a composition of 96% Al and 4% Cu. The belt is 17 m long, 1.5 m wide and 0.001 m thick and has a series of 5-cm-high paddles that are 0.3 m apart which will be used to carry the fibers from the main bin to the secondary bin. This conveyor will have one drive pulley, two non-drive pulleys, and three idlers which will keep the belt at proper operating tensions. The speed of the conveyor was determined to be 3.09 m/hr.

Secondary Bin

The purpose of the secondary bin is to supply the main conveyor belt with the fiberglass via the feed roller. The feed roller is located at the bottom of the secondary bin. The secondary bin is 1.5 meters high, 2 meters wide, and 0.005 meters thick. The bin walls are sloped 28 degrees from the vertical. The mass of the bin is approximately 120 kg.

Feed Roller

The feed roller is the mechanism that insures an even laydown of the fiberglass on the conveyor. Fibers from the secondary bin fall through a 2 m by 0.1 m opening to the feed roller which deposits onto the conveyor 70.7 kilograms of sized fiber per hour of operation. In order to achieve this laydown rate, the roller requires a speed of 7.06 revolutions per hour. Small "hooks" are located at certain intervals along the roller and are spaced in such a way as to allow random fiber orientation laydown on the conveyor. This will insure that the fiberglass mat has dimensional stability. The hooks are also slightly bent at the tip in order to grab fibers from the secondary bin if a clog occurs where the fibers enter the roller. There is clearance of approximately 1 mm between the tip of the hook and the secondary bin which provides a space so that fibers caught on the top of the hook will not be crushed between the hook and the bin. The hook spacing and the low gravity will combine to give an even laydown of fibers onto the web.

Main Conveyor

The fabric process chosen requires a main conveyor to transport the fiberglass effectively from the feed roller to the mat formation process. This conveyor picks up the fibers from the feed roll and moves the fibers to the infrared heater positioned down the conveyor. The conveyor is 4.75 m long on one side from the center of the end roller to the center of the drive roller. The conveyor material will be 1.05 m wide and 10 mm thick. The speed of the conveyor will be 8.63 m/hr. Using formulas, values, and assumptions from conveyor literature, it was calculated that a 152.4-mm roller was necessary to uphold the tension in the belts and required revolutions per minute. A 42.75-mm shaft was found to be the size that would provide the necessary strength in the system. In fact, the shaft is over-designed for its purposes but was needed because of the large face width that is present in the system. A 1/4-hp motor was found to be needed to fulfill the desired speed of the conveyor. In order to achieve the 8.63 m/hr conveyor speed the pulley must rotate at 18 revolutions per hour. In addition to the drive pulleys, idlers must be employed to prevent sag in the conveyor belt. By calculation, the idlers should be placed 2.0 m apart. In order to fit the design, idlers will be placed 1.6 m apart, which will provide better tension restoration. The conveyor will be made of hot butyl material with a coating of silver. The hot butyl stands up well under high temperatures but has problems degrading in a vacuum. To take care of problems in the vacuum, silver is used to coat the butyl material. Experts on material processing have confirmed that this material design should be adequate. Skirt boards will be placed 78 mm from the edge of the conveyor belt. The skirts are used to keep any materials on the belt from falling off. The skirts will only be 50 mm high because of the small width of the product before and after compression.

Compression Conveyor

The compression conveyor is used to compress the fibers into a web of the desired thickness (5 mm). This conveyor moves at the same speed as the main conveyor and is made of the same materials as well. The compression conveyor is 500.6 mm long, 1.05 m wide, and moves at a speed of 18 revolutions per hour.

The belt is 10 mm thick and is made of hot butyl coated with silver.

Infrared Heating Lamps

Many of the heating processes used on Earth use convection as the primary way of transporting the heat. Large ovens need a medium to carry heat from the heating source to the material being heated. In a vacuum, heating is a much more difficult process than heating on Earth because heating by convection is no longer a possibility. Therefore, conduction and radiation are the only means of heating on the moon. Radiation doesn't require a medium to transport the heat, making it a good heating source on the lunar surface. The main considerations for heating by radiation are the emissivity of the material that is to absorb the radiation and the intensity of the radiation. Glass has a high emissivity and therefore a good absorptivity; it will be heated very easily by radiation. Given this, the resin will be melted by infrared lamps that will be housed in a mega reflector box 1 m long by 0.25 m wide by 0.33 m high. The housing of the lamp should reflect most of the radiation down to the mat, improving the efficiency. As the radiation is absorbed by the glass and resin, the temperature will rise up to the melting point of the resin. The entire fabric formation process will be operational during the time the equipment is exposed to the sun, influencing the amount of power required to heat the fabric. During this time of fabric formation, the temperature range on the moon is approximately 50 to 120° C. Therefore, the amount of power needed for the curing process will also change as the temperature varies between 50° and 120° C. Given these two numbers, the final curing temperature of the process (400° C), the mass rate and the specific heat of the glass, the power required to heat the fabric will range form 4.38 kW to 5.49 kW. When the power of the motors is added to these numbers, the total power ranges between 5.31 kW and 6.42 kW.

Take-Up

The take-up roll, a device used in textile manufacturing today to take up fabric, was chosen because it is simple and easily implemented. There are problems with this method, however. A week's worth of fiberglass mat production produces a roll that has a mass approaching 12,000 kilograms and a diameter of

just over three meters. On the earth 1,200 kg would weigh nearly 26,200 pounds. Thanks to lunar gravity, that same mass on the moon weighs only 4,400 pounds, which is still heavy, but more manageable. The diameter of the roll could be greatly reduced if the width of the fabric were increased. However, power considerations prohibit this. Guide bars attached to the sides of the take-up roll keep the mat from spilling over the side. Based on these calculations, the rollers would only have to be changed 26 times per year.

Mechanical Elements

Parts considered here include pulleys, idlers, shafts, bearings, and motors. On the main conveyor, two pulleys, one driving and the other non-driving, need to be installed to move the conveyor belt. Since the loads are so small compared to Earth uses, a 152.4-mm pulley with a 42.75-mm shaft will be able to support the necessary force requirements for all moving parts (rollers, pulleys). Again, the small shaft can be used because of low forces and speeds. In fact, the shafts will be over-designed for the process, which will allow for an increase in production rate if desired. Idlers are necessary to keep the belt from sagging in between the pulleys. For the main conveyor, idlers should be placed 1.6 m apart on both the upper and lower parts of the conveyor. 50.8 mm idlers will be sufficient to keep the conveyor at its proper tension. Bearings will be deep groove, single row ball bearings 43 mm in diameter, from the FAG Corporation. Since forces will be so small, the smallest and cheapest bearing that meets the need was chosen. The motor chosen to drive the moving elements was a 1/4 hp-Leeson Electric variable speed motor. This motor will be able to handle the roller, conveyors, and take-up. Five of these motors will be necessary. Gear reductions for each case will be necessary. The motors are still a little oversized, which means that the motors could perform at increased rates, if necessary. This is why the motors were chosen to be a little larger than needed. All parts will be made of aluminum.

Lubricant

In the design of the fabric process, various pieces of equipment are needed. Many parts rotate and require the use of bearings. In order to keep these parts in good working condition, a suitable lubricant is necessary. Considerations for a proper lubricant were difficult because of the performance environment. First of all, the lubricant needed to work in a vacuum, which ruled out many possible oils and greases. Secondly, the material needed to withstand the high temperature of the moon without losing its viscosity. Oils and greases, solid lubricants, laminar solids, ceramics, and polymers were explored. After looking at many possibilities, a mix between a grease and solid lubricant was chosen. Shell Apeizon High Vacuum grease and molybdenum disulfide were decided upon. Since most solid lubricants are applied with either a grease or oil, the best characteristics of each material were mixed to form an excellent lubricant. The grease works very well in vacuum situations, but has limited temperature effectiveness. The MoS_2 on the other hand has excellent temperature properties, but lacks the vacuum ability of the high vacuum grease. It should be noted that both the grease and the MoS_2 have been tested in vacuums at temperature extremes and have performed well. In mixing the two, the properties of the lubricant should become even better. By mixing the two together, the lubrication of the moving parts is fulfilled. From looking at experiments done in a vacuum at high temperatures, the estimated life of the lubricant is six months. This is very good, meaning that the lubricant will have to changed only twice a year. A sufficient amount should be applied in order to achieve full-film lubrication, which will reduce friction forces and provide better efficiency.

Control Scheme

In any process design, some control strategy must be formulated, though specifics are not given here for equipment since it was not required for this particular part of the design.

At the beginning of the process, weigh cells are necessary on the main bin to keep the fiberglass from filling too high. The control of these weigh cells will return to production of the fiberglass itself, where the regulation will be made. Secondly, a velocity control is necessary on the paddle conveyor to keep the flow into the secondary bin at the proper rate. Readouts will be taken from the weigh cells on the secondary bin and mass monitor on the web laydown conveyor. The

readings are put into the paddle velocity control and the paddle speed is regulated.

As previously mentioned, a weigh cell monitor will be employed to keep track of fiber buildup in the secondary bin. Next, a velocity control will be employed on the feed roller to keep the mat at a constant mass. Readouts from the mass monitors at the web laydown position and final take-up will be fed back to the feed roller velocity control. If mass readings are too high, the roller will slow down, and if too low, the feed roller speeds up.

A mass monitor will be employed on the conveyor to keep the mat at the correct mass. Values will be fed back to the velocity control of the feed roller and conveyor. A velocity monitor will also be supplied on the compression conveyor and connected to the velocity control of the conveyor. This will help to insure that the fiberglass fabric will be not be torn or damaged through the processing points.

Next, a temperature monitor will be used to check the temperature of the formed fabric to insure that the resin is being cured and will obtain the necessary strength. A velocity control will also be employed on the take-up roll. Values from the mass monitor and velocity monitor will also be fed back to the velocity control of the feed roller to maintain the uniform feed that is necessary.

In general, two controls have been employed on the equipment in order to maintain operations even though one of the monitors may fail. This faulty piece of equipment could than be replaced without having to shut down the process. This is done to alleviate downtime and keep production going.

Conclusions

A fiberglass fabric that is both useful and cost efficient can be produced on the lunar surface. Nonwoven fabric, while not as strong as a woven fabric, is easier to manufacture and has adequate strength for the intended uses described. The nonwoven process moves slowly and contains a minimum amount of moving parts; thus the design should be extremely reliable. Cost savings over a three-year lifespan of the

process are in the tens of billions of dollars, compared with shipping the fabric from the Earth. Research into more efficient heating methods and resins with lower melting temperatures could drive these cost savings even higher. Overall, production of a fiberglass fabric on the lunar surface is a highly feasible process that merits more research and development.

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