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# New Material Concepts for Flapper Valve Design

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# NEW MATERIAL CONCEPTS FOR FLAPPER VALVE DESIGN

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## SYNOPSIS

The paper describes in general terms two new material concepts which may find application in flapper valve design. One material is suggested as a possible substitute for conventional flapper valve steel to provide, where desired, the property of inherent damping. The new material is an all metal composite composed of two conventional materials, e.g. stainless steel/copper, and is designed to have a prescribed set of properties. Data is presented to illustrate typical properties of such a material in wire form and general composite configurations as well as the mill forms compatible with the processing of the material are described. A case history of the solution of a vibration control problem is given as an illustration of the application of this new material concept. The question is posed to valve designers as to the desirable specifications of a composite material for a typical flapper valve application.

The second new material concept for flapper valve design enumerated is in the category of a reed support material. The supposed desirable properties of such a material are listed and these are compared with the special characteristics of the collimated hole structure material, CHS®. This material is a monolithic metallic (304-type stainless steel) structure composed of a large number of parallel capillaries providing a flat sealing surface, structural rigidity and high fluid flow with minimum resistance. As an example of the application of the support material, a reed valve designed at the Naval Ship Research and Development Center is described and serves to stress the uniqueness of the structure in terms of the designed operating pressure differential of 3400 psi with 0.003" reed stock and quiet operation compared to an equivalent poppet valve.

## INTRODUCTION

Two separate and distinct new material concepts are considered for potential use by the designers of flapper valve components and ancillary equipment. The materials were developed for wide application of their generally unique properties; the purpose of this paper is to suggest their application to some specific problem areas associated with valve design. The successful incorporation of the material into particular valve configurations will require a thorough understanding of the basic problems and will of necessity involve a certain level of development by the user and the material supplier. It is not the intention of the following discussion to result in the proposal of any specific valve design but rather to stimulate the design engineer by offering new material concepts and posing pertinent questions regarding material specifications.

The topics to be discussed are metallic energy absorbing composite materials and support structure for reeds.

## METAL COMPOSITES FOR FLAPPER VALVE APPLICATION

It is first necessary to appreciate the significance of composites as a general class of materials. Composites are in the broadest sense designed materials. They are a combination of two or more discrete material compositions in a proportion and configuration designed either to exploit the most desirable properties of each component or establish new properties for the combination.

Composites provide for the efficient use of materials, a means to accentuate a particular property, and provide a basis for designing a material to a specific need.

The particular material characteristic of energy absorption has been designed into an all metal composite structure by the Brunswick Corporation (1,2). The composite generally referred to as EAC™ material is a combination of two components whose deformation characteristics are specially chosen. For the simplified model shown in figure 1, component A will ideally have a high elastic modulus and low yield strength, while component B will ideally exhibit an intermediate modulus and high yield strength. The combined stress-strain curve, that is, the composite characteristic during cyclic deformation is a closed loop. In terms of the energy balance this model system reduces to a proportion or recoverable mechanical energy, defined by the area y, and that energy defined by the closed loop area x, which is dissipated in the form of heat.

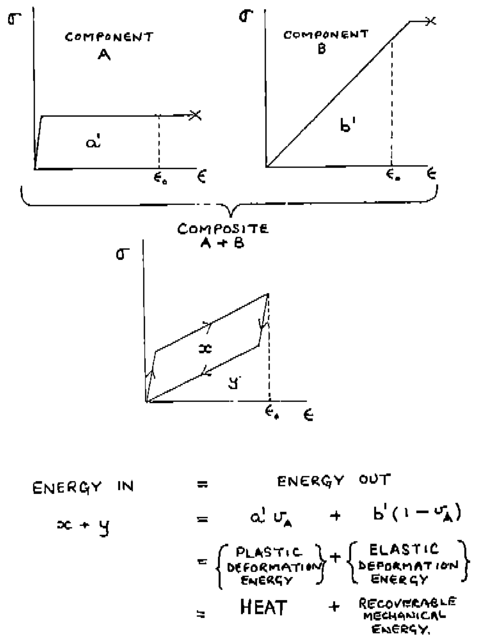


Figure 1. Simplified model of EAC[TM] material showing construction of cyclic deformation hysteresis loop.

For the simplified model,

$$x = a^1 v_A$$

$$y = b^1 \ (1 - v_A)$$

Where $a^1$ is the area under the stress-strain curve for component A between stress levels zero to $\varepsilon_o$, $b^1$ is the complimentary area for component B and $v_A$ is the volume fraction of component A.

Leaving the ideal material model and looking at a real composite material, a typical example would be a stainless steel/copper composite in wire form. Characteristic cyclic deformation loops are shown in Figure 2 for two tensile load levels. The envelope of the hysteresis loops being represented by the dotted curve. The composite configuration in this case is simply stainless steel clad copper subjected to appropriate heat treatment and diffusion bonding. The proportion of the components is 26% stainless steel, 74% copper. Selected properties of the composite are listed below:

$UTS = 79.1$ ksi

$E_{sec} = 8.8 \times 10^6$ psi

$G_{sec} = 3.4 \times 10^6$ psi @ 60 lb. or 58.9 ksi

$C_S = 37\%$

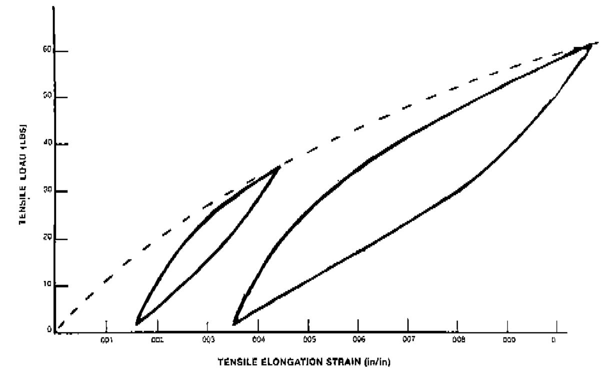


Figure 2. Hysteresis loop formation in a stainless steel/copper wire composite under tensile loading.

The EAC material is compatible with fabrication in most mill forms e.g. wire, rod, plate, sheet and tube and can have a variety of internal configurations of the individual components.

The application of the EAC material may best be appreciated by considering a case history involving vibration isolation.

Problem: Mechanically isolate random vibrations of an airframe structure from thin walled tübing carrying low temperature liquified gases.

Mount Requirements:

| | |
|---|---|
| static load | = 2 lbs. |
| resonance frequency | = 20 Hz. |
| transmissibility at resonance | = 10 |
| weight | < 0.05 lb. |
| temperature range | = -165 to 400° F |

Solution: Applying the all metal Enerby Absorbing Composite technology, design an appropriate miniature mount to meet the above specifications. Although the design steps to reach the final solution are interdependent, they do constitute three distinct procedures, namely

1. Choose a material combination for adequate damping, strength and temperature tolerance (stainless steel/copper).
2. Design a configuration compatible with end use performance, ease of fabrication and low cost (304 SS clad copper wire).
3. Design a component to satisfy dynamic performance, life, and with suitable attaching means. (Double acting helical coil with retaining and attachment hardware.)

A photograph of the final design hardware is shown in Figure 3.

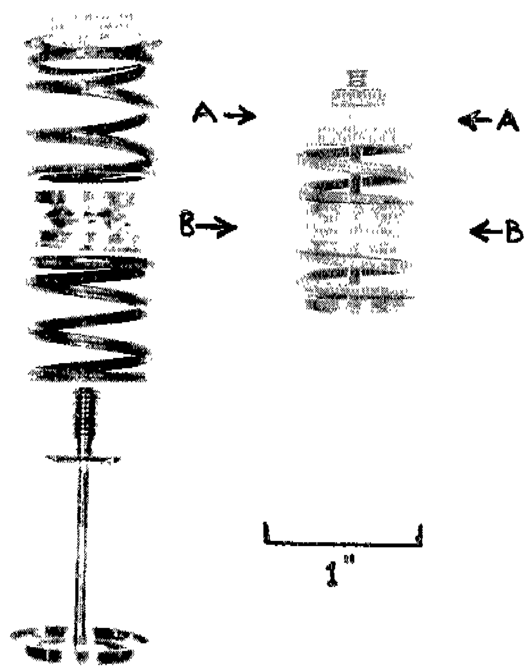


Figure 3. Miniature vibration isolation mount showing composite wire and associated attachment hardware: exploded view on left, assembled device on right.

AA Cryogenic line support
BB Airframe support structure

The performance of the final device is indicated by the random frequency vibration test data shown in Figure 4, which illustrates the degree of attenuation and isolation achieved over the frequency range 20 to 2000 Hz. With maximum deflection and at 20 Hz. excitation frequency the mount exhibited a fatigue life of $1.2 \times 10^7$ cycles.

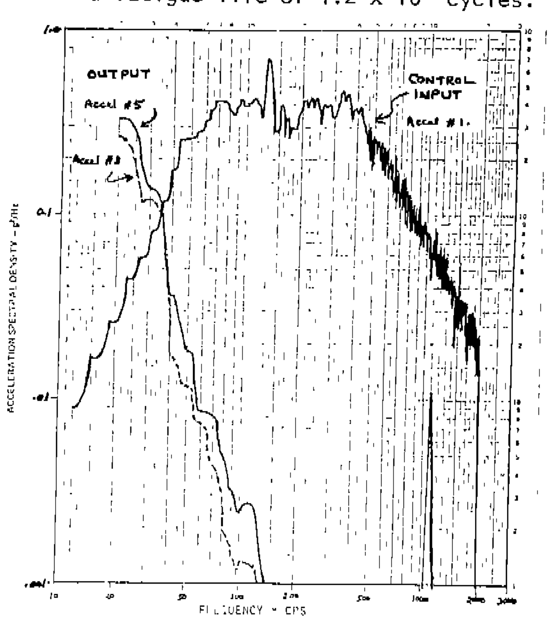


Figure 4. Random frequency vibration test data for miniature mount at 70° F. Acceleration spectral density ($g^2$ Hz) vs. frequency.

Having demonstrated the efficacy of the EAC material concept in a particularly demanding application, it is now suggested that consideration be given to the use of the material in flapper valve design. From the material science standpoint we must first attempt to understand the problem being addressed and ask the following pertinent questions:

Is damping in a flapper (or reed) valve material desirable?

What would be the specifications for a typical valve application, e.g., degree of damping, strength, modulus, fatigue life, operating temperature, environment, etc.?

Can a composite be designed to meet the performance requirements economically?

Can a 'value in use' be clearly established?

Could composites have application in areas other than the reed, e.g., valve seat, springs, etc.?

It is not the intention of the author to attempt to answer such questions, but it is hoped that a dialogue can be initiated between the applications engineer familiar with the valve design problems and the materials scientist or materials 'designer' in the case of composites.

SUPPORT MATERIAL FOR REED VALVES

The use of thin strip steel for port closure in flapper valves imposes serious limitations on the maximum span consistent with the bending forces experienced by the reed and the consequent deflection into the port. To increase the effective size of the port, while maintaining adequate support area on which this reed can impact, it is necessary to provide in the port a high open area porous structure with a number of specific characteristics. Such characteristics should include but may not be restricted to:

- low flow resistance
- structural stability
- minimum 'span' repeat between flow channels
- metallurgical and chemical compatibility with environment
- wear resistant surface
- flat surface
- minimum particulate clogging or fowling.

Many of these characteristics can be found in CHS® material, which is a proprietary product of the Brunswick Corp. (3). This material is best described as a monolithic metallic structure comprising a plurality of parallel capillaries. A typical example of the surface of such a 304 type stainless steel structure is shown in the scanning electron micrograph in Figure 5. The special characteristics of CHS material over other porous structures, is to be found in the combination of features that are attainable in a single product. High open area, actually up to 65 percent of the surface, with small holes (0.005" to 0.0500") suggests that both high flow and uniform reed support can be achieved, while the high aspect ratio (hole length to hole diameters up to 500:1) implies structural stability.

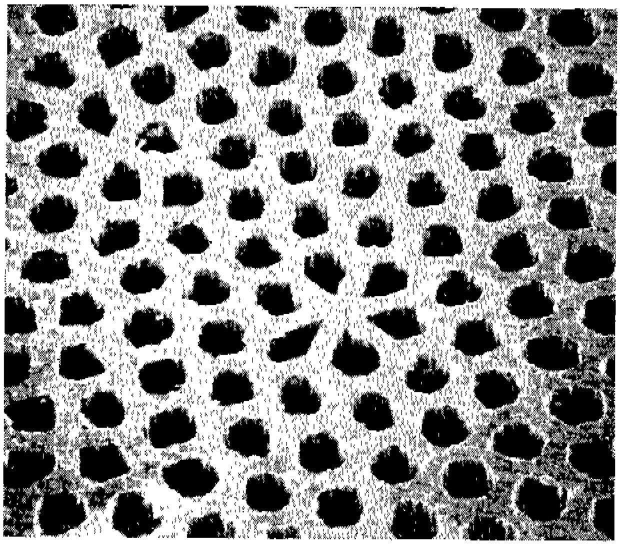

Figure 5. Scanning electron micrograph of CHS® material showing surface characteristics and hole geometry. The equivalent circular hole diameter is approximately 0.005".

The potential benefits to valve designers employing a CHS material support structure may be summarized as follows:

i. High pressure differential possible because of the short span reed support and high l/d (hole length to diameter).

ii. Thinner reed material can be used resulting in:

(a) higher operating speed (greater volumetric efficiency)

(b) increased reed life.

iii. 'Silent' Operation as a consequence of:

(a) lower mass of reed and relatively high impact area (more uniform distribution of stress)

(b) lamina flow in capillaries over wide range of flow conditions

iv. Surface treatment potential of either support material or reed surface for optimum properties, e.g., sealing, wear and possibly impact fatigue.

Again the most expedient approach to emphasize the potential value of the support structure would be to review a case history involving the use of the material in a specific pertinent application. The development of a novel reed valve design for high pressure air compressors by Morehead (4) of the Naval Ship Research and Development Center, adequately fulfills the criteria. The basic valve concept is shown in Figure 6.

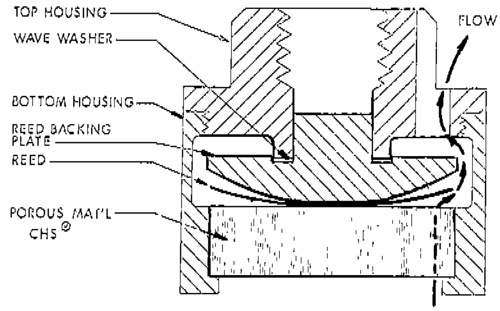


Figure 6. High pressure reed valve design using CHS® material as reed support structure. The valve design is by C.A. Morehead of the Naval Ship Research and Development Center.

The design is intended to show improved performance over the currently employed poppet valve and was evaluated in prototype form in the 4th stage discharge port of a 4500 psi Worthington air compressor. The dimensions of the 304 type stainless steel reed support used in the prototype are as follows:

| | |
|---|---|
| CHS material diameter | = 0.970" |
| CHS material thickness | = 0.300" |
| Capillary diameter | = 0.009" |
| Number of capillaries (approx.) | = 5,200 |
| Open area | = 50% |

The valve operating conditions involved a pressure differential of 3400 psi and a temperature of 375° F. Satisfactory performance was achieved with a stainless steel reed of thickness 0.003". The structure borne noise was reduced significantly when compared to a comparable poppet valve; the most probable explanation being associated with the relative mass of the moving components and the change or redistribution of impact area.

This example of an application of CHS in valve design serves to indicate some of the benefits possible. Additional benefits may be realized in other areas by following the design ingenuity demonstrated by the NSRDC.

ACKNOWLEDGEMENTS

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