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Stress Analysis of Glass-Bonded Ferrite Recording Heads

Abstract: Glass-bonded ferrite recording heads are subject to appreciable thermal stress because of the difference in thermal expansion between glass and ferrite in the temperature range of the glassing cycle. A theoretical analysis reveals the complexity of stress distributions in the structure and pinpoints the critically stressed areas in which a potential fracture or a magnetic degradation of the material may occur. It is found that the stresses are sensitive not only to the thermal mismatch of the component materials but also to the structural configuration. Low stress levels can be achieved by matching expansions of the materials and by proper head design, particularly in the optimization of fillet angle and fillet height.

Introduction

This communication is an analytical study of the stresses in a glass-bonded ferrite recording head, the general shape of which is indicated in Fig. 1. The ferrite pole pieces are bonded together by melting glass into the front and rear gaps. An excess amount of glass is used in the apex area to reinforce the joint near the shallow front gap. Because the thermal expansions of glass and ferrite are different, the glass layer as well as the adjacent ferrite material will be subjected to appreciable stresses when the head structure is cooled from glassing temperature to room temperature. These stresses are more or less permanent.

Excessive tensile stress in the head structure may initiate a crack in the subsequent stages of machining [1] or cause a magnetic degradation of the ferrite material in service [2]. Traditionally, a low stress level is achieved by selecting a bonding glass that has a thermal expansion compatible with the mating material in the temperature range of the glassing cycle. This method alone is not adequate for a complex structure of two brittle materials. Since stress distributions are also related to the geometrical configuration of the head, further stress reduction can be achieved by optimizing head geometry.

The purposes of this investigation are (1) to develop a theoretical stress analysis for the head structure, (2) to identify critically stressed areas, and (3) to relate the thermal mismatch of the materials and the head geometry with the critical stresses. The results can be used as design guides in achieving acceptably low stress levels.

Stress analysis

Thermal stresses in a composite head structure are very complex functions of space and temperature. Brittle fractures observed on this type of recording head indicate that the critical stresses are in the plane of the structure. This enables us to simplify the analysis to a two-dimensional study in the *x-y* plane. Structural symmetry further reduces our analysis to half of the structure.

The state of stress on a macroscopic element in the composite structure is shown in Fig. 2, where σ_x and σ_y are the horizontal and vertical components of normal stress and τ_{xy} is the shear stress. Within the structure, the stresses are functions of location and temperature, i.e.,

$$\begin{aligned} \sigma_x(x,y,T) &= S_x(x,y)\delta(T), \\ \sigma_y(x,y,T) &= S_y(x,y)\delta(T), \\ \tau_{xy}(x,y,T) &= S_{xy}(x,y)\delta(T), \end{aligned} \qquad (1)$$

where $\delta(T)$ in cm/cm/°C is the thermal mismatch (differential contraction) between glass and ferrite at temperature T. The functions S_x, S_y, and S_{xy} are the stress-per-unit thermal mismatches. They are independent of temperature but vary with head geometry.

Analytic expressions of the stress functions S_x, S_y, and S_{xy} can be derived only for very simple structures, such as bonded concentric cylinders and bonded parallel strips. For complex structures such as the magnetic head, solutions are obtained numerically with finite-ele-

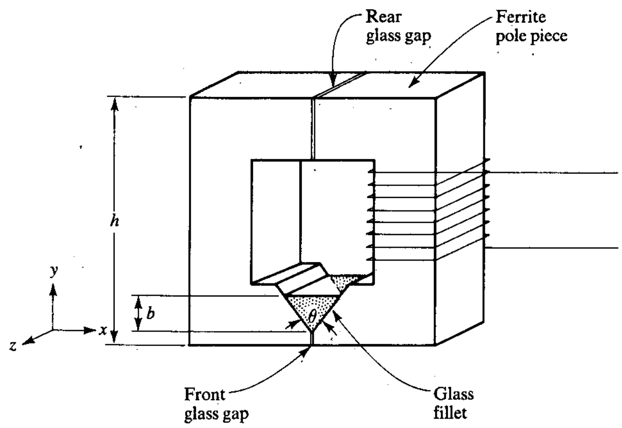


Figure 1 General configuration of a ferrite recording head.

ment stress analysis [3]. Computations are executed by using an MIT-developed structure analysis program, ICES STRUDL II [4].

Thermal mismatch of glass and ferrite

A typical linear expansion curve for the ferrite and a nonlinear curve for a commercial sealing glass are shown in Fig. 3. To relate stress with thermal mismatch, the glass curve is transposed upward until it crosses the ferrite curve at the glass setting point. When the glass is cooled from the molten state, the composite structure is stress-free until it reaches the glass setting point. Upon further cooling, the difference in contraction rates of the two component materials causes thermal stresses to develop. The thermal mismatch δ at a given temperature is the difference in height of the glass and the ferrite curves,

$$\delta(T) = [(\Delta L/L)_{\text{glass}} - (\Delta L/L)_{\text{ferrite}}]_T. \quad (2)$$

The glass-ferrite structure is cooled very slowly at a controlled rate so that the temperature in the structure is practically uniform. At any structure temperature, T, $\delta(T)$ of Eq. (2) can be obtained from the cooling curves in Fig. 3. When this value of $\delta(T)$ is substituted into Eq. (1), the stress distribution in the structure can be calculated for this temperature. Since the values of δ are known from the glass setting point to room temperature, the stress history in the structure during cooling can be completely determined.

Between the setting temperature and 150 °C, glass contracts more rapidly than ferrite. Stresses reach maximum at about 300 °C, where the magnitude of δ is maximum, $\delta(300) = -0.00025$. At 150 °C, the crossover point, the mismatch is zero [$\delta(15°) = 0$]. Therefore, the structure is stress-free again. With further cooling, ferrite

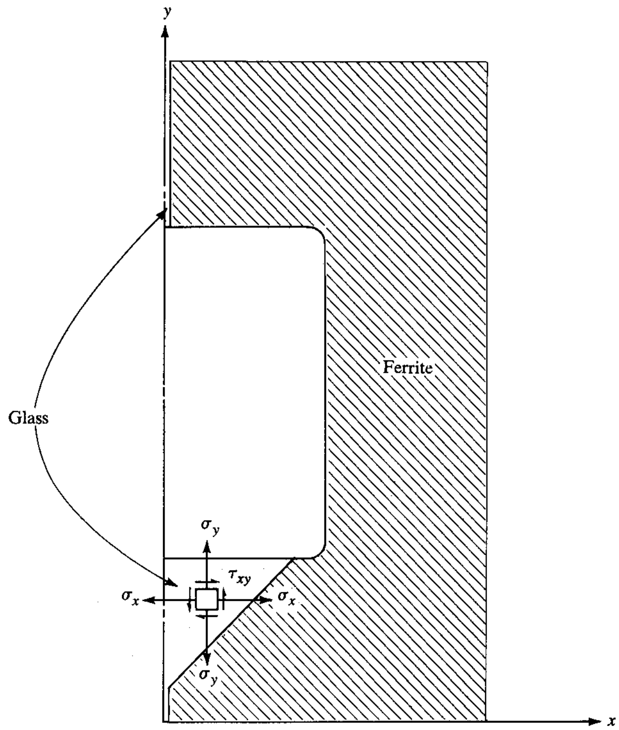
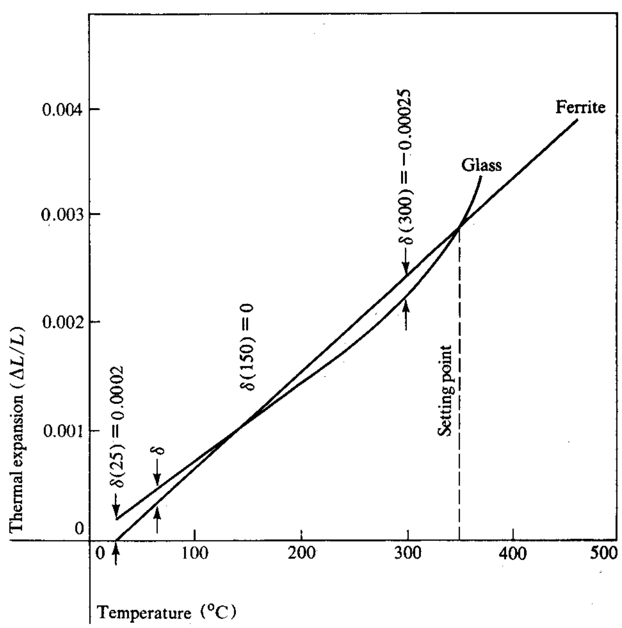


Figure 2 The state of stress on a macroscopic element in the x-y plane of half of a ferrite recording head. Relations governing normal stress σ and shear stress τ are given in Eq. (1) in the text.

Figure 3 Typical expansion curves of a ferrite and a commercial sealing glass, showing extent of thermal mismatch parameter δ as a function of temperature.



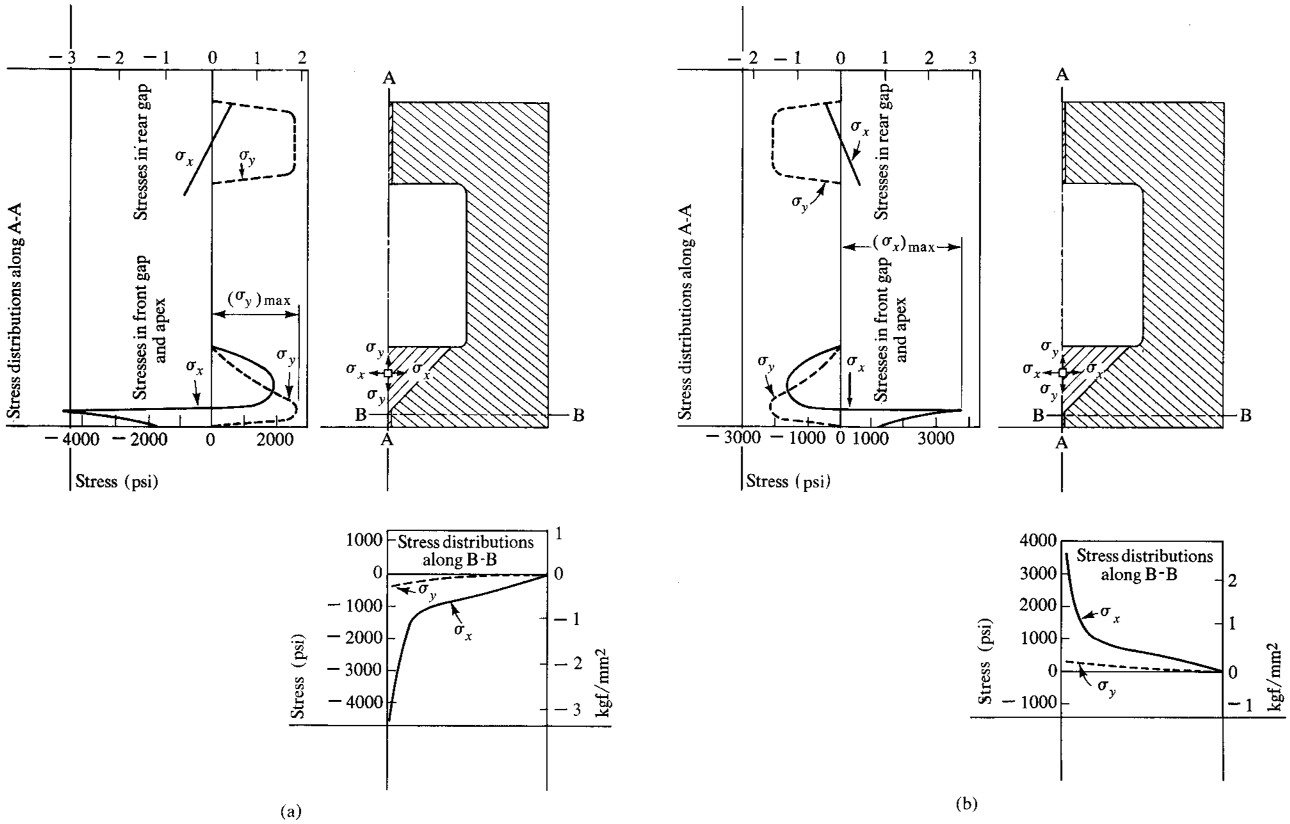


Figure 4 Stress distributions along the front and rear gaps and in the fillet of the recording head, for fillet angle $\theta = 90°$ and fillet height $b = 0.508$ mm. (a) $T = 300$ °C, $\delta = -0.00025$. (b) $T = 25$ °C, $\delta = 0.0002$.

contracts more rapidly. The thermal mismatch is now positive ($\delta > 0$]. The stresses reverse their directions and reach another maximum at room temperature if there is no further cooling below this temperature. The corresponding mismatch δ at 25 °C is 0.0002.

To avoid high stress development, δ must be kept small over the entire temperature range from the setting temperature to room temperature. Notice that we have not mentioned "the matching of thermal expansion coefficients" (as often appears in the glass literature) because the matching of expansion coefficients, either defined locally at a given temperature or averaged over a temperature range, is not directly related to stress. The coefficients, however, help to define δ.

Of the two worst-stress situations, at 300 °C and 25 °C, the latter deserves particular attention for several reasons. First, the magnetic head is expected to operate at or near room temperature. Second, a more severe fracture problem exists at room temperature, because the strength of glass is greater under momentary stress (transient stress at 300 °C) than under prolonged load [5] (steady stress at 25 °C). Third, for a given value of δ, the stress at room temperature is actually higher because the moduli of elasticity of the component materials are lower at an elevated temperature [6].

Since an exact expansion match is impossible over the complete temperature range, a usual compromise in glass sealing practice [7, 8] is to achieve a low-compressive stress in glass by allowing a small positive value of δ at the working temperature of the seal. Unfortunately, for the composite head structure a small positive δ does not guarantee a total small compression in glass. Therefore, controlling δ alone does not necessarily resolve the stress problem.

Analytical results

Stress distributions in the glass-ferrite structure at 300 °C and at room temperature are calculated for a number of fillet configurations, with fillet angle θ varying from 90° to 30°, and fillet height b varying from 0.508 to 0.254 mm (20 to 10 mils). Typical stress distributions for $\theta = 90°$ and $b = 0.508$ mm are shown in Figs. 4 (a) and (b). Only normal stresses σ_x and σ_y are plotted in the figures.

Stresses in the glass gaps are plotted on the left side and stresses in the ferrite leg are plotted at the bottom. A positive value of stress indicates tension and a negative value, compression.

Figure 4(a) shows the stress distributions in the structure at 300 °C, $\delta(300) = -0.00025$. For the stresses in the rear gap, the vertical component σ_y is nearly uniformly tensile along the length of the gap; the horizontal component σ_x varies linearly from tensile to compressive stress along the length of the gap. In the fillet, glass is in tension in both directions. But in the front gap, glass is in tension vertically and in compression horizontally. The ferrite is subjected to compression near the glass gap and becomes stress-free at the boundary. The critical tensile stress $(\sigma_y)_{max}$ in the glass is the vertical component σ_y near the tip of the fillet.

Figure 4(b) shows the stress distributions in the same structure at room temperature, $\delta(25) = 0.0002$. The stress at any point is equal to the stress at the same point in Fig. 4(a) multiplied by a factor of $\delta(25)/\delta(300)$. The critical tensile stress in glass $(\sigma_x)_{max}$ is now a horizontal component near the tip of the fillet. If this stress exceeds the breaking strength of the glass, it would initiate a vertical crack along the front gap.

It is clear from these plots that tension and compression exist simultaneously in the structure regardless of where $\delta < 0$ or $\delta > 0$. A safe joint requires that both $(\sigma_y)_{max}$ of Fig. 4(a) and $(\sigma_x)_{max}$ of Fig. 4(b) be small.

Stress distributions in structures of different fillet configurations are similar to those in Figs. 4(a) and (b). In general, smaller fillet angle θ and smaller fillet height b result in lower stress peaks. Figure 5(a) shows the linear relationship between stress and fillet angle. Figure 5(b) shows the relationship between stress and fillet height. In these plots, the stresses are normalized to unit mismatch.

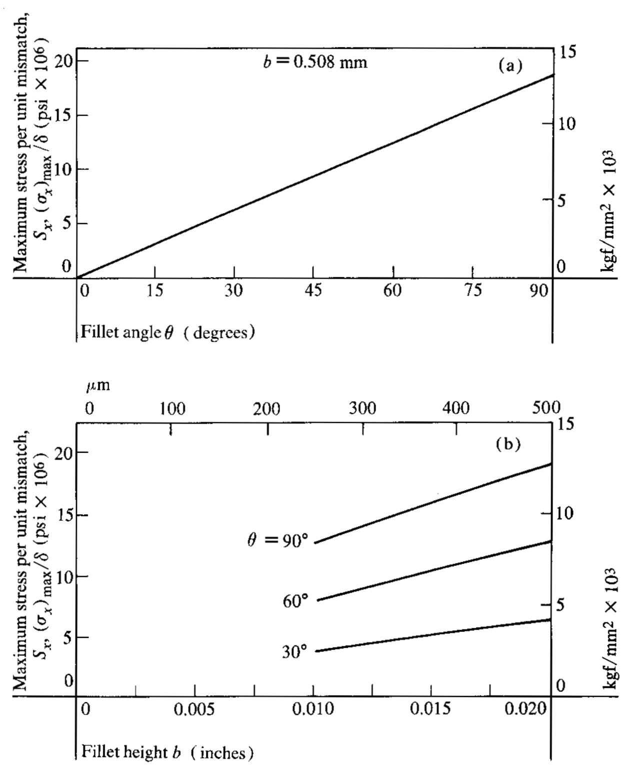


Figure 5 Maximum stress plotted as a function of (a) fillet angle and (b) fillet height.

Reducing the fillet angle θ is equally effective in reducing stress because of its linear relationship with stress [Fig. 5(a)]. The limitation is the magnetic flux leakage in the fillet for a small fillet angle.

Reducing the fillet height b also reduces the stress level, but less effectively [Fig. 5(b)]. The limitation is the weakening of the joint strength at the front gap with a shallow fillet.

To achieve a very low stress level requires the combination of all three design modifications. For instance, the peak tensile stress of the head in Fig. 4(b), $(\sigma_x)_{max} =$ 2.6 kgf/mm^2 (3800 psi), can be effectively reduced by reducing δ, θ, and b. Suppose that δ is reduced from 0.0002 to 0.0001, θ from 90° to 30° and b from 0.508 to 0.381 mm. From Fig. 5(b), the apex design change reduces the stress per unit mismatch, S_x, from 13.4×10^3 to 3.5×10^3 kgf/mm^2. Applying Eq. (1) gives

$$(\sigma_x)_{max} = 3.5 \times 10^3 \times 10^{-4} = 0.35 \text{ kfg/mm}^2,$$

or 500 psi.

Thus the room-temperature thermal stress in a glass-bonded ferrite head cannot be entirely avoided, but safe joints with low stress levels can be achieved by a combination of proper head design and suitable material matching.

Conclusions

The stress analysis has shown that thermal stress in a glass-bonded ferrite head is related not only to the thermal mismatch of the component materials but also to head parameters such as fillet angle and fillet height. A tensile stress peak exists in the glass gap at a point near the tip of the fillet and is a potential source of glass cracking.

An effective way to reduce the tensile stress peak in the structure is to minimize the thermal mismatch δ by selecting proper glass and heat treatment. However, it is limited by the glasses available and by the practicality of the heat treatment process. Moreover, precise control of δ in the entire temperature range is often doubtful in production, because δ is usually sensitive to the tolerances specified for the materials and processes.

The analytical technique described is applicable to bonded structures consisting of two or more materials, provided that the temperature throughout the structure is uniform. Moreover, its application is limited to structures in which the bond is stronger than the component materials such that fractures, if any, do not begin at the bonding interface.

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References and note

1. S. Duinker, "Durable High-resolution Ferrite Transducer Heads Employing Bonding Glass Spacers," *Phillips Research Reports* **15,** 342–367 (1970).
2. J. Smith and H. P. J. Wijn, *Ferrites*, John Wiley & Sons, New York, 1959.
3. W. C. Paulsen, "Finite Element Stress Analysis," *Machine Design* **43,** 46 (September 1971).
4. The well-known structure analysis program NASTRAN was not available when this study was made.
5. *Properties of Selected Commercial Glasses*, published by Corning Glass Works, Corning, New York.
6. G. Morey, *Properties of Glass*, Reinhold Publishing Corporation, New York, 1954.
7. M. B. Volf, *Technical Glasses*, Pitman Publishing Co., New York, 1961.
8. L. F. Oldfield, "Sealing Glasses," Lecture given at the British Society of Scientific Glassblowers Colloquium, 1963.

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