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Principles of Thermal Shock Testing

Up to about 25 years ago, thermal shock testing, though practiced by some firms, was performed in an uncontrolled manner and frequently gave erratic results. This was due in part to the variability of the apparatus, which was often crude and always unstandardized, and the method of using the apparatus, which was always home-made, was also unstandardized. This was natural, perhaps inevitable, for it is not immediately obvious what factors affect the severity of the shock. It might be supposed for instance that if the bottle is transferred from a bath at 150° F. to a bath at 70° F, we have completely defined the shock - it is a shock of 80° F. differential. But this is not the case. The shock proper, that is, the likelihood of breakage, depends on a lot of details which affect the change of temperature in the glass, not the differential between the tanks. Most of these details concern the transfer of heat across a thin boundary film between glass and liquid.

For instance if we use baths of glycerine instead of water, it takes twice as much differential to break the glass. If we use lubricating oil instead of glycerine, then we need three times as much differential as with water. Heat is transferred more rapidly to water, from hot glass, than to most other liquids, and thus the shock is greatest with water. Since water is cheap, clean, and generally convenient, we naturally use water: and since water is always ~~,~~ water, it is natural to assume that there is no further complication. This expectation does not work out. Still water, for instance, is much more gentle than turbulent water, since the latter brings new, cold, water in contact with the hot glass. With hand-lowering of a loose basket of bottles on a rope into the water, you get one result if you lower gently and hold the basket still, and another if you lower rapidly and swill the basket around in the tank. To standardize the test you have to agree either to swill or not to swill, and since there must be some disturbance anyway, it seems better to swill and do it vigorously. There is a point beyond which more vigor in swilling has no effect. We therefore decided to circulate the tank water with a fair-sized pump. This has the further advantage that it mixes the water in the tank continuously so that the whole tankful is at the same temperature, and is not "stratified", while it gives as severe a shock as water is capable of giving.

But now the basket turns out to be not just a basket or support, but an influence upon the severity of the shock. If, in the present standard thermal shock machine, you put a continuous sheet of any substance, such as a piece of cardboard for instance, between the bases of the bottles and the open grid on which the bottles are supposed to rest, then your bottles show up better, because you have stopped, or cut down, the circulation of water over the bottoms of the bottles. This reduces the severity of the shock.

If you do a good enough job of obstructing the water, you in effect insulate the bottle and it will stand any "shock" you like to give it. The remedy is to make the basket as open as possible, so that the shock is as severe as possible. It cannot be made more severe indefinitely, and if the basket is open enough, it is equivalent to no basket at all. Since we want to learn about the properties of the glassware and not the properties of baskets, we must use a basket that suffices to support the bottles but does not interfere with the shock.

But even now we have not completely standardized the insulation of the bottle, for we heat the bottle in a hot water tank, and when we lift it out, a film of water clings to the bottle, and this acts as a thin insulating blanket. We should like to be rid of this film. We found that if we allowed enough time to elapse between hot tank and cold, the glass surface cooled off a little and the test rated the glassware too highly. If we went as fast as possible from one tank to the other, the hot water we transferred on the outside of the bottle cushioned the shock a little. If we took about 15 seconds , we seemed to reach optimum, that is, maximum severity. For most of the hot water drained away or evaporated before the hot glass hit the cold water, and yet the glass itself had not cooled appreciably. Thus the transfer time became important, and we standardized on a 15 second transfer.

But the severity of the shock does not depend even on the change of temperature of the skin of the bottle: it depends on the tensile stress you can develop there, and this in its turn depends on the temperature throughout the wall thickness of the bottle. Thus if you briefly dip a bottle in hot water and then plunge it into cold, you do not develop the shock that comes if you have held the bottle in hot water long enough to get the glass heated right through. The physics or mechanics of this is not hard to understand, but I shall not elaborate on it here. In the old days people did not always get their bottles heated throughout, and this could produce great variations in the severity of the test.

It is important therefore to leave the bottles in hot water long enough to eliminate temperature gradients in the glass. We found that if we let the hot water get inside the bottle, so that we heated the glass from both inside and outside, then, with the rather thick-walled bottles of those days it took about five minutes to reach stability. Perhaps with modern thin-walled ware we could manage on less than five minutes. But we standardized on five minutes in those days and it has remained at five minutes. We call this the soaking time. The water inside the bottle is a degree or two colder, as a rule, than the outside circulating water, but this is not serious.

There remains one other major element that must be standardized, and that is the time the bottle is held in the cold tank. We found that 30 seconds was sufficient. Breakage is not instantaneous, but it is prompt. You must not give the bottles a mere perfunctory dip in the cold water without allowing time for the stresses to develop, but if the bottle does not break in a few seconds it will not break at all, the stresses becoming less severe after a short time. So we standardized on 30 seconds.

There are other things that affect the severity of the test to a slight extent, but we believe them to be unimportant in comparison with those above discussed. To summarize them: the liquid should be plain water, the bottles clean, and both water and bottles free of oil and grease. The water should be circulated vigorously and have free access to all the glass surface; for this purpose the basket should be of very open mesh construction. The bottle wall must be heated completely through in the hot tank: the transfer time should permit hot water to drain off the bottles but should not be enough to permit the bottle to cool: the time in the cold tank should be enough to permit the development of the maximum stress but need not be much longer. The inside of the bottle should be filled with hot water, and this should remain in the bottle (and not be emptied) while the cold shock is administered to the outside.

F. W. Preston

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