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TECHNICAL REPORT

DESIGN AND SAFETY FACTORS FOR PE4710 MATERIALS UNDER THE PROPOSED REVISION TO AWWA C906

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The AWWA standards process plays a crucial role in ensuring the integrity of our water distribution infrastructure. Those who have accepted the responsibility of stewarding this process have the critical role of ensuring its overall success, of being agents of responsible change, ensuring that the industry, that society, can take full advantage of progress in a responsible way.

When faced with a change, such as the current introduction of the new generation PE4710 materials, where there is the potential to confer benefit to society, yet for which there remains some debate regarding the design approach, the committee has taken its charge responsibly in calling for greater clarification. At the heart of the matter are the discussions pertaining to design or service factors and safety factors, which, fundamentally, are really discussions of whether PE4710 materials will perform in service as intended and indeed be a benefit and not a detriment to society.

The plastic pipe industry, partly due to efforts to compete between materials and partly due simply to error, has not always presented the issue clearly. Over the past 30 plus years, there have been many instances whereby the design approaches to plastics (which are made unique by the time-dependent viscoelastic response of these materials) have been misinterpreted or misapplied. The most common engineering error is the attempt to apply engineering design approaches for elastic materials (such as metals) to viscoelastic plastic materials. Much of the current confusion within the industry seems to stem from a lack of simple clarity as to how these engineering design approaches differ.

This summary is designed to provide clarity to this topic and to facilitate the AWWA Committees and Councils to make an informed and appropriate decision regarding these (and other viscoelastic) materials. The summary seeks to demonstrate, when the appropriate viscoelastic engineering design approaches are applied, that: 1. The Safety Factor (SF) is clearly not the reciprocal of the Design Factor (DF); 2. PE4710 materials have the same, or better, design Safety Factor as the current PE3408 materials; and 3. The additional requirements imposed on PE4710 materials provide for greater design safety than for current PE3408 materials.

Safety and Design Factors for Viscoelastic Materials

The DF and SF for viscoelastic piping materials are two different concepts. By engineering convention[1] (while the example from this reference is for PVC pipe, the concepts are applicable to all viscoelastic pipe materials), the SF for viscoelastic piping materials is defined as:

SF = Short-Term Strength/Short-Term Load in Service (1)

The DF is defined as[2]:

DF = Maximum Recommended Long-Term Design Strength/Ultimate Long-Term Strength (2)

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or, in piping engineering conventions:

DF = HDS/HDB (3)

where HDS is the Hydrostatic Design Stress and HDB is the Hydrostatic Design Basis. To be absolutely clear, then, the HDS is the Maximum Recommended Long-Term Design Strength and the HDB is the Ultimate Long-Term Strength.

Clearly the SF is not the reciprocal of the DF for viscoelastic materials. The two, for time-dependent viscoelastic materials, refer to events happening on vastly different time scales. The SF addresses the ability of the system to handle short-term loads in excess of the long-term strength of the material. The DF provides for determination of the Maximum Recommended Long-Term Design Strength (or HDS) as a function of the Ultimate Long-Term Strength (or HDB) of the material. The DF is an empirical quantity based on engineering considerations of how the Ultimate Long-Term Strength of the material was derived in conjunction with the behavioral properties of the material.

Comparison of Safety Factors for PE4710 and PE3408 Materials

The SF for viscoelastic materials[1], expressed as the ratio of Short-Term Strength to Short-Term Load in Service (Eqn. 1), needs to be considered in terms of the time scale of the applied short-term load. In viscoelastic piping systems[1] it is the surge load that needs to be considered. As surge loads occur on the order of seconds or fractions of a second, it is the very short-term response of the materials that needs to be considered. To this end, AWWA C906[3] requires that the 5 second sustained pressure strength (Short-Term Strength) is a minimum of 3200 psi (hoop stress) for PE4710 materials. As per the calculations for PVC in The Handbook for Thermoplastic Piping Design[1], for a DR32.5 (the worst case on a hoop stress basis) PE4710 pipe, the pressure surge for a 5 fps velocity change, from M55 is 39.8[4] psig, corresponding to a hoop stress of 627 psi, therefore:

Short-Term Load in Service = HDS + 627 psi
= 1627 psi (hoop stress)

After equation (1), the SF is, therefore,

= 3200/1627
≈ 2 (1.97)

The SF for PE4710 materials with a 0.63 DF under aggressive surge conditions is, therefore, 2. (As the 3200 psi 5 second strength is a minimum requirement and the 32.5 DR represents the worst case for C906 pipes, the actual safety factor will be >2.) This is actually slightly higher than that for PE3408 materials when the same calculation is applied.

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Consideration of Additional Design Constraints on PE4710

Due to the nature of viscoelastic materials and their time-dependent properties, the design approach for long-term loads is again different from that for elastic materials. For viscoelastic materials, the phenomenon of creep needs to be taken into consideration when characterizing long-term strength. For plastic piping materials, this is done through the HDB in combination with consideration of the long-term loads that the materials will experience in service. As long-term loads are more predictable than short-term loads and viscoelastic materials essentially respond to the average loading over these timescales, a different approach to design safety is taken than that for short-term loads presented previously. Essentially, the long-term resistance to hydrostatic loading is so far beyond the design life of the pipe (for PE4710 materials running continuously at 120% of maximum design stress, the 95% lower confidence limit for the projected time to rupture is >50,000 years) that it is the confidence in the long-term projection that determines design safety. For PE materials, this is done through ensuring that there is not a transition from the ductile rupture mode upon which the design is based to the brittle slow crack growth mechanism (there is also the potential for transition into another mechanism due to chemical loading that is not addressed in this brief summary). For PE3408 materials, when the requirements for validation are combined with the consideration of the maximum allowable design stress based on a 0.5 DF, the result is the assurance that this transition will not occur before 100 years. For PE4710 materials, even with the higher design stress based on the 0.63 DF, the additional validation requirements ensure that this transition will not occur before >250 years, or a 2.5 increase in design safety in terms of the occurrence of these mechanisms over the current PE3408 materials.

Summary

When considered in the appropriate engineering framework, it is seen that the DF and SF for viscoelastic materials are different concepts, and, further, that the design SF for PE4710 materials is the same (slightly higher) as that for PE3408 materials. It is also seen that the additional constraints imposed on PE4710 materials (via the ASTM standards) results in an increase in design safety over that of the current PE3408 materials.

References

1. T. Sixsmith and R. Hanselka, *Handbook of Thermoplastic Piping Design*. Marcel Dekker, 1997.
2. PPI TR-3 *Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Hydrostatic Design Stresses (HDS), Pressure Design Basis (PDB), Strength Design Basis (SDB), and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe,* Plastics Pipe Institute, Irving, TX, 2010.
3. ANSI/AWWA C906 *AWWA Standard for Polyethylene (PE) Pressure Pipe and Fittings, 4 In. (100 mm) Through 63 In. (1,575 mm), for Water Distribution and Transmission*, American Water Works Association, Denver, CO, 2007.
4. AWWA M55 *PE Pipe--Design and Installation,* American Water Works Association, Denver, CO, 2006.

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