



SPE/PS/CHOA 117486
PS2008-369

Mechanical Evaluation of a New Sand Control Screen for SAGD Applications

Glenn Woiceshyn, SPE, Absolute Completion Technologies; Ezio Toffanin, SPE, Schlumberger; Jueren Xie, SPE, Brian Wagg, SPE, and Chengye Fan, C-FER Technologies, Canada

Copyright 2008, SPE/PS/CHOA International Thermal Operations and Heavy Oil Symposium

This paper was prepared for presentation at the 2008 SPE International Thermal Operations and Heavy Oil Symposium held in Calgary, Alberta, Canada, 20–23 October 2008.

This paper was selected for presentation by an SPE/PS/CHOA Program Committee following review of information contained in a proposal submitted by the author(s). Contents of the paper, as presented, have not been reviewed by the Society of Petroleum Engineers, the Petroleum Society of Canada, or the Canadian Heavy Oil Association and are subject to correction by the author(s). The material, as presented, does not necessarily reflect any position of the SPE/PS/CHOA, its officers, or members. Papers presented at SPE, PS, and CHOA meetings are subject to publication review by Editorial Committees of the SPE and PS. Electronic reproduction, distribution or storage of any part of this paper for commercial purposes without the written consent of the SPE or PS is prohibited. Permission to reproduce in print is restricted to a proposal of not more than 300 words; illustrations may not be copied. The proposal must contain conspicuous acknowledgement of where and by whom the paper was presented. Write Librarian, SPE, P.O. Box 833836, Richardson, TX 75083-3836, U.S.A., fax 01-972-952-9435 and Editor, Journal of Canadian Petroleum Technology, Petroleum Society of Canada, Suite 425, 500 - 5th Avenue S.W., Calgary, AB, Canada T2P 3L5, fax 01-403-262-4792.

Abstract

Steam assisted gravity drainage (SAGD) wells typically require the deployment of an open hole completion combining sand control with adequate mechanical strength to withstand: 1) aggressive installation loads—compression, torque, bending—that are characteristic of shallow horizontal wells, and 2) severe operational loads—tension, compression, collapse, burst—caused by a combination of high temperature steam injection and formation collapse around the completion.

Historically, slotted liners have been used in Western Canada, primarily because of low cost relative to wire-wrapped screen (WWS) or premium mesh screens. However, slotting base pipe can significantly weaken its mechanical strength, particularly in torsion and collapse, and the slot width can change as the liner deforms under certain load conditions. Reported incidents of mechanical failure and loss of sand control of slotted liners in SAGD wells have generated interest among operators to investigate alternative technologies.

A new sand screen has been developed that involves flush-mounting and securing 25.4 mm diameter fusion bonded metal laminate (FBML) cartridges/discs directly into the base pipe wall. The open flow area of the screen, which can be as high as 20% (versus 2.5% for slotted liner), is dictated by the number of inserted discs (holes) per foot. For an equivalent open flow area, drilling holes in the base pipe is less detrimental to the mechanical strength of the liner than cutting slots. This new geometry results in a sand screen that is cost competitive to slotted liner on a same-open-flow-area basis, significantly stronger, and comparable to a premium mesh screen in terms of sand retention performance.

To independently quantify the mechanical strength and integrity of this new screen for SAGD, an extensive Finite Element Analysis study was performed on 177.8 mm (7"), 38.7 kg/m (26 lb/ft), L80 base pipe for two different hole densities and various single loads, combined loads and thermal cycling. The results, as presented herein, demonstrate that inserting FBML discs into base pipes does not significantly weaken it compared to cutting slots. A stand alone screen (SAS) with almost four times the open flow area of a slotted liner has significantly more torsion and collapse strengths.

Introduction

SAGD wells are horizontal and typically completed in shallow, unconsolidated heavy oil reservoirs with a liner or Stand Alone Screen (SAS) for sand control. A typical SAGD completion requires adequate mechanical strength to withstand 1) aggressive installation loads—compression, torque, bending—that are characteristic of shallow horizontal wells, and 2) severe operational loads—tension, compression, collapse—caused by high temperature steam injection in combination with formation collapse around the screen. Any deformation of the liner/screen due to such loads must not impair sand control or the production/injection of oil/steam.

Historically, slotted liners (SL) have been the choice for SAGD wells in Western Canada, primarily because of low cost. However, slotting pipe can significantly weaken its mechanical strength under certain load conditions, particularly in torsion and collapse, and the slot width can change as the liner deforms¹. Opening of slots causes sand production; closing of slots reduces oil production (or steam injection). To preserve mechanical strength the percent open flow area (OFA) of slotted liners are typically kept below 2.5%, thereby restricting flow rates, increasing velocities and risking "hot spots." Reported incidents of sand production and mechanical failure with slotted liners have generated interest among operators to investigate

alternative technologies. What operators presently seek is a completion that provides superior mechanical strength and sand retention characteristics, and is cost competitive with slotted liner.

A new sand screen has been developed that involves flush-mounting and securing 25.4 mm diameter fusion bonded metal laminate (FBML) cartridges/discs directly into the base pipe wall, referred to herein as a flush absolute cartridge system or FACS. The OFA, which can be as high as 20% compared to 2.5% maximum for slotted liner, is dictated by the number of inserted holes per foot. For an equivalent OFA, drilling holes in base pipe is less detrimental to the mechanical strength of the liner than cutting slots. This geometry results in a sand screen that is cost competitive to slotted liner on a same-open-flow-area basis, significantly stronger in several key load modes, and is comparable to a premium mesh screen in terms of sand retention performance.

To quantify the mechanical strength and integrity of this new screen for SAGD, an extensive Finite Element Analyses (FEA) study was undertaken on 177.8 mm (7"), 38.7 kg/m (26 lb/ft) L80 base pipe for two different disc densities equivalent to 3.6% and 9.6% OFA and various single loads, combined loads and thermal cycling. This paper presents the results of this FEA study.

Description of New Sand Screen

Liner Description

A FACS liner consists of FBML discs flush-mounted and secured into the base pipe, as shown in **Fig. 1**. The OFA is proportional to the number of holes (i.e., discs) per foot (HPF) and can be selected according to production/injection expectations. (The OFA is also proportional to the fractional open area of the FBML material which is around 0.58 depending on the woven mesh used.) The discs are typically arranged in a pattern that maximizes liner strength, but the pattern can be designed to accommodate other completion objectives such as instrumentation and downhole flow control.

For a 177.8 mm (7") liner the maximum disc density is 132 HPF corresponding to an OFA of 19.5%, which is almost 8 times greater than SL and over twice greater than WWS. To match the OFA of SL (2.5%) only 17 HPF is required. However, a minimum of 24 HPF (3.6% OFA) is recommended to minimize the "effective skin" due to flow convergence in the near wellbore region resulting from the large spacing between discs. A similar effect is experienced with slotted liner⁴.

Disc Geometry

A photo and sketch of a FACS disc are shown in **Fig. 2**. In the current design, the disc is 25.4 mm diameter and 6.5 mm thick in the center (3.0 mm thick at the outer edge). The flat side of the disc faces outward towards the reservoir sand. As illustrated in **Fig. 3**, a somewhat complex hole geometry is required to insert the disc securely such that it has adequate retention strength and prevents bypass of fluid around the disc.

In the original design of the hole geometry, the disc was first press-fitted into the hole and then the top of the hole was plastically deformed to form a lip around the sharp edge of the disc, providing a reliable outward retention or "burst" strength of 14 MPa (2000 psi), which is more than adequate for most applications, including SAGD. The inward retention or "collapse" strength is much higher (greater than 35 MPa [5000 psi]) due to the shoulder created by the smaller hole. (A new and more complex hole geometry has been recently invented which avoids plastically deforming the liner around the disc without compromising retention strength, however the FEA study herein is based on the original design.)

For either hole geometry there is a minimum pipe wall thickness that could accommodate the disc such that it can be securely flush-mounted into the base pipe—neither protruding inwards nor outwards from the pipe wall. For 177.8 mm and larger, the minimum wall thickness is 8.6 mm (0.34") which is fine for 38.7 kg/m (26 lb/ft) base pipe. For smaller diameters, the minimum thickness increases slightly due to base pipe curvature effects. The FACS disc diameter and thickness can be made smaller to reduce the minimum required wall thickness, but more engineering work is required to evaluate the resultant retention strength.

Disc Construction and Properties

The current FACS disc is punched from a FBML sheet made up of 12-13 layers of stainless steel woven metal meshes sintered together to form a permeable solid structure. Conventional premium mesh screens use only 1-5 layers³. The wires crisscross to create pores of roughly uniform size, depending on the weave. As shown in **Fig. 4**, there are four basic types of weaves to choose from: a) plain square, b) plain dutch, c) twilled square, and d) twilled dutch. For each weave type there is a wide range of micron filtration ratings to choose from^{5,2}. Furthermore, there are a wide range of materials to choose from to meet virtually any corrosion requirement.

Each layer has its own sand retention rating (related to the mesh opening dimensions and typically expressed in microns) as measured by a Whitehouse Scientific glass bead test⁶. Most of the layers in a FACS disc serve to provide structural strength. Only one or a few are chosen to provide the required sand retention performance properties. The micron rating of a FACS disc is determined by the layer with the smallest micron rating, referred to as the "cut-off" layer, which can be located closest to the formation sand or within the structure to generate a 3D filtration structure to increase the retained permeability of the sand pack that forms against the screen⁷.

Once the lay-up is designed to achieve the desired characteristics, the individual layers are stacked together and then sintered to create a highly porous/permeable solid with significant structural strength. The sintering process is illustrated in

Fig. 5. Magnified photographs of FACS are provided in **Fig. 6.** For manufacturing convenience, the weave layers are typically stacked so that the wires in the structure either run parallel or perpendicular to each other, which creates strength anisotropy. For example, the disc is stiffer in the direction parallel to the wires and weakest in the direction 45° to the wires. However, the selection and orientation of the weaves can be modified to minimize this anisotropy if it proves problematic. The FACS discs are punched out of sintered metal mesh sheets such that the (radial) cut surface is effectively welded together and does not fray or separate.

Following the sand control evaluation methods developed by Constien et al⁸, **Fig. 7** shows a sand control performance curve for 250 µm FBML material (similar to what is used in FACS) and four typical Western Canadian SAGD sands (vertical dashed lines). Lower micron ratings are available for much finer sands encountered in other areas of the world.

Potential Applications for FACS Screens

A FACS screen offers significant advantages in terms of the adaptability of its configuration. A wide variety of materials, hole densities, disc patterns and sand retention characteristics are possible. Here is a list of the potential applications of this technology:

- Primary & thermally-stimulated (e.g. SAGD) horizontal heavy-oil wells
- High rate oil and gas wells
- Conventional long horizontal and deviated wells
- Aggressive corrosion/erosion environments & HPHT wells
- Under-pressured (e.g. coal-bed methane) or depleted wells (i.e. high overburden stresses)
- Support screens for gravel/frac packing
- Fireflood applications with downhole catalyst accommodation
- Water injection wells where easy wellbore access to the filtration surface is required for cleaning (e.g. bacteria)
- Other specialty applications to incorporate flow control and instrumentation

Our focus herein is on the application of this technology to SAGD wells where operators are looking for a robust, reliable, low-cost SAS that optimizes strength, sand control and productivity.

Finite Element Analysis Description

FACS Input Parameters

The mechanical strength of a FACS liner was evaluated for the loading conditions expected in a typical SAGD application. Similar analyses have been used to assess the structural performance of slotted liners and WWS in the same application¹⁰. This analysis requires comprehensive finite element models that can simulate the contact between the discs and the holes in the base pipe. Advanced material models are also required for both the base pipe and the discs to account for changes in the material properties at the expected elevated operating temperatures. The following parameters were chosen for the FEA analysis:

- a) One Base Pipe Size: 177.8 mm (7"), 38.7 kg/m (26 lb/ft), L80
- b) One disc design: 25.4 mm OD; 6.5 mm max thickness, 100 micron (µm) discs; cut-off layer on outside (Fig. 2)
- c) One hole geometry: original design with plastic deformation around top of hole to create retention lip (Fig. 3)
- d) Two hole densities: 1) 64 HPF = 16 rows of holes, 4 HPF per row, diamond (staggered) pattern
2) 24 HPF = 8 rows of holes, 3 HPF per row, diamond (staggered) pattern

Fig. 8 illustrates the patterns of the two disc densities modeled. Note that for most SAGD wells in Western Canada a 250 µm disc would be applicable for sand control, but a 100 µm disc was chosen for the FEA analysis because it was readily available from a non-SAGD application, and a different cut-off layer was not expected to alter the mechanical properties of the disc in any significant manner.

Disc Property Measurements

Although the thermal/mechanical properties of L80 base pipe were available from previous studies on casing⁹, slotted liner¹ and WWS¹⁰, the thermal/mechanical properties of the FACS discs had to be determined through a series of thermal/mechanical tests on 100 micron FACS discs. The measured properties were then used as input to the FEA model.

Thermal Expansion Measurements

The thermal expansion coefficients of the FACS disc were measured in all relevant directions for temperatures between 20 and 300 °C. As expected from the disc construction, anisotropy exists whereby the stiffness in the direction of the wires was 15% greater than in the direction 45° to the wire. The FEA model used these results to describe the anisotropy in the stiffness of the discs.

Mechanical Response Measurements

Numerous mechanical response (compression) measurements versus temperature were performed on the FACS discs to characterize the stiffness in the thickness direction and in three diametrical directions relative to the wire directions: a) 0°; b) 45°; c) 90°. The results show that the apparent stiffness in the thickness direction is about an order of magnitude higher than the diametrical stiffness. Also, the stiffness at 45° is about half that at 0° or 90°, which is not surprising given that the wires provide extra stiffness when aligned with the applied force. **Fig. 9** shows the disc in the two different applied force directions relative to the wire directions. This anisotropy is caused by the current design of the discs and can be minimized, if required, by altering the lay-up design of the weave layers.

The accuracy of the FEA model was verified by modeling the mechanical experiments. As shown in **Fig. 10**, the match between the lab measurements and the model results was reasonably good. Details of the disc modeling are beyond the scope of this presentation. For the FEA modeling of the FACS liner, the worst-case orientation of the disc was chosen to make its stiffness as weak as possible. As indicated, there is a sufficient flexibility in the design of the FACS disc to minimize the anisotropic effects and thus maximize the strength of the disc.

FEA Modeling Strategy for Installation Loads

The first part of the FEA analysis on the two FACS liners (64 HPF and 24 HPF) focused on the effect of installation loads—tension, compression, curvature (bending) and torsion—on both mechanical strength and disc gap opening. The interface between the disc and the base pipe was monitored for gap opening. For example, axial tensile strain would alter the hole shape (and disc) from circular to oval, eventually leading to a gap opening between the circumferential edge of the disc and the contact surface of the hole, as shown in the illustration in **Fig. 11**. A serviceability limit of 100 µm for the gap width was established to cover all possible sand control applications, which is conservative for SAGD wells in Western Canada where slotted liners are designed with gap widths between 300 and 460 µm¹. For each load scenario, a maximum load limit that may be applied to the liner during installation was established based on industry practices for blank pipe (BP). If the serviceability limit was not reached before the load limit then the FACS liner was deemed “suitable” for that installation load type. The load description, parameters measured/plotted, and load limits are tabulated below. In every case the gap that develops between the disc and pipe wall was recorded throughout the load.

Load Case	Load Description	Calculated/Plotted	Installation Load Limit
I1	Axial Tension	axial force (kN) vs. axial strain (%)	30% yield capacity of BP
I2	Axial Compression	axial force (kN) vs. axial strain (%)	30% yield capacity of BP
I3	Curvature (Bending)	bending moment (kNm) vs. dogleg (°/30m)	15°/30m
I4	Torque	torque (kNm) vs. rotational turn (over 10 m length)	20 kNm

Results for Installation Loads on FACS Liner

Tension

Fig. 11 presents the FEA analysis results for pure axial tension for 64 and 24 HPF. As expected the tensile strength decreases with HPF but not significantly so. No gap opening was observed at the load limit and the serviceability limit was not reached until 0.45% and 0.35% global axial tensile strain, which are significantly higher than the tensile strain limit corresponding to the 30% tensile yield capacity of a blank pipe. Therefore, FACS has sufficient capacity for tensile loading during installation.

Compression

Fig. 12 presents the FEA analysis results for pure axial compression for 64 and 24 HPF. As with tension, the compressive strength declines with HPF but not drastically so, and no gap opening is observed at the load limit. The serviceability limit (100 µm gap) is not reached until 0.92% and 0.78% global axial compressive strains, which are significantly higher than the compressive strain limit corresponding to the 30% compressive yield capacity of a blank pipe. Therefore, FACS has sufficient capacity in compression, which is important because rigs have been known to apply high compressive pushing force (up to 30% of blank pipe yield capacity as per design requirement) on SAGD liners to install them to the toe of long horizontal wells.

Curvature (Bending)

Fig. 13 presents the results for pure bending for 64 and 24 HPF. As expected, the bending strength declines with HPF but is still high for 9.6% OFA. No gap opening is observed at the load limit of 15°/30m. The moment-curvature relationships are generally linear up to about 50°/30m for both. The serviceability limit is not reached until 85°/30m and 70°/30m, respectively. This is an attractive feature for FACS for sharp radius turns such as in sidetracks and multilaterals.

Torque

Fig. 14 presents the results for pure torsion for 64 and 24 HPF. Note that a turn is defined as the number of rotations that would occur in the liner over a 10 m long section of liner under pure torsion. Again, the torsional strength decreases with increasing HPF but is still high (~85 kNm) for an OFA of 9.6%. Note that a 2.5% OFA slotted liner is especially weak in torsion¹. **Fig. 15** shows the comparison for the exact same base pipe between 24 HPF FACS, 64 HPF FACS and 2.5% OFA slotted liner (with 50-70 mm length and 0.30-0.46 mm width slots; and 576 slots per metre as per Ref. 1). A FACS liner with almost four times the OFA (9.6% vs. 2.5%) of slotted liner has over three times the torsional strength. Likewise, a FACS liner with 1.5 times the OFA (3.6% vs. 2.5%) has over four times the torsional strength. This again is an attractive feature for FACS for SAGD application because rigs have been known to apply high torque that may possibly damage slotted liners in order to get them to bottom, based on some of the slotted liner failures reported.

Results Summary for Installation Loads

A summary of the results of the installation load analysis is provided in the table below:

Load Case	Load Description	64 HPF (9.6% OFA)					24 HPF (3.6% OFA)				
		Structural Evaluation		Serviceability Evaluation			Structural Evaluation		Serviceability Evaluation		
		Plastic Strain	Structural Assessment	Critical Disc Orientation	Gap Opening (micron)	Serviceability Assessment	Plastic Strain	Structural Assessment	Critical Disc Orientation	Gap Opening (micron)	Serviceability Assessment
I1	Axial tension (30% pipe yield)	0.2%	✓	0°	0	✓	0%	✓	0°	0	✓
I2	Axial compression (30% pipe yield)	0.2%	✓	0°	0	✓	0%	✓	0°	0	✓
I3	Curvature (15°/30 m)	0%	✓	0°	0	✓	0%	✓	0°	0	✓
I4	Torque (20 kNm)	0%	✓	45°	0	✓	0%	✓	45°	0	✓

* Plastic strain was evaluated at the circumferential surface of the base pipe hole.

** ✓ represents "suitable" based on assessment.

The FEA studies indicate that FACS is a robust screen that can handle the severe installation loads encountered in SAGD (and other) wells.

FEA Modeling Strategy for Operational Loads

The second part of the FEA analysis on the two FACS liners (64 HPF and 24 HPF) focused on the effect of operational loads—tension, compression, collapse and “burst” (during steam injection)—on both mechanical strength and sand control. The operational loads are caused by a combination of high temperature steam and formation collapse around the screen. “Burst” of pipe is primarily significant for steam injectors. Regarding sand control requirements, the interface between the disc and the base pipe was monitored for gap opening, employing the serviceability limit of 100 µm gap width to cover all possible sand control applications which, as indicated, is conservative for SAGD wells in Western Canada where slotted liners are designed with gap widths between 300 and 460 µm¹. For each load scenario, the failure criterion was established based on previous experience with evaluating liners for SAGD operations. If the serviceability limit is not reached during the load cycle then the FACS liner is deemed “suitable” for the specific operational load type. The thermal/load description and parameters calculated/plotted are tabulated below. In every case, the gap between the disc and pipe wall was recorded. Special attention was paid to plastic deformation around the holes, which could lead to structural failure.

Case	Thermal Description (steps)	Load Description	Calculated/Plotted
O1	1) 20-275 °C; 2) hold at 275 °C; 3) 275-20 °C	Confined Prior to Heating	axial force (kN) vs. temperature (°C)
O2	1) 20-275 °C; 2) hold at 275 °C; 3) 275-20 °C	Confined Prior to Cooling	axial force (kN) vs. temperature (°C)
O3	A) 275 °C O1; B) 20 °C O1-3; C) 20 °C O2-3	“Burst”	internal press. (MPa) vs. disc displacement
O4	A) 275 °C O1; B) 20 °C O1-3; C) 20 °C O2-3	“Collapse”	external press. (MPa) vs. ovality (%)

Case O1 is the maximum compressive scenario whereby the liner is axially confined by the formation prior to heating. Case O2 is the maximum tensile loading scenario whereby the liner is free to expand during heating but is axially confined after it has reached the maximum temperature, generating tensile forces upon cooling. Case O2 is the more plausible of the

two for Western Canadian SAGD reservoirs because heating the “tar sands” oil significantly reduces its viscosity thereby decreasing the “consolidation” of the formation sand. Note that Cases O3 and O4 make reference to Cases O1 and O2 in the thermal description. For example: “(C) 20 °C O2-3” for O3 in the table above means that the collapse analysis was performed at the end of the thermal cycle in O2 at 20 °C.

Results for Operation Loads on FACS Liner

Confinement Prior to Heating (O1)

Fig. 16 shows the FEA analysis results for the case of confinement prior to heating which initially generates compressive (i.e. negative) forces. Holding the temperature constant at State A causes some stress relaxation prior to the cooling period. During cooling to State B the stress changes from compression to tension. The gap between the disc and hole doesn’t appear until about 175 °C during the cool down period when the base pipe experiences tension. The reason is that the disc plastically deforms during compression and does not recover its shape as the hole is elongated in tension. Unlike slotted liners (and WWS), where the gap width, hence sand control, is very sensitive to plastic deformation, moderate plastic deformation of the disc is not expected to significantly alter its sand control characteristics because of its structure, although experimental work is required to confirm this. The maximum gap openings for 64 and 24 HPF are 65 and 76 μm respectively, which satisfies the serviceability criteria of 100 μm maximum gap width. The maximum local plastic strains at the holes are 1.93% and 3.77% respectively, which are too low to result in structural failure of the base pipe. Interestingly, 64 HPF has a smaller maximum gap and plastic strain than 24 HPF. The reason is that the thermal strain imposed during heating/cooling localizes around the holes in the liner. With fewer holes, more localization can occur at each hole, resulting in higher plastic strains.

Confinement Prior to Cooling (O2)

Fig. 17 shows the results for the case of liner confinement occurring after the heating period (O2) which generates tensile forces during the cooling cycle. At State A the tensile force begins as cooling begins and continues to increase until cooling ends at State B. A gap appears at about 200 °C in each case and continues to increase until 20 °C. Maximum gap openings are 73 and 102 μm for 64 and 24 HPF, respectively. Maximum plastic strains around the holes are 1.16% and 2.79% respectively, which are too low to result in structural failure of the base pipe. Although the serviceability limit of 100 μm was breached for 24 HPF, the gap is still significantly below the minimum slot width of 300 μm for Western Canadian SAGD wells so that sand production through the gap should not be an issue.

Since the gap opening in the 24 HPF FACS exceeded the serviceability requirement, there is concern about the ability of FACS to absorb additional compressive/tensile strain after the O1/O2 thermal cycles. Sectional buckling (“bird-caging”) of slotted liners in the field⁹ has been attributed to strain localization or “dumping” whereby the strain is not absorbed equally along the liner but localizes due to variations in the base pipe parameters (material properties, wall thickness, etc.) as well as wellbore/reservoir parameters. This is considered to be an important design criterion for slotted liners¹ and for WWS¹⁰ in thermal wells.

Fig. 18 shows the capacity of FACS to absorb additional tensile strain for Case O2, the maximum tensile scenario that proved to be the most severe case for FACS. Note that 64 HPF has more strain capacity than 24 HPF because, as indicated earlier, the extra holes absorb the strain caused by thermal expansion/contraction. If the maximum gap width for a SAGD liner is 300 μm, then 24 HPF has a total strain capacity of 0.7% before sand control starts to become compromised. While “strain localization” is a potentially important consideration, more research is required on quantifying its causal nature and its probability of occurrence, and on applying that knowledge to all screens considered for thermal applications.

Another related concern is the localized plastic strain that occurs around the holes for the severe operational loads. As indicated, the plastic strains calculated appear to be too low to cause structural failure, but if strain “dumping” occurs, the plastic strain could become significant. **Fig. 19** shows the plastic strain profile for 64 and 24 HPF for State B in **Fig. 17** (case O2). Although enhanced plastic strain due to strain “dumping” is potentially an important consideration, more research is required to quantify such phenomenon for all screens considered for thermal applications.

Burst (O3)

One of the concerns raised about FACS is the pressure drop required to “pop out” the disc, which is effectively the “burst” pressure. Because the disc is retained by plastically deforming the hole around the disc to create a retention lip, the disc becomes the weakest link in the burst mode, assuming that the injection fluid can seal off against the FACS media and thereby generate a large enough pressure drop, which is an unlikely scenario for a SAGD producer. (The pressure drop across an unplugged 250 μm FACS disc will be negligible for typical SAGD steam injection rates.) For a SAGD steam injector, the pressure of saturated steam at 275 °C is about 5.95 MPa. Hence the burst pressure for FACS should be a minimum of 7 MPa to account for the possibility of discs getting plugged during steam injection.

Fig. 20 shows the disc “pop out” or “burst” pressure for 64 and 24 HPF respectively for three states corresponding to the basic thermal cycle. The HPF and disc orientation have little effect on the “burst” pressure, which is 13 MPa, which is more than adequate for SAGD and most other applications. Interestingly, the FEA model gave a good match to mechanical disc retention strength data acquired during the development of FACS (14 MPa or 2000 psi).

Collapse (O4)

For collapse, the FEA data is presented as external pressure (applied radially around the liner) versus ovality, which is defined as follows:

$$\text{ovality} = \frac{OD_{\max} - OD_{\min}}{OD_{\text{ave}}} \times 100\%$$

where OD_{\max} is the maximum pipe outer diameter (OD), OD_{\min} is the minimum and OD_{ave} is the average. **Fig. 21** shows the collapse pressure versus ovality for 64 and 24 HPF at the following three different states in the thermal cycle:

- O4A – external pressure applied at peak temperature (State A) in case O1 (maximum compressive loading)
- O4B – external pressure applied at end of thermal cycle (State B) in case O1 (maximum compressive loading)
- O4C – external pressure applied at end of thermal cycle (State B) in case O2 (maximum tensile loading)

The collapse pressures are 27.1, 26.2 and 30.2 for 64HPF, and 33.4, 34.8 and 38.7 for 24 HPF, for O4A, O4B and O4C, respectively. These loads are significantly higher than the overburden and fracture pressures of most SAGD applications. As expected, the collapse strength decreases as the hole density increases, but for 64 HPF (9.6% OFA) it remains high. Note that these numbers are based on uniform external pressure and that liners can collapse at lower pressures if the pressure is applied unevenly. Therefore, high collapse strength is often preferred for base pipes.

Fig. 22 shows the comparison of collapse resistance for the same base pipe with 24 HPF FACS, 64 HPF FACS and 2.5% OFA slotted liner (50-70 mm x 0.30-0.46 mm slots; 576 slots per metre, staggered, as per Ref. 1). However, the slotted liner analysis was performed at room temperature which does not account for the axial loading effect on the base pipe material that may result in slightly lower collapse resistance than shown in this comparison. A FACS SAGD liner with almost four times the OFA of the slotted liner (9.6% vs. 2.5%) has over twice the collapse resistance. Likewise, a FACS liner with 1.44 times the OFA (3.6% vs. 2.5%) has over 2.4 times the collapse resistance.

Results Summary for Operational Loads

The results for the analysis of the impact of operational loads on the FACS liner are summarized below. As with installation loads, FACS satisfied all the operational load requirements except that the gap for Load Scenario O2 might slightly exceed the serviceability limit of 100 μm . However, given the severity of the simulated conditions and the fact that a gap of 300 μm would be acceptable for most Western Canadian SAGD wells, this should not be a barrier for using FACS in SAGD wells, especially given the problems associated with alternative screens such as slotted liner¹ and WWS¹⁰.

Case	Thermal Description (steps)	Load Description	Evaluation
O1	1) 20->275 °C; 2) hold; 3) 275->20 °C	Confined Prior to Heating	acceptable plastic strain; max gap = 76 μm
O2	1) 20->275 °C; 2) hold; 3) 275->20 °C	Confined Prior to Cooling	acceptable plastic strain; max gap = 102 μm
O3	A) 275 °C O1; B) 20 °C O1-3; C) 20 °C O2-3	“Collapse”	Min. collapse = 26.2 MPa (64 HPF; 9.6 % OFA)
O4	A) 275 °C O1; B) 20 °C O1-3; C) 20 °C O2-3	“Burst”	Disc retention 13 MPa

The results so far are based on computer modeling. Apart from disc retention measurements, which were matched by the FEA, no mechanical testing had been performed to date. Full scale physical testing is being planned to confirm the analysis result for the other loading scenarios discussed in this paper.

Conclusions

The following conclusions can be made based on the FEA analysis:

- 1) Both FACS 24 HPF (3.6 % OFA) and 64 HPF (9.6 % OFA) satisfied all of the SAGD mechanical strength requirements for all the installation loads, such as tension, compression, bending and torsion.
- 2) For a typical SAGD SAS—177.8 mm (7”) OD, 38.7 kg/m (26 lb/ft) L80—a FACS liner with almost four times the OFA (9.6% vs 2.5%) of slotted liner has over three times the torsion strength and almost twice the collapse strength. A FACS liner with 1.44 times the OFA (3.6% vs. 2.5%) has over four times the torsion strength and 2.4 times the collapse strength.
- 3) Both FACS 24 HPF (3.6 % OFA) and 64 HPF (9.6 % OFA) satisfied all of the SAGD mechanical strength and serviceability requirements for the operation conditions/loads established at the outset (with one borderline exception).
- 4) One concern was that although FACS basically satisfied the operational criteria, it had very limited ability to absorb additional strain at the end of the thermal cycle which means any additional strain “dumping” in the liner would open the gap beyond 100 μm . Further research work is required to quantify the seriousness of this concern for all thermal screens.

- 5) For the most severe operation loads, plastic deformation around the holes can be high, although not deemed high enough to cause structural failure of the base pipe. However, any additional strain due to “dumping” could possibly cause enough plastic deformation to cause structural failure of liners. Further research is required to assess this.
- 6) Based on the results of this FEA structural analysis, FACS appears to be a potential alternate form of SAS for SAGD wells.

Acknowledgements

This work was funded by Schlumberger in support of the development of the FACS screen by Absolute Completion Technologies. The mechanical strength evaluation work, i.e. finite element analyses and coupon tests, described in this paper was performed by C-FER Technologies. The authors wish to thank Schlumberger, Absolute Completion Technologies and C-FER for their support in this project and for their permission to publish this work.

Nomenclature

BP = base pipe
 FACS = flush absolute cartridge system
 FBML = fusion bonded metal laminates
 FEA = finite element analysis
 HPF = holes per foot
 OFA = open flow area (%)
 PSD = particle size distribution
 SAGD = steam assisted gravity drainage
 SAS = stand alone screen
 SL = slotted liner
 WWS = wire-wrapped screen

References

1. Xie, J., Jones, S.W., Mathews, C.M. Wagg, B.T., Parker, P., and Ducharme, R. 2007: “Slotted Liner Design for SAGD Wells – Staggered slot and gang slot patterns show better performance in FEA models than overlapping slot patterns.” World Oil, Defining Technology for Exploration, Drilling and Production, pp. 67-75, June 2007.
2. Adams, P.R., Davis, E.R., Hodge, R.M., Burton, R. C., Ledlow, L., Procyk, A. C., Crissman, S. C. 2007: “Current State of the Premium Screen Industry; Buyer Beware. Methodical Testing and Qualifications Shows You Don’t Always Get What You Paid For.” SPE 110082 presented at the 2007 SPE Annual Technical Conference and Exhibition held in Anaheim, California, U.S.A., 11-14 Nov., 2007.
3. Mathisen, A.M., Aastveit, G.L., and Alterås, E. 2007: “Successful Installation of Stand Alone Sand Screen in More Than 200 Wells – The Importance of Screen Selection Process and Fluid Qualification.” SPE 107539 presented at the SPE European Formation Damage Conference held in Scheveningen, The Netherlands, 30 May – 1 June 2007.
4. Kaiser, T.M.V., Wilson, S., Venning, L.A. 2002: “Inflow Analysis and Optimization of Slotted Liners.” SPE 80145 first presented at the 2000 SPE/Petroleum Society of CIM International Conference on Horizontal Well Technology, Calgary, 6-8 November, 2000.
5. Ott, W.K. and Woods, J.D. 2005: “Modern Sandface Completion Practices Handbook, 2nd Edition.” Gulf Publishing Company; Houston, Texas, 2005; pg. 37 and 38.
6. Rideal, G. R., 2004: “A New Sonic Challenge Test for the Pore Size Measurement of Sand Screens.” Whitehouse Scientific Ltd, 2004. (www.whitehousescientific.com)
7. Underdown, D.R., and Hopkins, S. 2006: “Design and Implementation of Retention/Filtration Media To Improve Heavy Oil Production.” SPE 103782 presented at the 2006 SPE International Oil & Gas Conference and Exhibition in China held in Beijing, China, 5-7 December 2006.
8. Constien, V. and Skidmore, V. 2006: “Standalone Screen Selection Using Performance Mastercurves.” SPE 98363 presented at the 2006 SPE International Symposium and Exhibition on Formation Damage Control held in Lafayette, L.A., 15-17 February 2006.
9. Xie, J. 2000: “Understanding the Mechanisms of Well Casing Deformations.” C-FER Final Report to Joint Industry Members, C-FER Project 99023.
10. Xie, J., Zahacy, T.A., Fan, C. and Mathews, C.M. 2008: “Design Considerations for Wire Wrapped Screens in SAGD Well Applications.” 2008 World Heavy Oil Congress, Edmonton, Alberta, March 10-12, 2008, Paper No. 2008-389.

Figures



Fig. 1: Display Sample of FACS Screen

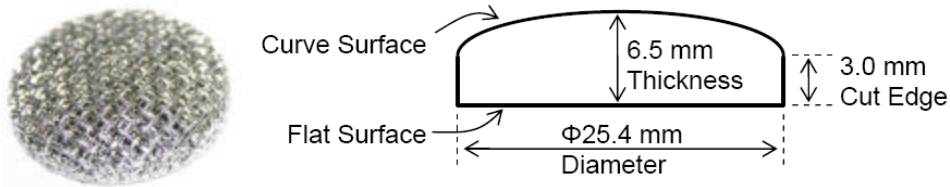


Fig. 2: Photo and Sketch of Current Disc Design

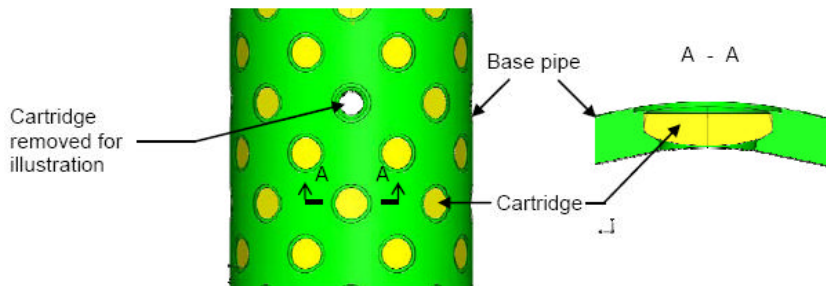


Fig. 3: Illustration of Discs Securely Flush-Mounted into Base Pipe

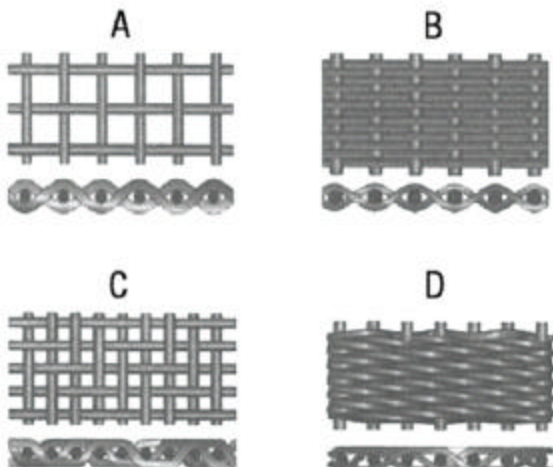


Fig. 4: Woven wire cloth weave patterns: plane square (A), plain dutch (B), twilled square (C) and twilled dutch (D) [Courtesy of World Oil/Gulf Publishing; Ref. 5, pg. 37.]

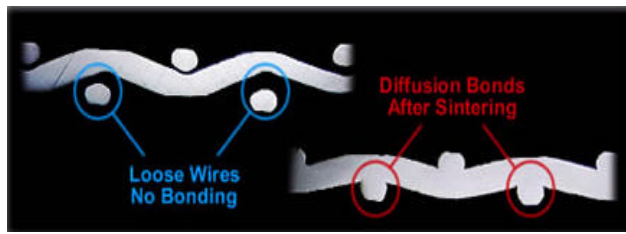


Fig. 5: Illustration of Fusion Bonding of Weave Wires [Courtesy of Martin Kurz & Co. Inc. (MKI)]

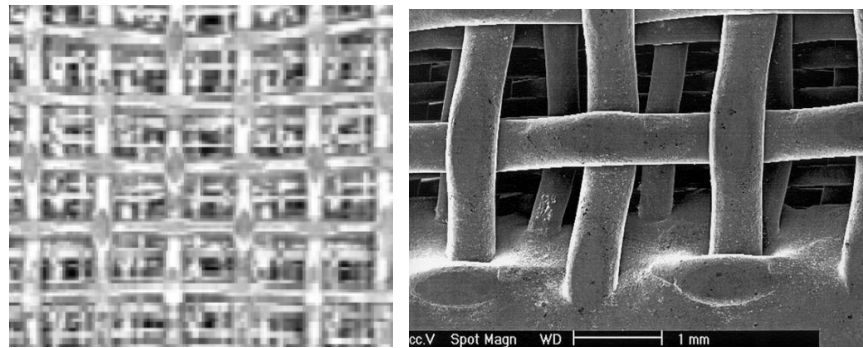


Fig. 6: Magnified Photos of FACS [Right photo courtesy of Martin Kurz & Co. Inc. (MKI); <http://www.mkicorp.com/o-techpapers.asp>]

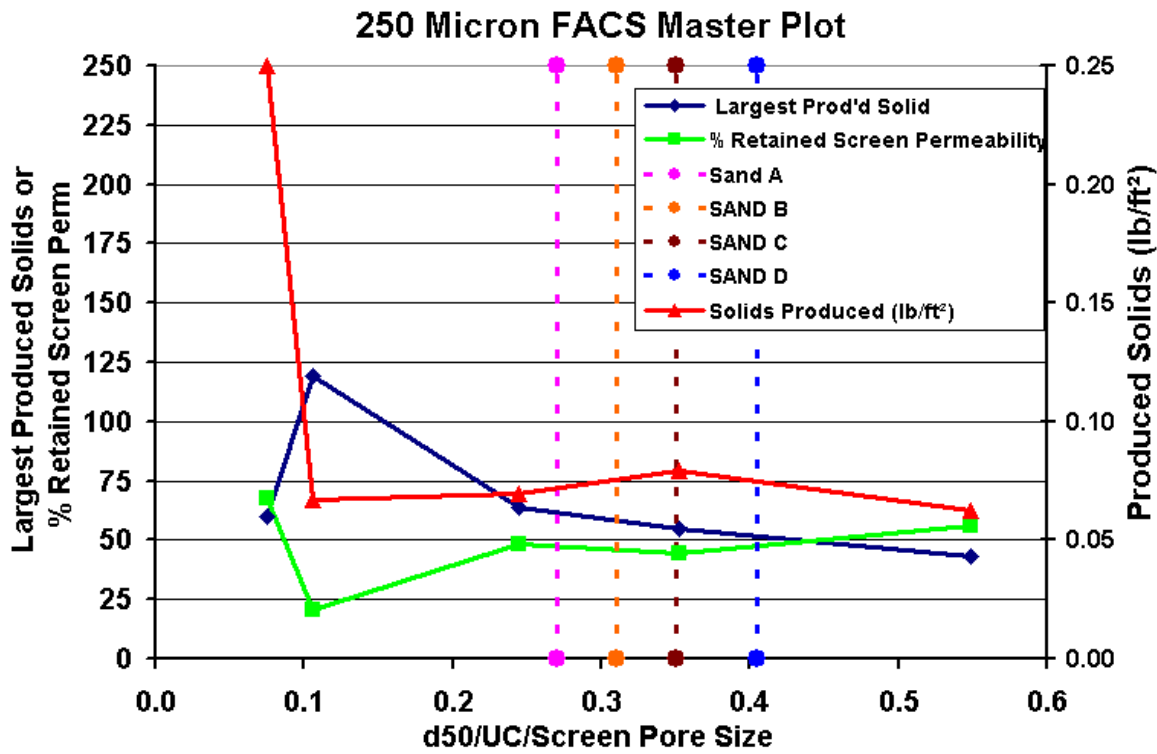


Fig. 7: Typical Sand Control Performance Curve for 250 μ m FBML for SAGD Application

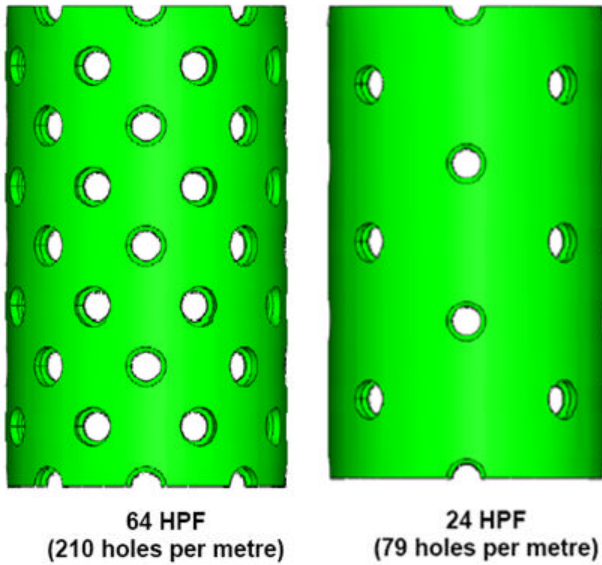


Figure 8: Illustration of the Two Hole Density/Patterns used in the FEA Analysis (177.8 mm OD)

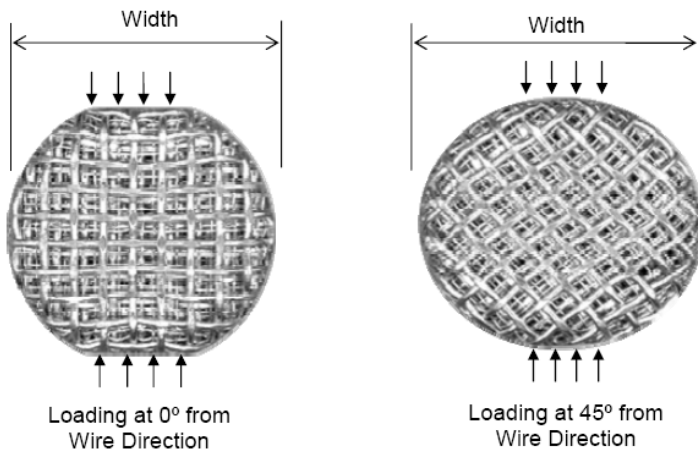


Fig. 9: Diametrical Deformation of Disc Specimen Loaded at Two Angles

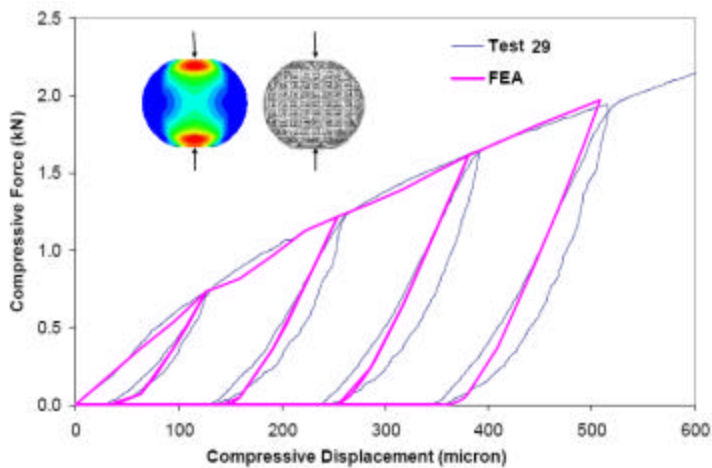


Figure 10: Load Displacement Curves for FEA Analysis and Mechanical Test

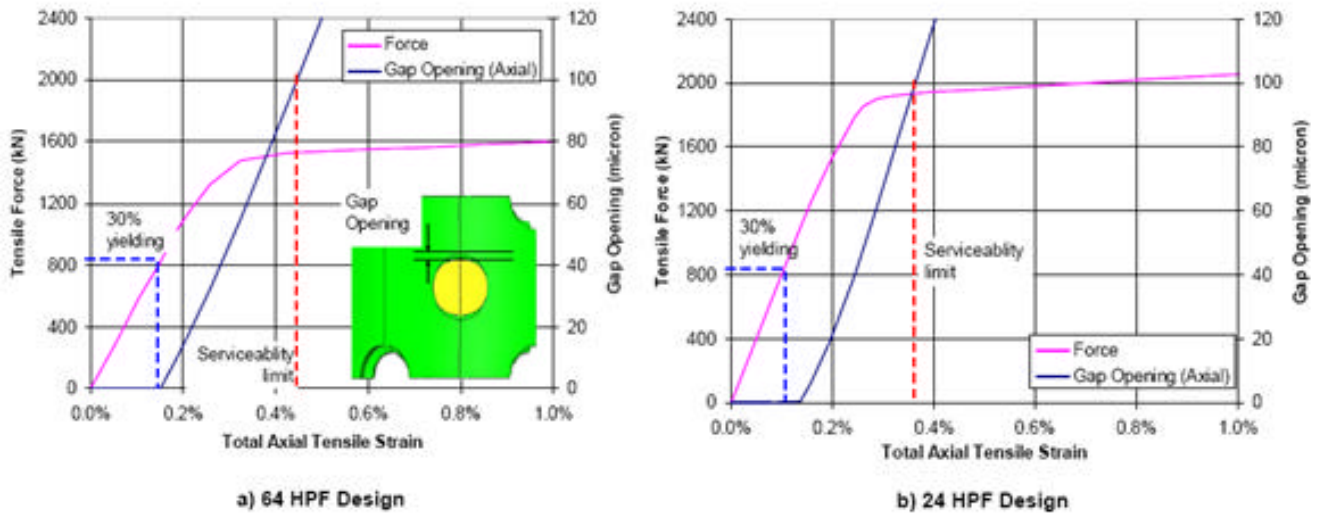


Fig. 11: Tensile Force and Gap Opening vs. Total Axial Strain for Two Hole Densities

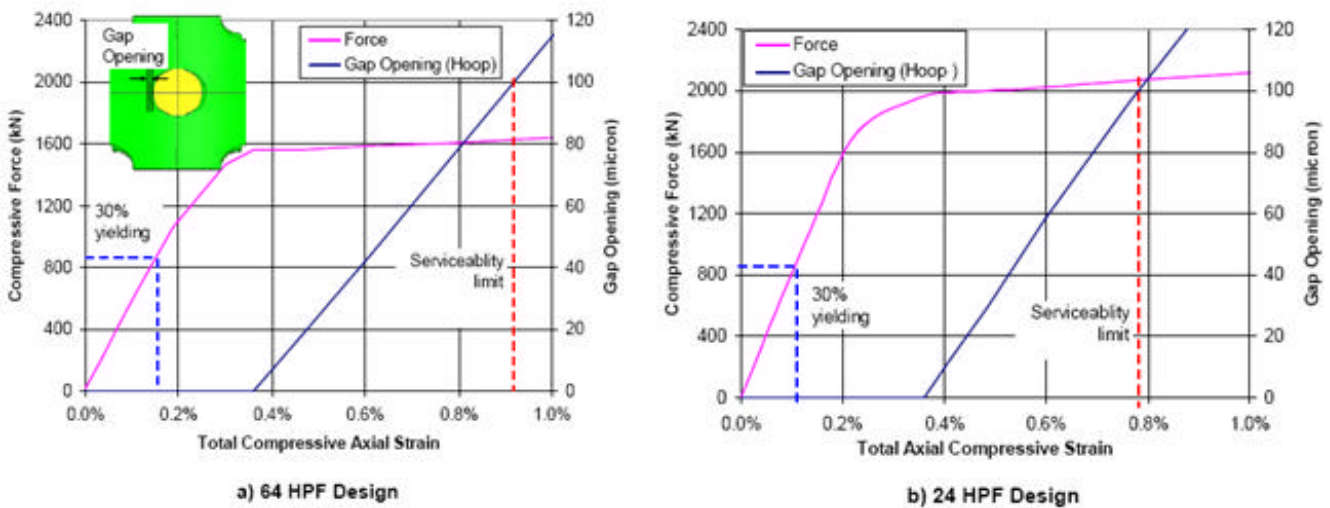


Fig. 12: Compressive Force and Gap Opening vs. Total Axial Strain

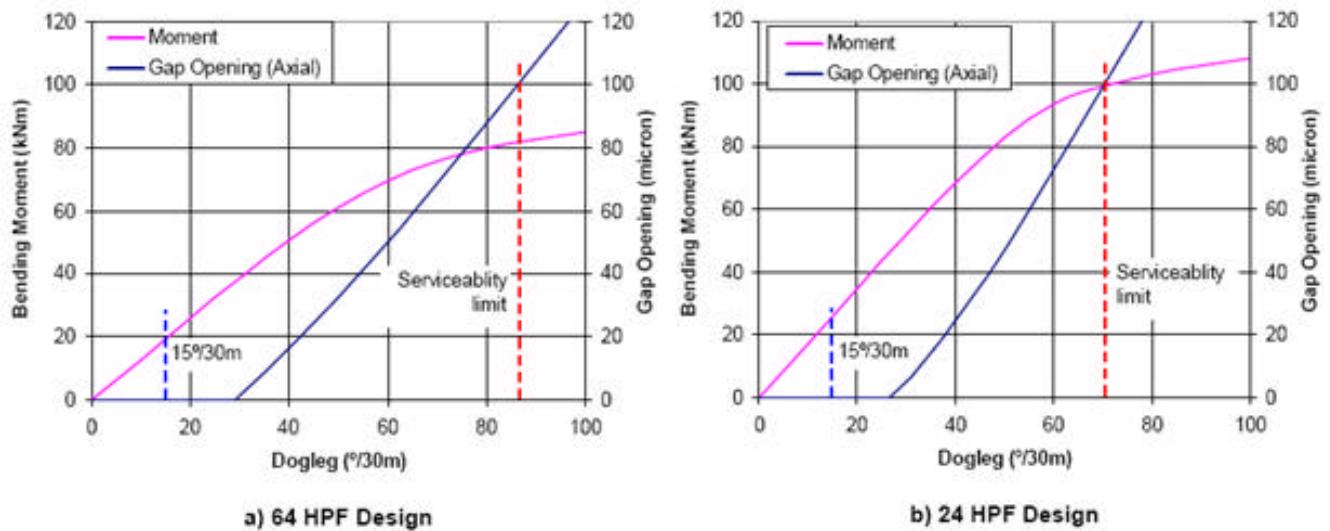


Fig. 13: Bending Moment and Gap Opening vs. Dogleg Severity

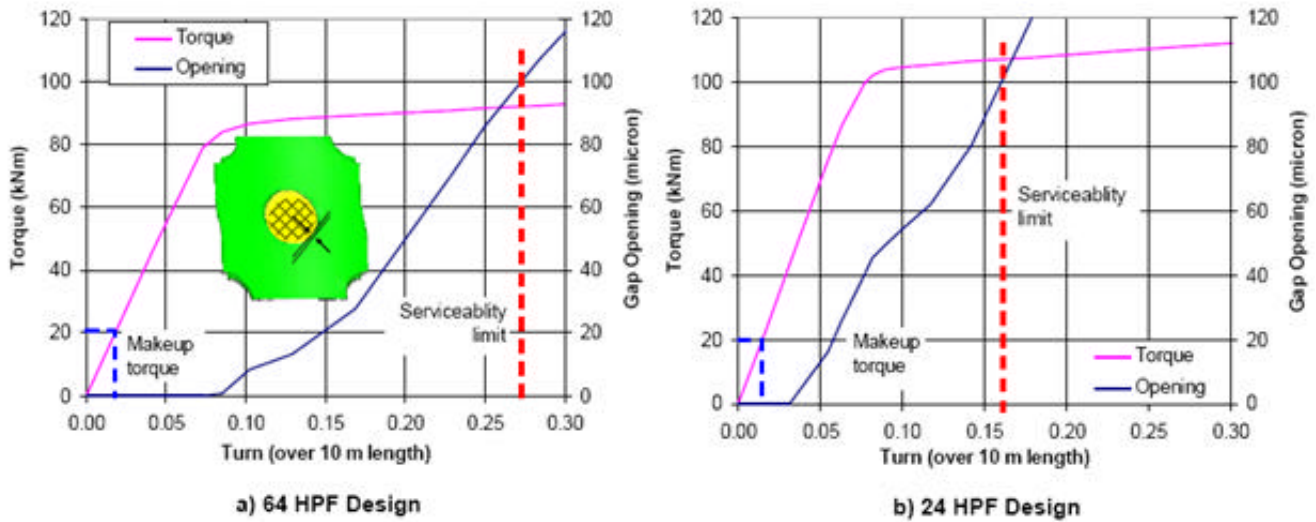


Fig. 14: Torque and Gap Opening vs. Turn over 10 Meters Length.

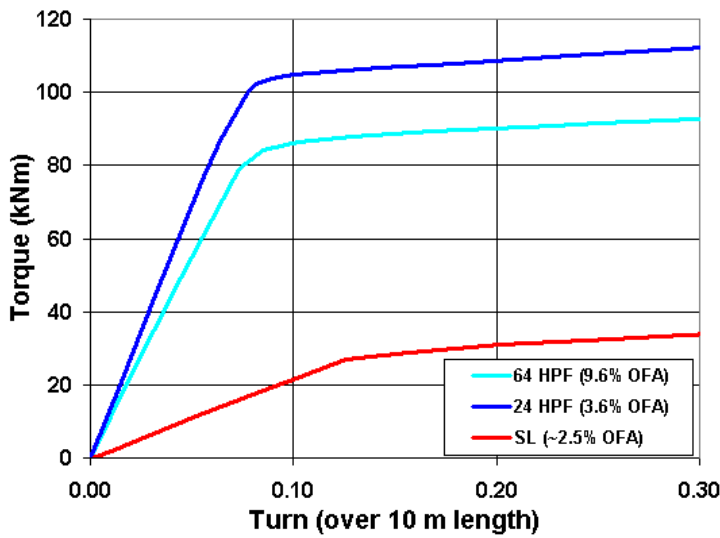


Fig. 15: Torque vs. Turn Comparison between FACS and Slotted Liner

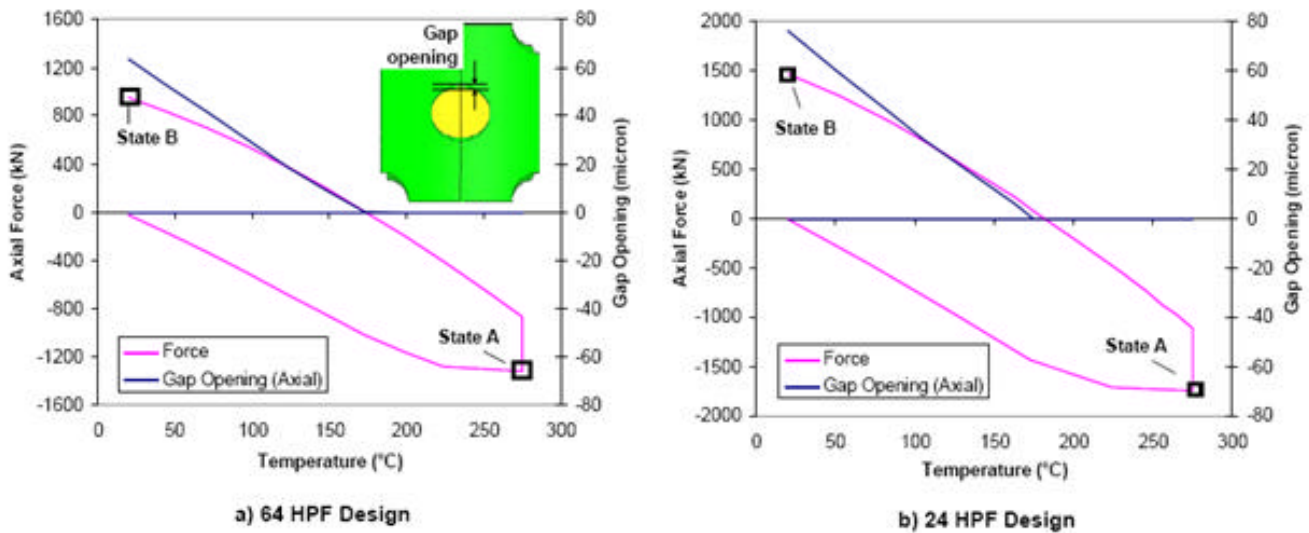


Fig. 16: Axial Force and Gap Opening vs. Temperature for O1 Operational Loading (Maximum Compressive)

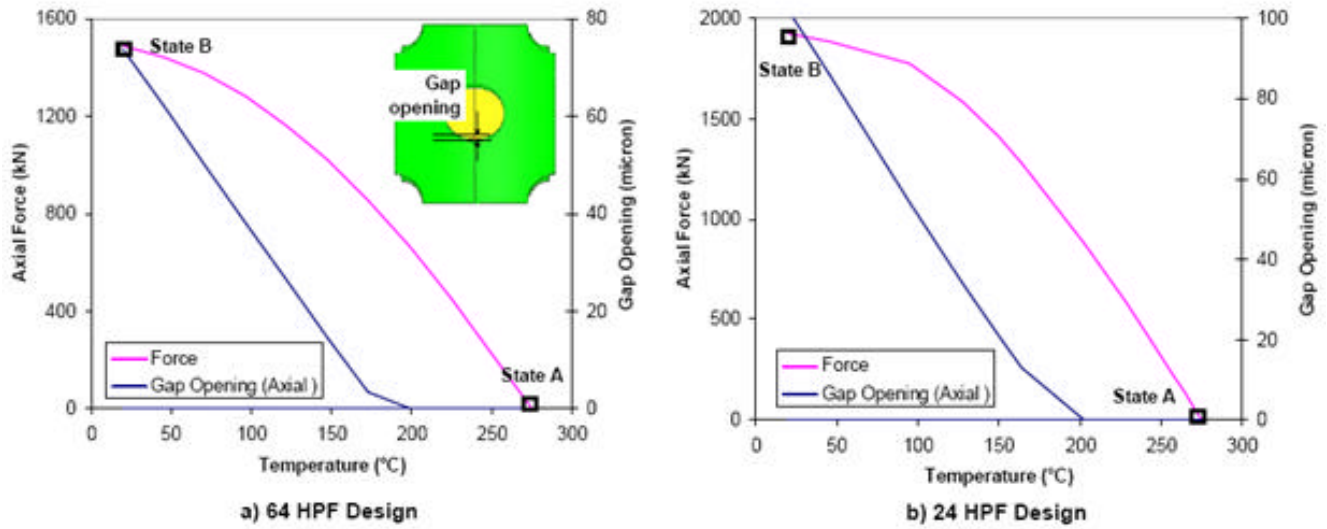


Fig. 17: Axial Force and Gap Opening vs. Temperature for O2 Operational Loading (maximum tensile)

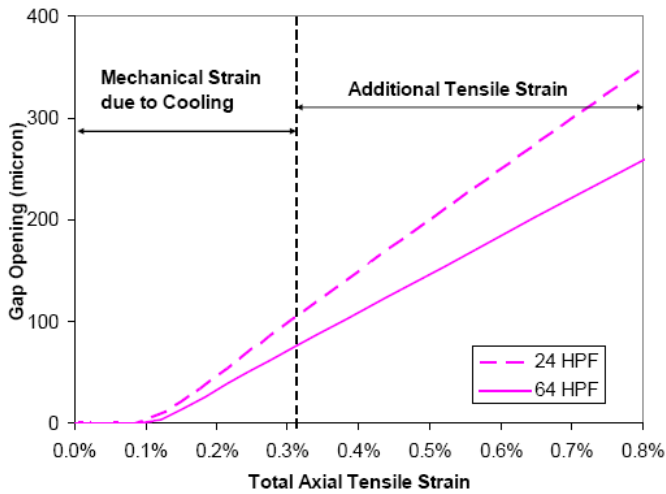


Fig. 18: Gap Opening vs. Total Axial Tensile Strain for O2 Operational Loading (maximum tensile)

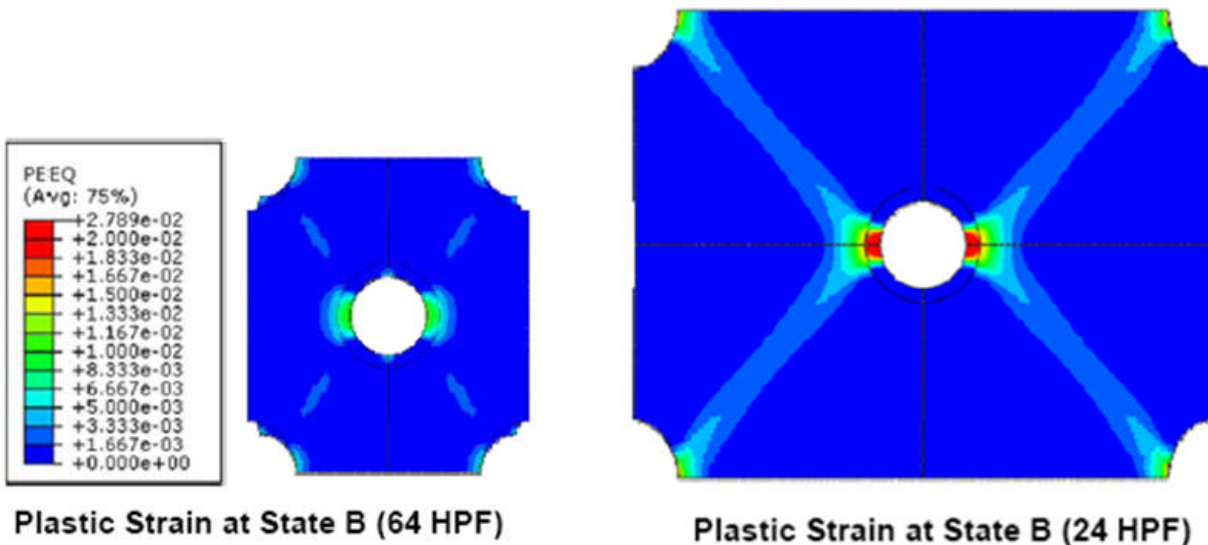


Fig. 19: Plastic Strain Profiles for State B in Figure 17 (Operational Loading O2)

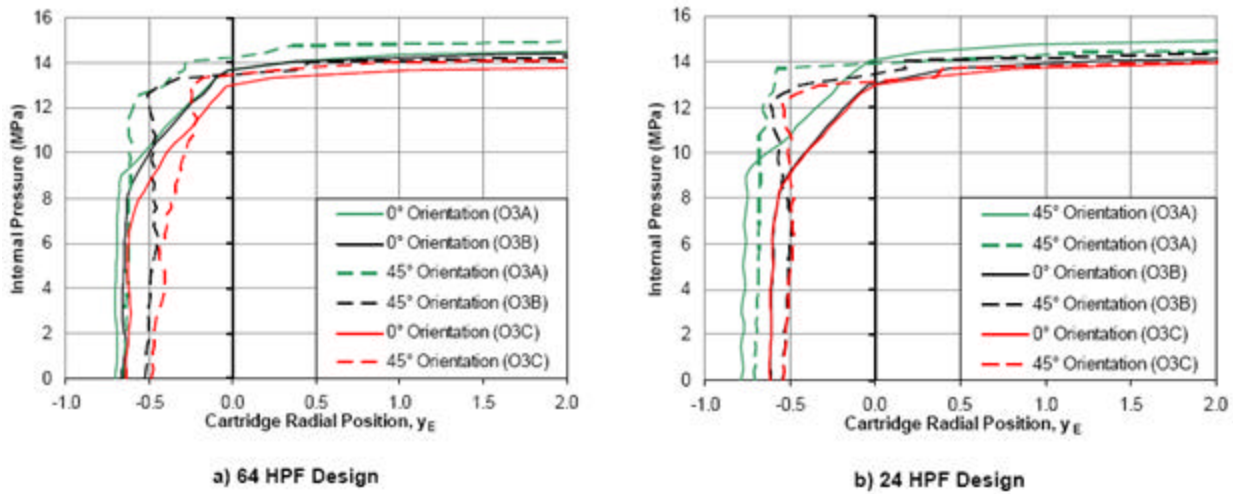


Fig. 20: Internal (“Burst”) Pressure vs. Disc Expulsion for Different States and Orientations

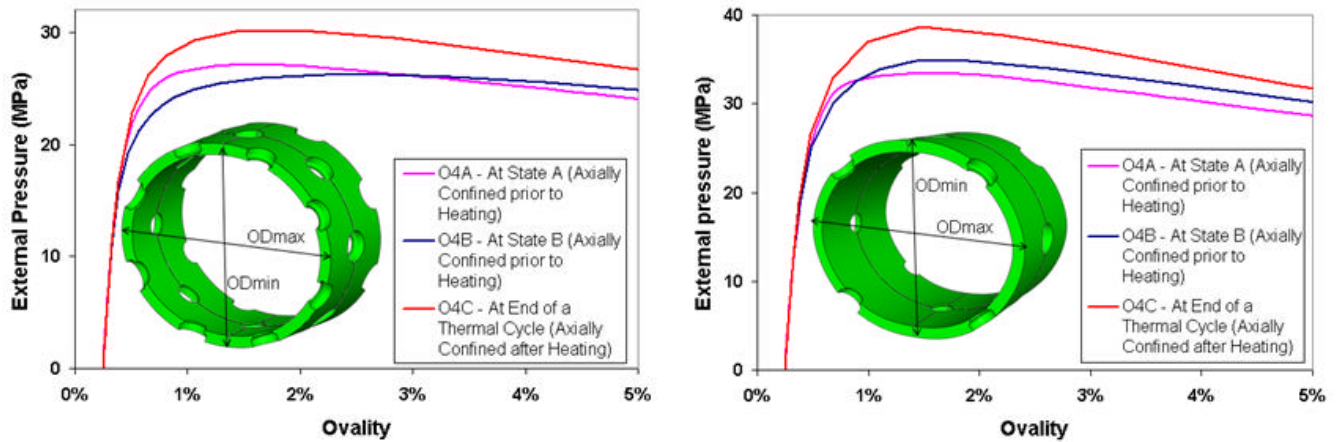


Fig. 21: External (Collapse) Pressure vs. Ovality for Different Load Scenarios

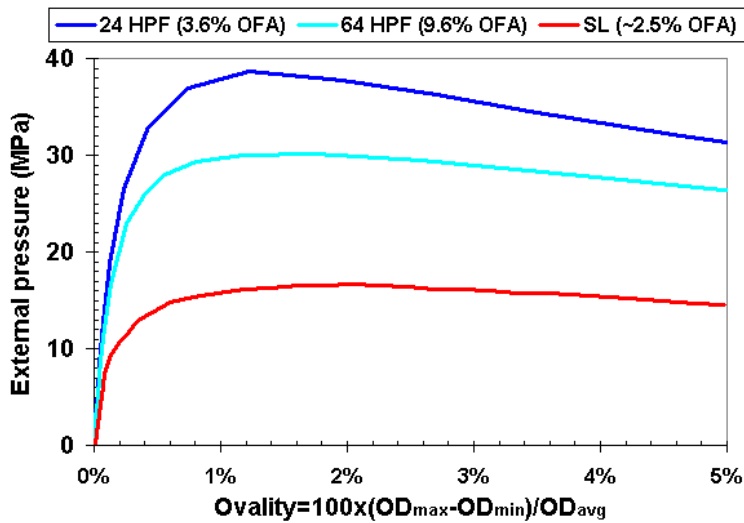


Figure 22: Collapse Pressure vs. Ovality Comparison between FACS and Slotted Liner