Creep and thermal ratcheting characterization of polytetrafluoroethylene-based gasket materials

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Abstract

Characterization of Teflon polymer based gaskets under expedited aging is the objective of this work. Teflon gaskets are exploited frequently as a replacement to asbestos fiber gaskets because of their excellent leak tightness and nonhazardous physical degradation properties. The research focuses profoundly on the adverse influence of temperature and thermal cycles on the creep and cumulative damage phenomenon under compressive load. Virgin and expanded PolyTetraFluoroEthylene (PTFE) are tested under 28 and 41 MPa of gasket stress at different temperatures. Intricate analysis of creep under coalesces of thermal ratcheting and principal stress is achieved through Universal Gasket Rig (UGR). The instigated cumulative damage is distinguishable into upper and lower bound temperature region indicating the escalation and decrease of thickness change during cycling which saturates after 12 thermal cycles for expanded PTFE while no saturation is reached for virgin PTFE in even after 20 thermal cycles. Percentage of thickness reduction at different applied stress is nearly the same for virgin PTFE whereas expanded PTFE shows largest reduction under lower stress. Compressive creep bespeaks the impact of temperature and load, thereby dictating the magnitude of ratcheting damage and contrariwise. Finally, the creep and thermal ratcheting has a proliferating effect on value of the coefficient of thermal expansion for all chosen gaskets. Copyright © 2017 VBRI Press.

Keywords: PTFE-based gaskets, compressive creep, thermal ratcheting, coefficient of thermal expansion.

Introduction

Polytetrafluoroethylene is one of the sought-after material for gasket components. Its excellent leak tightness and chemical resistant made it stand out among conventional gaskets. In addition to high temperature applicability, PTFE are nonhazardous degradable material in contrast to the asbestos fiber gaskets making them appropriate for aggressive fluid and corrosive environment applications. In spite of the advantages, one of the major drawback for PTFE material is the creep response to compressive load while the other is the extrusion failure when utilized in class 150 and 300 pipe flanges under particular environments [**1,2**]. This lead to the development of a standardized procedure on relaxation and blow-out characteristics of PTFE based gaskets [**3**]. The standard test procedure is developed on a Nominal Pipe Size (NPS) 3 class 150 flange joint fixture with relaxation capabilities.

Researches [**4,5**] evaluated the test method for characterizing of non-asbestos gasketing material at elevated temperature. However, numerous gaskets are operated under cyclic temperature environment and climatic discrepancies creating the necessity to inspect the damage under ratcheting. The thermal ratcheting or cycling of temperature on the cumulative creep damage of PTFE materials is of importance in bolted gasketed joints. Thermal ratcheting induces cumulative damage on the gasketed material leading to its thinning. This generates a further loss of compressive load on the gasket projecting for radial extrusion under the internal pressure and instigating failure by blow out. Only few reported literature [**6-10**] investigated on to the thermal ratcheting phenomenon of PTFE based materials but none studied the coupling of creep and thermal ratcheting.

Literatures [**8,9**] explored into the effect of thermal ratcheting and applied load on the thermal expansion of PTFE nonetheless these researches were limited to couple of thermal cycles and a maximum ratcheting temperature of 204^0C. Coefficient of thermal expansion is an important characteristic for the modern design codes of bolted joints including finite element analysis. The prevailing test standards developed by the American Society of Testing and Materials [**11-13**] do consider the effect of load or thermal ratcheting induced creep phenomenon. The work by Bhattachar [**14**] on instantaneous coefficient of linear thermal expansion is independent of reference temperature in contrary to the ASTM E228 and E289. However, the effect of thermal ratcheting on polymer materials is not addressed. While independent researches by Kirby [**15**] and Touloukian [**16**] have reported quantitative results on coefficient of thermal expansion for PTFE and other polymer materials respectively, none scrutinized the behavior under creep and thermal ratcheting at high compressive loading.

Converging from the literature search the objective of this research is focused on comprehending the creep and thermal ratcheting response of expanded and virgin PTFE materials. In excess, elaborated information on the thickness reduction of gasketing material and coefficient of thermal expansion under compressive load, creep and thermal ratcheting behavior are attempted.

Experimentation and test procedure

The creep and thermal ratcheting of gasket materials are studied through Universal Gasket Rig (UGR) shown in **Fig. 1**. The UGR has the capacity to conduct both mechanical and leakage characterization test to provide for multiple physical properties of gasket materials. The experimental test bench composed of two platens (upper and lower) between which the gasket material is compressed by means of a manual hydraulic system. The platen accommodates gasket of minimum inner diameter of 50 mm and maximum outer diameter of 100 mm with the thickness up to 10 mm. The inbuilt test rig facilitates the application of internal pressure and temperature on to the gasket as illustrated in **Figs. 1** and **2**. The maximum controlled gasket internal pressure of 5 MPa is achievable at the limit temperature of 450 ^{o}C.

The highlight of Universal Gasket Rig is to simultaneously measure the creep and thermal ratcheting of materials under high compressive loads. High sensitive Linear Differential Variable Transformer (LVDT) is used to monitor the change in thickness under creep and cumulative damage phenomenon. A central stud and hydraulic bolt tensioner operated by a manual hydraulic pump is used to impose the desired compressive stress on the gasket between two platens. A full bridge strain gauge fixed to the central stud measures the load imposed on the gasket with the information of gasket dimensions (**Table 1**).

Table. 1. Gasket dimensions.

Material Type	Outer Diameter (mm)	Inner Diameter (mm)	Thickness (mm)
Expanded PTFE	76.2	45.72	3.2
Virgin PTFE	75.4	45.72	3.2

The hydraulic tensioner is connected with an accumulator to maintain a relatively constant load on the gasket while thickness of the gasket reduces. The machine is capable of applying a maximum gasket stress of 69 MPa on a gasket area of 645.16 mm^2. Specially designed inlet and outlet ports in the upper platen are available to pressurize the internal gasket surface and measure the leak rate, when required.

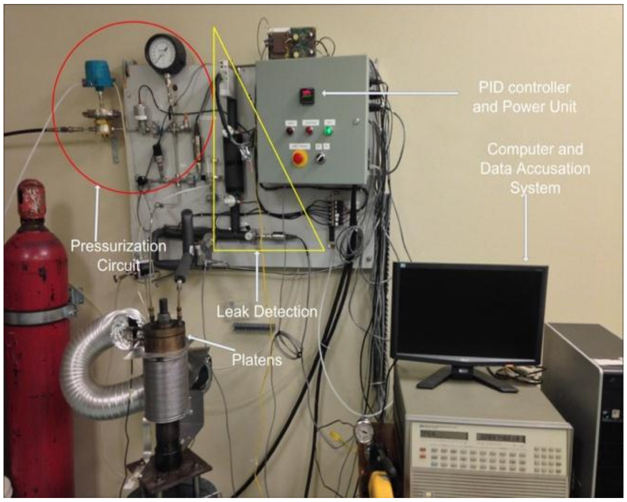

Fig. 1. Universal gasket rig.

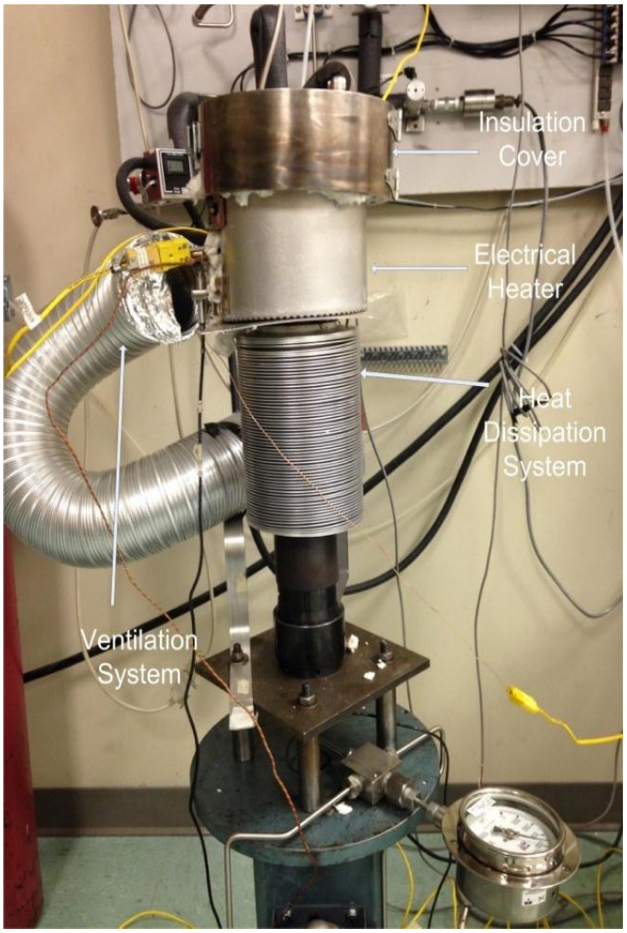

Fig. 2. Heating system – UGR.

The heating of gasket is achieved through an electrical ceramic band heater which is enfolded around the platens to transfer the heat by conduction to the gasket material. A Proportional Integral Derivative (PID) controller is used to control the temperature of the heater by monitoring the temperature of gasket materials through thermocouples which are connected to a computer through data acquisition and control system. The power unit consists of electrical control panel for the heater with on-off switch, emergency stop button and digital monitor for set and current temperature of the platens and heater system. The heat applied in ramp of 1.5^{o}C/min which is a representation of most bolted gasketed joint applications. Special insulation cap and fiber materials are used to avoid any loss of heat to the surroundings. The system is cooled through natural convection after the shut off of heater. The rigidity is controlled through the use of Belleville washers.

The experimental procedure begins with the measurement of gasket dimensions for the determination of applied gasket load through the strain gauge. Initially, the gasket is compressed between the two platens manually by hand tightening of a nut on the central stud. This position is set to be the zero reading for gasket load and displacement. The gasket material is compressed to the desired load through the hydraulic system which is followed by heating at a rate of 1.5 ^{o}C/min. Data acquisition system monitors readings every 10s while recording them every 60 seconds for post processing. Cycling of temperature to induce thermal ratcheting phenomenon is accomplished through automation with PID controller. Different gasket materials are scrutinized under different test conditions depending on their material properties which are elaborated in **Table 2**. In general, the gaskets are compressed and subjected to 24 hours short term creep and then ratchetted with temperature to study the coupled damage and estimating the perennial property of the material. LabVIEW program is used to monitor and record various parameters of the system to characterize the gasket behavior.

The coefficient of thermal expansion is calculated with respect to reference [**7**] which elaborates the importance for measuring the property during the cool down cycle. The axial displacement or thickness variation measured by the LVDT sensor is thermally compensated to counter act the effect of heat which is negligible in terms of gasket load.

Results and discussion

The results extracted from the compressive creep and thermal ratcheting tests on the selected PTFE based gasket materials provided valuable insights into the coupling behavior of the two-damage phenomenon. The compressive creep on 3.2 mm thickness expanded and virgin PTFE is shown in **Fig. 3a**. It is clearly seen that the compressive creep for virgin PTFE is higher than the expanded PTFE under a lower gasket stress than the latter. The difference is sighted to the rigidity of the two materials where the expanded is soft while the virgin is harder. As the initial reduction of thickness under compressive load is significant for expanded, it exhibits better resistance to creep.

It is important to note that the secondary creep rate is slightly higher for virgin than expanded PTFE which is alleged to extreme thickness loss and small growth of creep curve even after 5 days of compressive creep testing. **Fig. 3b** illustrates the influence of magnitude of compressive load on the creep behavior for virgin PTFE gaskets. As suspected the compressive creep increases with increase of applied gasket stress level. As expected the primary creep rate if higher when the extent of load is higher.

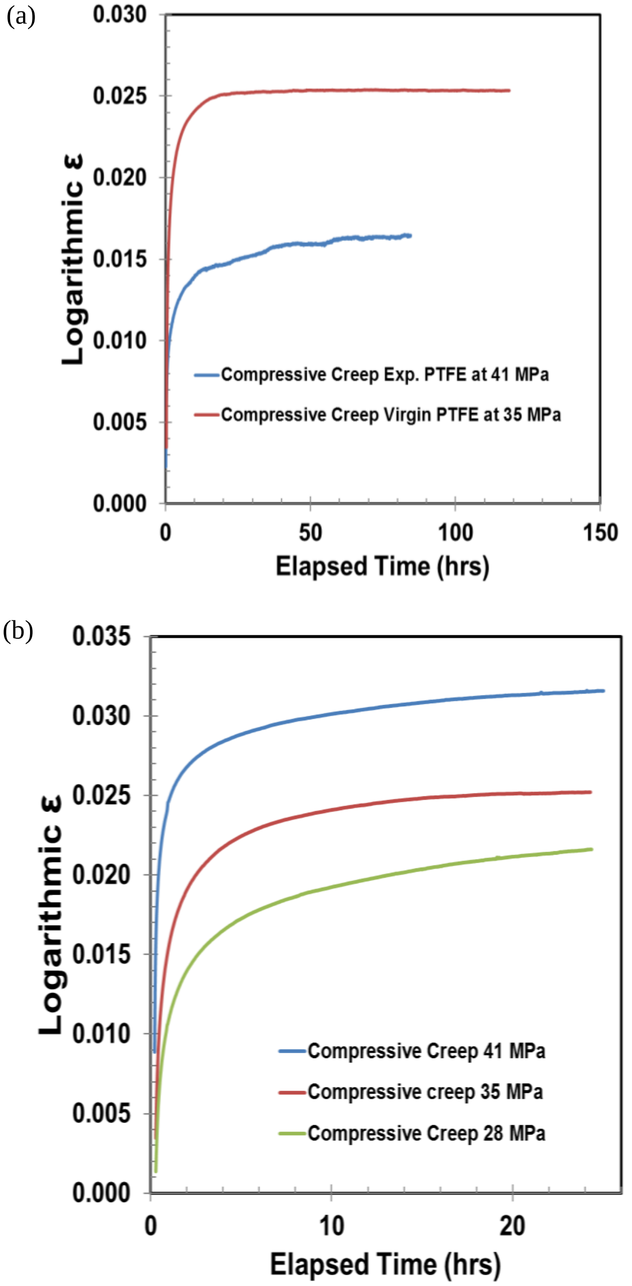

Fig. 3. Compressive Creep (a) comparison between expanded and virgin PTFE, (b) Compressive creep response under different loads -virgin PTFE.

The cumulative damage incurred due to the cycling of temperature or thermal ratcheting is significant in two types of selected gasket materials under different ratcheting temperature as mentioned in **Table 2**. The characterization of damage due to thermal ratcheting is visualized through decrease of gasket thickness after each cycling of escalation and decline of temperature. The originated cumulative damage under ratcheting of temperature is distinguishable into upper and lower bound region indicating the thickness change during the cycling. The expanded PTFE material under thermal ratcheting exhibits saturation of the cumulative damage around the 12th cycle as shown in **Fig. 4a**. The magnitude of damage depends on the applied load and ratcheting temperature as evident from the **Fig 4a**.

Table. 2. Thermal ratcheting and creep test parameters.

Expanded Polytetrafluoroethylene			
Test title	Gasket Stress	Ratcheting Range	Number of cycles
Test 1	28 MPa	38-260 ^{o}C	20
Test 2	41 MPa	38-260 ^{o}C	20
Test 3	41 MPa	Ambient	1 (5 days)
Virgin Polytetrafluoroethylene			
Test title	Gasket Stress	Ratcheting Range	Number of cycles
Test 1	35 Mpa	Ambient	1 (5 days)
Test 2	41 MPa	38-177 ^{o}C	20
Test 3	28 MPa	38-177 ^{o}C	20

The response of virgin PTFE to thermal ratcheting (**Fig. 4b**) is quite similar to expanded PTFE but do not display saturation of damage even after 20 cycles. As compared to expanded PTFE, the virgin gasket's thickness change due to expansion-contraction under consecutive thermal cycles varies tremendously especially in the initial few cycles.

The adverse influence of thermal ratcheting is clearly shown in the graph of percentage of thickness reduction versus number of thermal ratcheting cycles. As anticipated, virgin PTFE (**Fig. 5b**) exhibited higher proportion of material thickness loss in comparison to the expanded PTFE (**Fig. 5a**). The reason is attributed to the inherent rigidity of the two materials or their capacity to resist load. Initial thickness reduction of 73% for expanded gaskets as compared to the 33% drop for virgin PTFE under stress of 28 MPa justifies lower loss in the case of the former. Therefore, the relatively greater loss of thickness for expanded gaskets under initial loading is proposed as the reason for lesser percentage of thickness reduction under thermal ratcheting. Virgin PTFE exhibits similar percentage of thickness reduction when subjected to same ratcheting temperature conditions with two different applied stress of 28 and 41 MPa.

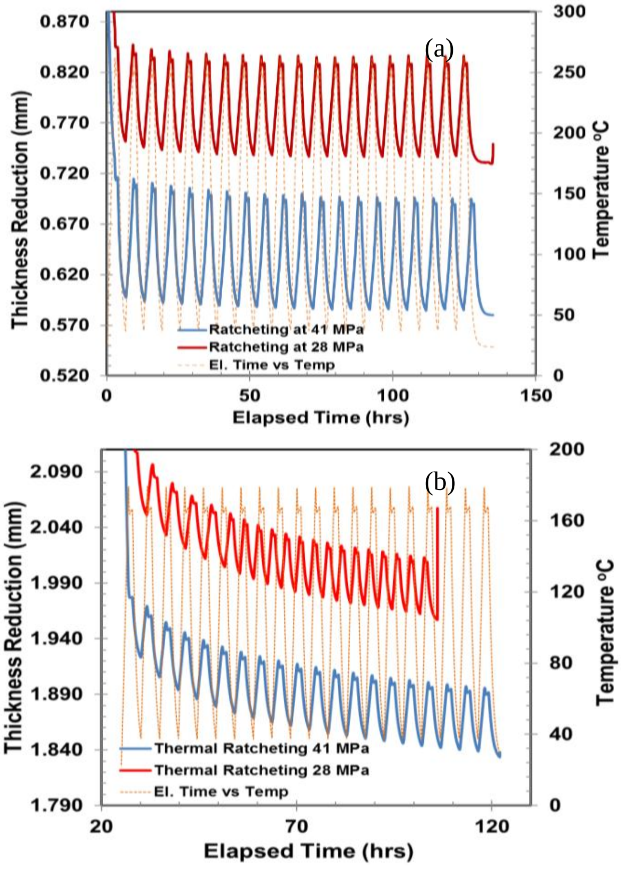

Fig. 4. Thermal ratcheting (a) Expanded PTFE, (b) Virgin PTFE.

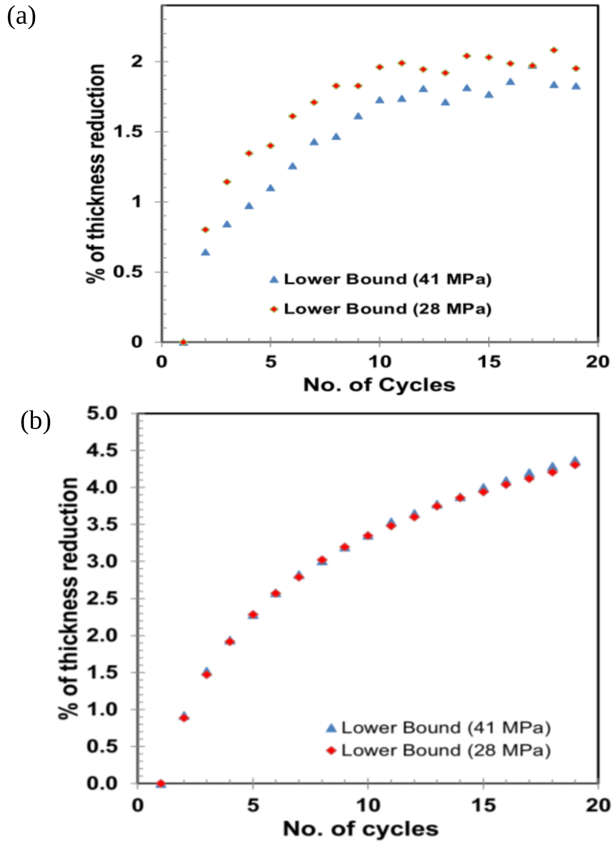

Fig. 5. Percentage of thickness reduction due to ratcheting (a) Expanded PTFE, (b) Virgin PTFE.

Nevertheless, a ratcheting test, in excess of 20 thermal cycles, preferably till saturation would lead to clearer understanding on the influence of stress level for virgin PTFE materials.

Fig. 5a displays the percentage of thickness reduction for same ratcheting temperature at two stress levels. Constructive effect with rise of applied load is evident due to the fact that the expansion is higher with lower applied load.

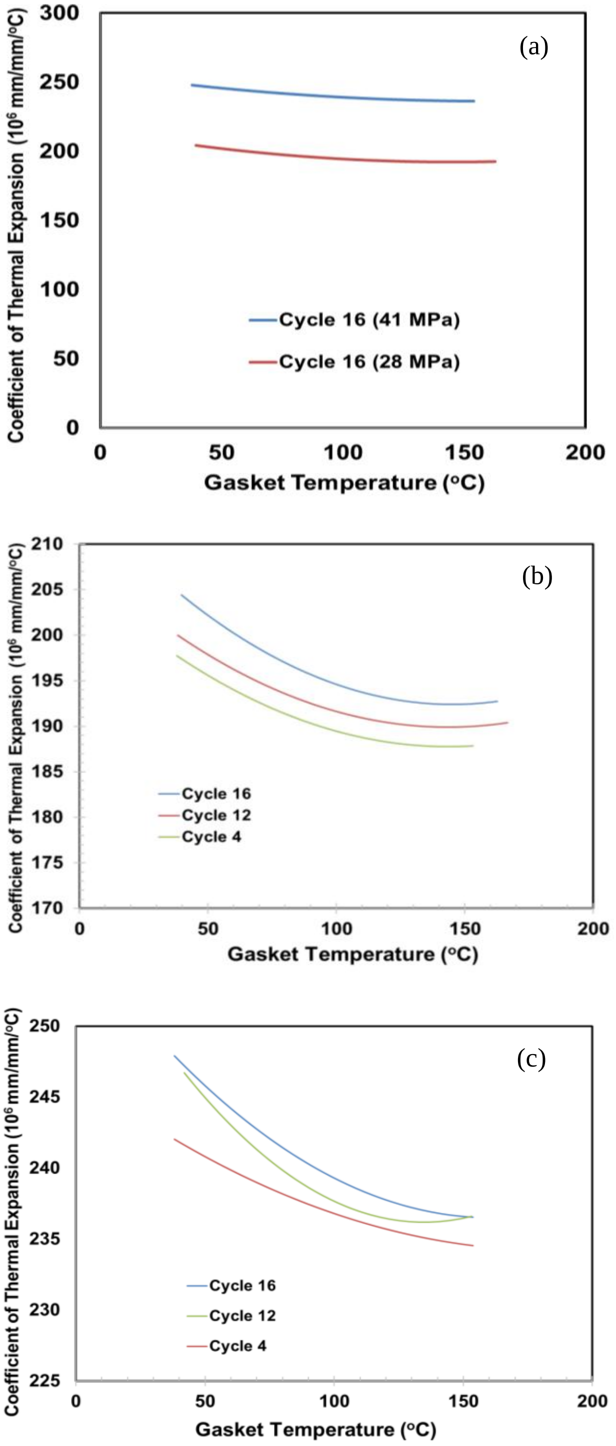

Fig. 6. Coefficient of thermal expansion – Virgin PTFE (a) under applied load, (b) under different ratcheting cycles for 28 MPa, (c) under different ratcheting cycles for 41 MPa.

The coefficient of thermal expansion (CTE) of the selected Teflon based materials are influenced by both applied stress and thermal ratcheting. From **Fig. 6a**, the appreciable rise in thermal expansion coefficient for virgin PTFE material between 28 and 41 MPa of compressive stress level is evident. CTE intends to surge with respect to the rise in applied load. The thermal ratcheting effect intensifies the surge of CTE with each thermal cycling till saturation is achieved as seen in case of expanded PTFE material. **Fig. 6b** and **Fig. 6c** illustrates the variation of coefficient of thermal expansion with respect to thermal cycles under 28 and 41 MPa of compression, respectively. While the uniaxial test conditions are replicated as to the standard tests, the data can be used in design and finite element analysis of bolted flange connections.

Conclusion

Assessment of thermal ratcheting and short-term creep response of PTFE based gaskets materials are performed through Universal Gasket Rig. Both types of gasket material exhibited substantial thinning and deformation; two material properties that are of major importance in gasketing product. Expanded PTFE gasket unveiled better resistance to creep and cumulative damage due to thermal ratcheting in comparison to virgin PTFE materials because it gets much thinner under load. Thermal ratcheting damage tends to get saturated around 12th cycle for expanded PTFE material while virgin PTFE material continued to reduce in thickness throughout 20 cycles of test. The coefficient of thermal expansion of these materials varied notably with applied load and thermal ratcheting where the contribution of former is higher than the latter. Hence, test results show the need for development of comprehensive standard test procedure to determine the thermal ratcheting, creep and co-efficient of thermal ratcheting for PTFE based gasketing materials under load.

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