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The influence of stress conditions on the wear of UHMWPE for total joint replacements

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In vitro studies of the effect of contact stress on the wear of ultra high molecular weight polyethylene (UHMWPE) in orthopaedic applications have produced contradictory results which predict both increased and decreased wear with increasing contact stress. *In vivo* studies of functioning hip prostheses have reported that 22 mm femoral heads generate lower linear and volumetric wear rates than 32 mm femoral heads. The effect of decreasing the head size will increase the contact stress but decrease the sliding distance per motion cycle. The present study consists of wear experiments under a range of contact stress magnitudes and application conditions in order to simulate the wear processes occurring *in vivo*. The results from these tests indicated that the wear factor actually decreases with increasing contact stress if the stress was not varied with time. If a time dependent or spatially varying stress was applied, the wear factor can increase greatly when compared to similar magnitude constant contact stress. This effect may be due to the complex relationship between the rate of wear particle generation and the rate at which the particles are released from the interface. The results of these wear experiments are discussed in terms of the influence of the stress conditions upon potential wear processes in total hip and knee prostheses.

1. Introduction

The success of low friction arthroplasty in reducing pain and increasing mobility can lead to significant improvements in the quality of many people's lives. The *in vivo* life span of these prostheses can exceed 20 years which for many elderly, less active patients would mean one prosthesis will be sufficient. Follow up studies show survivorship figures of over 75% at the 15 year follow up point for cemented implants and at the 12 year point for uncemented implants [1].

There are a large number of reasons for the failure of prostheses. Initially, infection in the bone can cause poor healing of the tissue surrounding the prosthesis, although this can be minimized by good surgical practice and the use of antibiotics. Once the possibility of infection has been removed the implant may fail prematurely due to poor location, fracture of either the bone or the implant or dislocation of the joint. However, the primary cause of failure of an otherwise functioning prosthesis is aseptic loosening whereby the prosthesis breaks free from the bone or bone cement causing pain for the patient and a loss of joint function. A revision operation is then necessary which is usually more complex than the primary operation, leads to greater loss of bony tissue and generates a further load on hospital resources. As total joint prosthesis are being implanted in younger, more active patients there is the possibility of a number of revision operations being required during their lifetime with the complexity of the operation increasing each time. In the Swedish study [1], of a total of 9965 primary revision operations, approximately 12% required a further revision with 30 of these needing three or more revisions within 15 years.

Aseptic loosening has been linked to the presence of large numbers of wear debris particles from either the metallic or polymeric components of the prosthesis [2, 3]. Of these particles, the majority have usually been worn from the articulating surface of the polymer component and thus the wear of the polymer must be minimized. Such particles are known to cause an inflammation reaction in the contaminated tissues with macrophage and giant cells being stimulated to engulf the particles and hence isolate them from the remaining tissue [4, 5]. These stimulated cells produce cytokines which affect the balance between osteoclastic and osteoblastic cell activities. The osteoclast cells are stimulated into resorbing bone tissue which occurs in the immediate vicinity of the prosthesis hence reducing the area of bone to prosthesis interface. This will eventually lead to the failure of the bond and thus the prosthesis will be free to move within the bone cavity. The previous studies [2, 3] indicate that the size and numbers of polyethylene particles are significant in the severity of the osteolysis although no direct correlation has been shown. The *in vivo* wear that generates these harmful particles is thought to occur on a number of different scales and by a range of processes [6–11]. The relative importance of each of these scales and processes may have an important influence on the size and numbers of particles released into the tissue and hence the severity of the osteolysis reaction.

In vivo, a prosthesis will be subjected to a large number of complex loading and motion cycles. The load has been shown to be highly variable with time for both the hip and the knee joint [12, 13]. Also, the contact area between the femoral and tibial components of a knee prosthesis have been shown to vary during the walking cycle [14] due to the relative sliding of the two components which is required by some designs to mimic the natural motion of the knee joint.

The influence of contact stress, contact area and motion of the contact area on wear of UHMWPE *in vivo* has been considered for both hip and knee prostheses. In a hip prosthesis, the size of the femoral head and, in both hip and knee prostheses, the thickness of the UHMWPE component are important variables [15, 16]. It has been described [15] that very thin polymer components generate very high sub-surface stresses which have been linked to the delamination wear that has been observed in some explanted knee prostheses. This is less important in hip prostheses where the acetabular cup is normally of sufficient thickness to prevent high sub-surface stress but the size of the femoral head and degree of conformity between the head and cup will affect the contact stress.

If the femoral head diameter is increased from 22 mm to 32 mm the contact stress will be reduced (assuming equal radial clearance), thus reducing the creep penetration of the head into the cup which, theoretically, will result in lower measurement of wear volume (since the measured volume change is the sum of the actual worn volume and the volume change due to creep deformation). However, this is offset by an increase in the sliding distance per motion cycle which will have the effect of increasing the wear volume. *In vivo* studies of the wear of functioning 22 and 32 mm femoral heads [17, 18] have described lower volumetric wear rates for the smaller head size and one study [18] has also described a noticeable decrease in the linear wear rate. These results imply that the increase in contact stress is reducing the wear for the 22 mm femoral heads even after compensation for the reduction in sliding distance.

In contrast, previous authors [19, 20] have described an increase in wear rates, implying increasing wear factors, for increasing contact stress under laboratory conditions. The reasons for this apparent discrepancy between *in vivo* and *in vitro* results are the subject of the present study. In a previous study [21] the influence of contact stress magnitude on the wear of UHMWPE was examined under conditions of constant load. This study used simple polymer pin on metal plate tests for a range of loads and contact areas with bovine serum lubrication. The results from these tests showed that the wear factor (the wear volume per unit load per unit sliding distance) did indeed decrease with increasing contact stress as suggested by the *in vivo* measurements.

In the present study the wear of UHMWPE is studied under a number of different loading and motion cycles which more closely resemble those found *in vivo*. A range of simple wear testing configurations including both polymer pin on metal plate and metal pin on polymer plate were used together with finite element modelling of the contacts to establish the stress conditions in greater detail.

2. Materials and methods

2.1. Materials

The standard European orthopaedic UHMWPE, Hostalen GUR 1120, was used throughout this study. This material was manufactured by Hoechst Aktiengescellschaft of Frankfurt am Main, Germany and was compression moulded into slab form by Poly Hi Solidur/MediTECH of Vreden, Germany. All the polymer materials in this study were supplied and tested in the non-irradiated form. The polymer wear pins were machined from the slab into the Leeds truncated cone shape, in which the wear face is at the end of the truncated cone. The polymer wear plates were also machined from slab to give a wear face of 80 mm by 20 mm and were of sufficient thickness to prevent sub-surface stress concentrations. All the polymer specimens were cleaned and pre-soaked in deionized water for a minimum of two weeks prior to testing.

The hard counterfaces were all manufactured from forged cobalt chrome alloy which was subsequently lapped to give a smooth wear surface. The metal plates had a flat wear surface of approximately 60 mm long by 20 mm wide whilst the metal discs for the cyclic load tests had an annular wear face of approximately 80 mm diameter. The metal pins had an 80 mm diameter spherical contact face of sufficient curvature to prevent the edge ploughing into the polymer. Prior to testing all the metallic wear surfaces were measured using contacting Talysurf machines and were only selected for testing if the Ra (roughness average) was below 0.05 μm and the Rtm (average of the highest peak to deepest valley reading), Rsk (factor describing the symmetry of the profile about the mean line) and Sm (mean spacing of the profile) values were all of similar magnitudes. As a further measure to reduce the effect of any counterface variability, the pin to plate configuration was interchanged during testing to prevent a single pin to counterface combination producing spurious results. In order to preserve the condition of the initial counterface surface, bovine serum lubricant with sodium azide anti-bacterial agent was used to inhibit transfer film formation for all the tests in this study.

2.2. Methods

2.2.1. Constant load polymer pin on metal plate tests

This test configuration subjected the polymer to a constant load on a constant contact area. Thus the same area of polymer was exposed to the load and the counterface at all times during testing. In this test, six independently loaded polymer pins slide against six reciprocating metallic counterface plates with the polymer pins being held so as to allow vertical movement only in order to transfer the load onto the plate

(Fig. 1). The plates were contained in a lubricant filled bath which was driven with uniaxial reciprocating motion by a scotch yoke mechanism.

Prior to testing the polymer wear face was microtomed to remove the surface material damaged during the machining process. The tests were conducted for more than 4 million cycles with the wear being measured by weight loss (corrected for moisture effects by unworn control pins) at approximately every 900 000 cycles. Two different levels of load were used together with four different pin contact areas to give the nominal contact stresses defined in Table I. Two pins were used per stress level giving at least 10 data points per stress level. These tests are described in detail in [21].

2.2.2. Cyclic load polymer pin on metal disc tests

This test configuration subjected a constant polymer contact area to a time dependent loading cycle. Thus the contact stress was varied with time although the same area of polymer was in contact with the metal disc throughout. These tests used three polymer wear pins, of the same truncated cone shape, held in contact with a metal disc submerged in lubricant (Fig. 2). The metal disc reciprocated with a cyclic angular velocity so as to match the linear velocity of the constant load tests described above and such that the wear tracks produced by the polymer pins did not overlap. The load was applied to the top of the pin holder and the time dependent nature of the loading was generated by a pneumatic system controlled by proximity switches attached to the outside of the lubricant bath. Thus the phase between the load and the motion cycle was held constant throughout the test. The load and contact area are defined in Table I.

The pin wear surfaces were microtomed prior to testing and the wear was measured by a weight loss method (adjusted for moisture effects using unworn control pins) at every 600 000 cycles over approximately 3 million cycles. The load cycle was monitored throughout the test using a load cell in the loading arm and could be controlled to give an approximate square wave form. The rates of loading and unloading were of the order of 1600 N s^{-1} and there was some vibration in the peak loading but these irregularities were small in comparison to the overall load wave form.

2.2.3. Constant load metal pin on polymer plate (spatially varying load) tests

This configuration applied a constant load to a smooth, spherical ended metal pin sliding across a flat polymer plate. Thus the polymer contact area

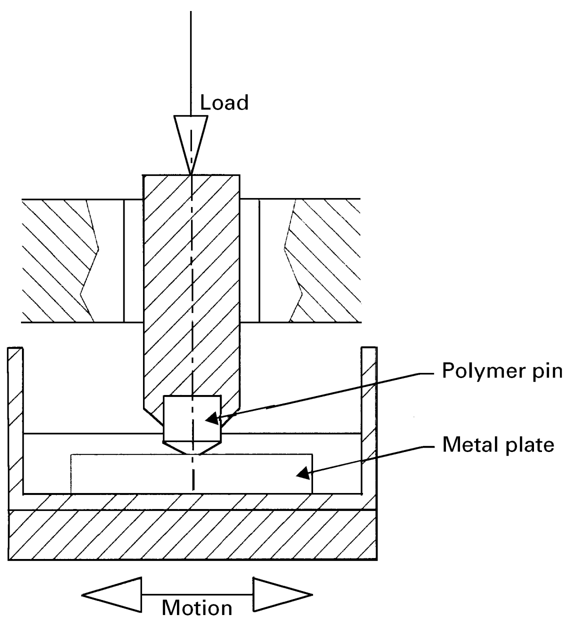

Figure 1 Constant load polymer pin on plate test configuration.

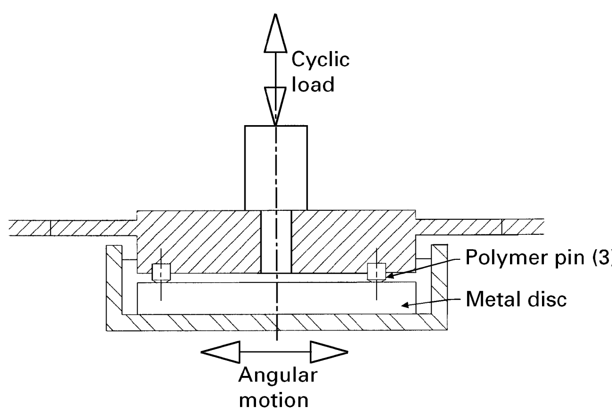

Figure 2 Cyclic load polymer pin on disc test configuration.

TABLE I Summary of the conditions of the wear tests

Configuration	Load (N)	Contact area (mm^2)	Nominal contact stress (MPa)
Constant load			
A	80	23.4	3.4
B	80	10.2	7.8
C	240	21.0	11.4
D	240	8.5	28.2
Cyclic load			
E	0–80	8.3	0–9.6
Spatially varying load			
F	80	8.0^a	0–10.0^a (0–15.04)^b
G	160	12.7^a	0–12.6^a (0–18.95)^b

^{a}Based on standard Hertzian theory. ^{b}Maximum Hertzian contact stress.

moved continually along a wear track on the surface of the plate producing a spatially varying stress in the polymer. These tests used the same wear testing rig as in the constant load polymer pin on metal plate tests described above but reversed the material configurations (Fig. 3). Two different loads were used with a constant pin radius to give two different contact stress levels as defined in Table I. The wear of the polymer plate was measured by taking a number of traces across the wear scar using a Talycontour profilometry machine. These traces show the cross-section of the worn profile which could be compared with the unworn surface in order to calculate the area of the wear scar. Thus the data from a number of such traces, together with the known length of the wear scar, could be used to generate the overall wear volume for each plate. As this method of wear measurement would include any creep deformation of the plate surface and since the wear surfaces were too large to microtome, the first data points from these tests were removed from any further analysis. Preliminary tests, not presented in this study, have shown that the creep deformation stabilizes within the first test period and once the wear scar has become established, the wear will occur on material which was not exposed to machining damage during the plate manufacture. Therefore disregarding the initial data points removed these artefacts from the results.

2.3. Finite element analysis

In order to study the actual stress fields occurring in the spatially varying test configuration, a finite element model was developed using the commercial FEA software ABAQUS version 5.3.1 [22]. This model consisted of plane strain elements modelling a section at the centre of the wear scar parallel to the direction of pin sliding as shown in Fig. 4. Interface elements were placed between the metal pin and polymer plate to initiate friction forces, assuming $\mu = 0.1$, and the

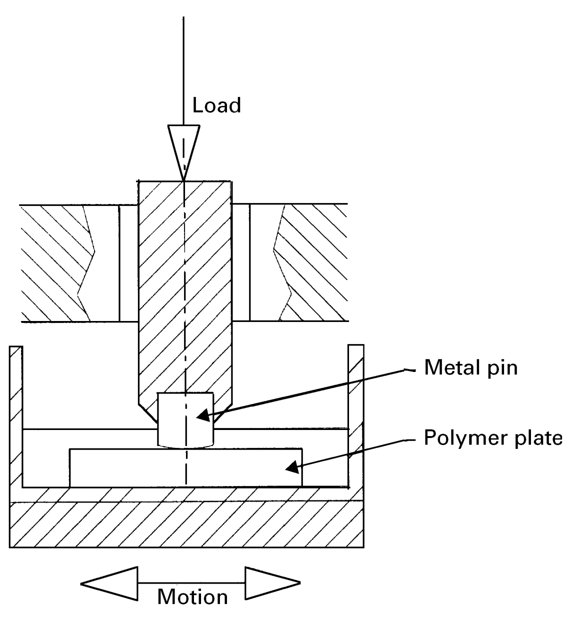

Figure 3 Constant load metal pin on polymer plate test configuration.

elastic/plastic polymer material properties were as described in [21]. The model consisted of a section of plate of actual depth, unit width and sufficient length to allow relative sliding to occur between the components. Initial Hertzian contact calculations gave an approximate value for the contact half width which allowed the mesh density near the contact to be adjusted to give a sufficiently fine mesh in this area.

The analysis was conducted in two parts; first, a direct load was applied to press the pin and the plate into contact and second, a horizontal displacement was applied to the pin to generate relative sliding with respect to the plate. Thus the surface traction forces reached a maximum governed by the friction coefficient. The displaced shape of the mesh due to this relative sliding under 160 N of vertical load is shown in Fig. 5.

3. Results

3.1. Wear equations

The results from the wear tests can be presented in three forms, the volume of material lost due to wear, the wear rate or the wear factor. The volume of material lost due to wear is simply the primary data from the

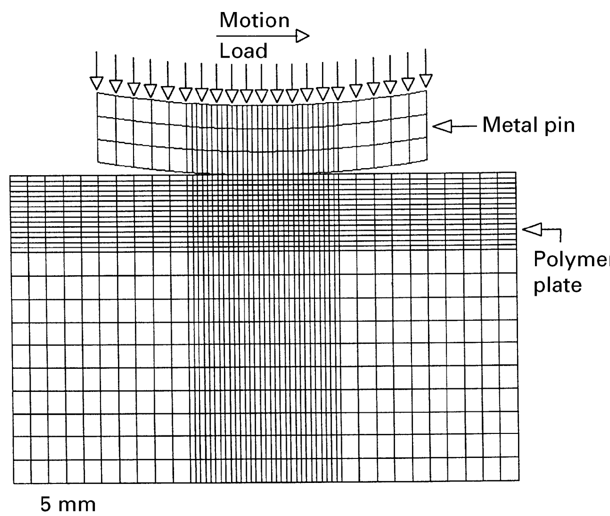

Figure 4 FEA model of metal pin on polymer plate test configuration (undeformed).

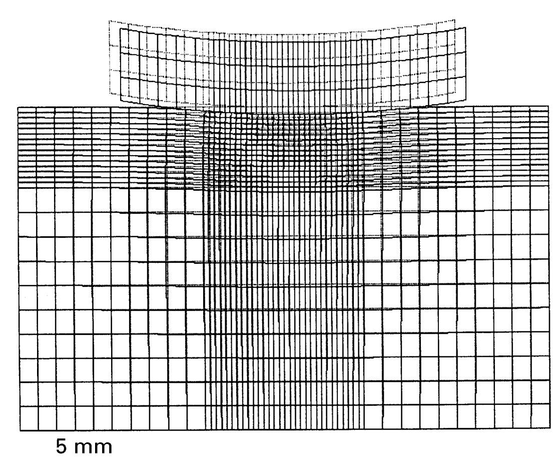

Figure 5 Deformed mesh showing relative sliding of metal pin on polymer plate under 160 N load.

experiment and does not account for the experimental conditions. Hence it is of limited use when comparing different test conditions. The wear rate can be defined as the volume of material lost due to wear per unit of sliding distance (Equation 1) and is the gradient of the wear volume versus sliding distance graph. Thus the effect of sliding distance can be removed.

$$\text{Wear Rate} = \frac{\text{Volume lost due to wear}}{\text{Sliding distance}} = \text{mm}^3/\text{m} \quad (1)$$

The wear factor, as defined in Equation 2, is derived from the wear rate but also accounts for the magnitude of the applied load. The wear factor can also be thought of as the gradient of the wear rate versus load graph. Conventional wear theory suggests that the wear factor is a constant for a given material combination and sliding conditions and is thus independent of the load or sliding distance.

$$\text{Wear Factor} = \frac{\text{Volume lost due to wear}}{\text{Sliding distance} \times \text{Load}} = \text{mm}^3/\text{Nm} \quad (2)$$

3.2. Effects of contact area and load in constant load polymer pin on metal plate tests

The wear rate results for the four test conditions employed in this study are shown in Fig. 6. This plot indicates that the wear rate (volume of material lost per unit sliding distance) was influenced by both the contact area and the applied load. For example, an increase in contact area from 8 to 22 mm^2 produced a 30 and 50% increase in the wear rate for the two loading levels, respectively. This implies that more wear occurred if a greater area of the polymer surface was exposed to the damaging effects of the metallic counterface. If the load was increased from 80 to 240 N (an increase of 300%) the wear rate again only increased by 30 and 50%, respectively, for each contact area. These results imply that the wear rate is not directly proportional to the applied load.

The wear rate results are normalized with respect to load to give the corresponding wear factors as shown in Fig. 7. If the wear rate was directly proportional to the load, as suggested by conventional wear theory, the wear factors would be equal but from Fig. 7 it can be seen that the wear factors actually decrease with the increasing load. Therefore there was less wear per unit load when the load was high (conditions C and D). It can also be seen from Fig. 7 that greater contact area has produced a higher wear factor. If the wear factor data are plotted against contact stress as in Fig. 8, then a clear trend of decreasing wear factor with increasing contact stress can be seen and that the rate of change is greater at the lower end of the contact stresses tested in this study. In all these test configurations the metallic wear surface remained undamaged with no transfer film throughout the tests.

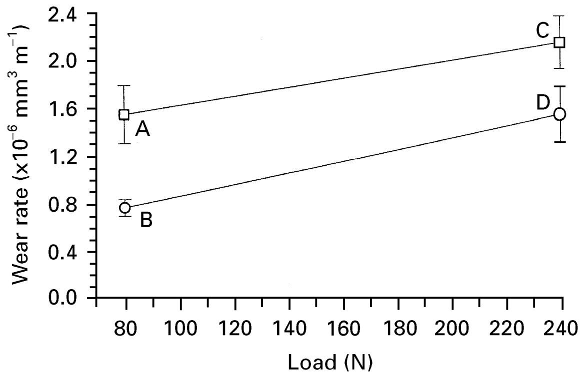

Figure 6 Wear rate versus load for constant load polymer pin on plate test configuration (mean ± SE). Contact area: –□– 22 mm^2; –○– 8 mm^2.

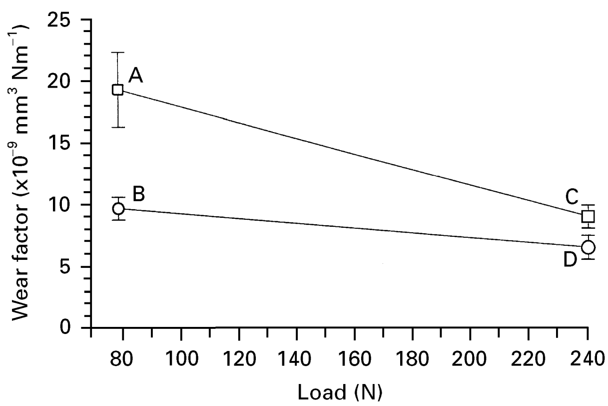

Figure 7 Wear factor versus load for constant load polymer pin on plate test configuration (mean ± SE). Contact area: –□– 22 mm^2; –○– 8 mm^2.

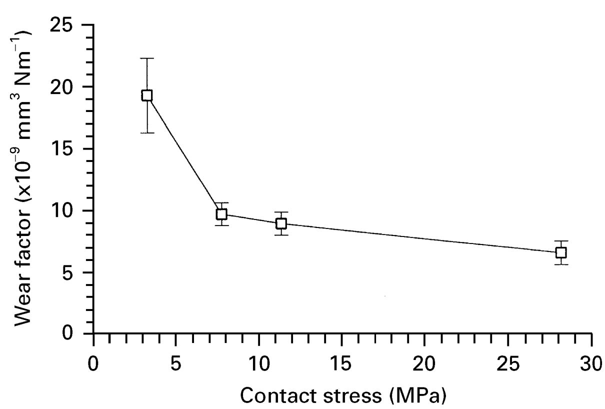

Figure 8 Wear factor versus contact stress for polymer pin on plate test configuration (mean ± SE).

3.3. Effect of cyclic load in polymer pin on metal disc tests

The average wear factor results for the cyclic load polymer pin on disc test are compared in Fig. 9 to a constant load result under a similar load magnitude. From these results it can be seen that the cyclic load produced a 30% increase in the wear factor. This implies that the time dependent nature of the load in the cyclic load test was affecting the wear processes generating higher wear factors. The effect of the cyclic load on the wear processes is discussed further in Section 4. Again, no damage or transfer film was observed on the disc surface.

3.4. Effect of spatially varying load in metal pin on polymer plate tests

The wear rate results for the spatially varying test conditions shown in Fig. 10 indicate a significant increase in wear rate under these conditions when compared to a constant load polymer pin on plate test (Table II). The results also show a two-fold increase in wear rate if the load is increased from 80 to 160 N which implies a near constant wear factor as shown in Fig. 11. However, due to the Hertzian nature of the initial loading and the subsequent changes in the contact area as the wear scar develops, the contact stress will not increase proportionally to the load.

These test results imply a significant change in the wear processes under spatially varying stress conditions compared to those occurring with a constant contact stress. The increase in wear cannot be attributed to either a roughening of the metal pin surface or to delamination of the polymer surface. No damage or transfer film occurred on the wear surface of the metal pins throughout these tests and no delamination of the polymer plate surface was detected. Post-testing examination of sections of the polymer plates failed to show any sub-surface birefringence effects indicating low sub-surface strains. Thus the wear processes were probably occurring on the plate surface.

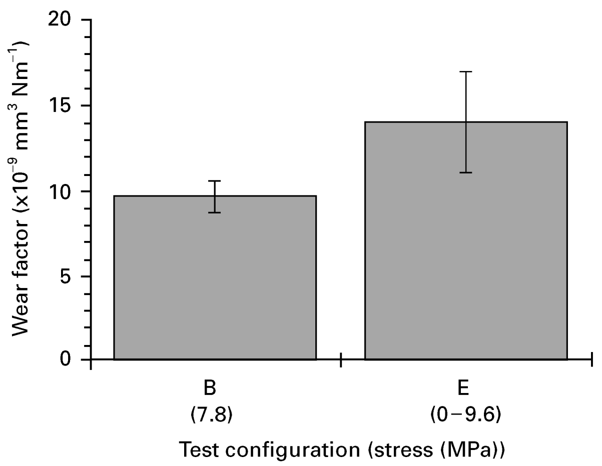

Figure 9 Wear factors for constant and cyclic load polymer pin on plate test configurations (mean ± SE).

3.5. Finite element analysis results from spatially varying stress models

The translation of the contact area and the high stresses that occur in knee prostheses have been considered

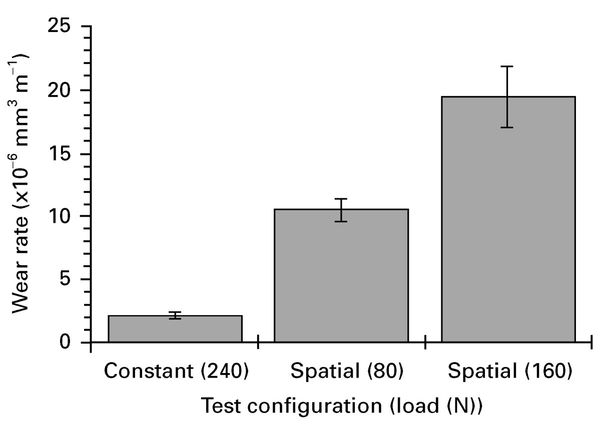

Figure 10 Wear rates for constant load polymer pin on metal plate and metal pin on polymer plate test configurations (mean ± SE).

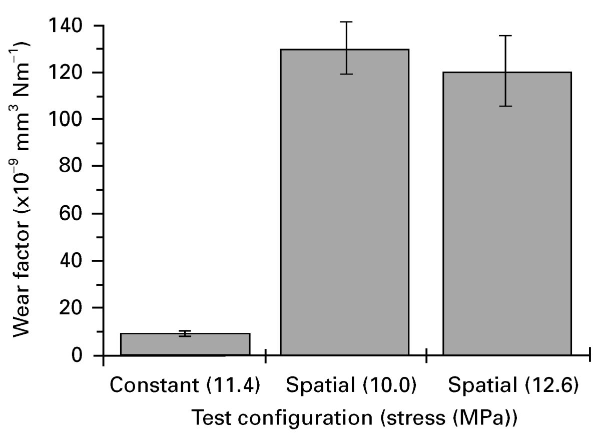

Figure 11 Wear factors for constant load polymer pin on metal plate and metal pin on polymer plate test configurations (mean ± SE).

TABLE II Summary of test results

Configuration	Nominal stress (MPa)	Mean wear rate ± S.E. ($\times 10^{-6}$ mm^3 m^{-1})	Mean wear factor ± S.E. ($\times 10^{-9}$ mm^3 Nm^{-1})	*n*
Constant load				
A	3.4	1.55 ± 0.24	19.3 ± 3.0	10
B	7.8	0.77 ± 0.07	9.67 ± 0.92	12
C	11.4	2.13 ± 0.22	8.89 ± 0.92	10
D	28.2	1.53 ± 0.23	6.39 ± 0.96	12
Cyclic load				
E	0–9.6	0.56 ± 0.19	14.0 ± 3.0	15
Spatially varying load				
F	10.0	10.4 ± 0.88	130 ± 11	30
G	12.6	19.2 ± 2.40	120 ± 15	18

S.E. = standard error, *n* = number of samples.

to be the causes of the delamination of large pieces of polymer from the surface of the tibial components that can lead to the early failure of these prostheses. The fact that this wear process has not been observed in hip prostheses, where the articulating surfaces are highly conforming and there is less translation of the contact area, indicates that this process is more likely to occur when the contact area is in motion. However, delamination did not occur during the spatially varying stress tests which indicates that either the contact stress was insufficient to cause sub-surface cracking or the fatigue resistance of the material was too great. The finite element study was conducted to generate data on the actual stresses occurring in the polymer at the start of the test, i.e. before the wear scar developed.

The contour plots of von Mises stress, shown in Figs 12 and 13 indicate that yielding of the polymer only occurred at the higher load level. Once yielded the plastic strain in the material increases rapidly

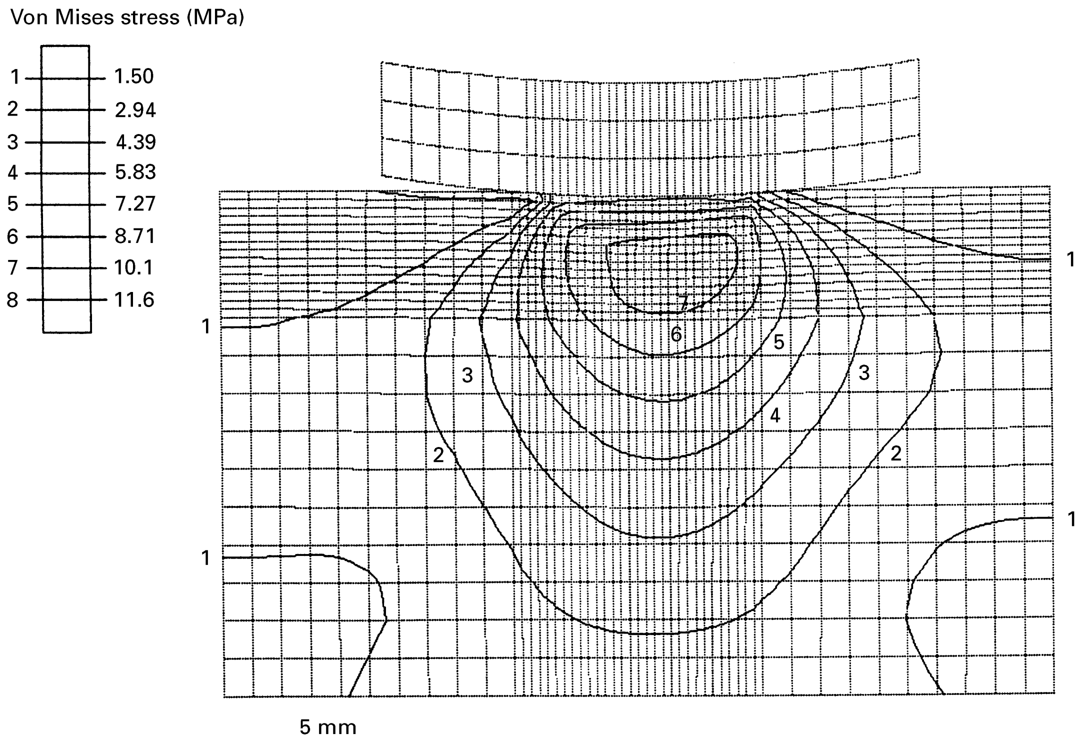

Figure 12 Von Mises stress contours for metal pin on polymer plate test configuration under 80 N load and relative sliding.

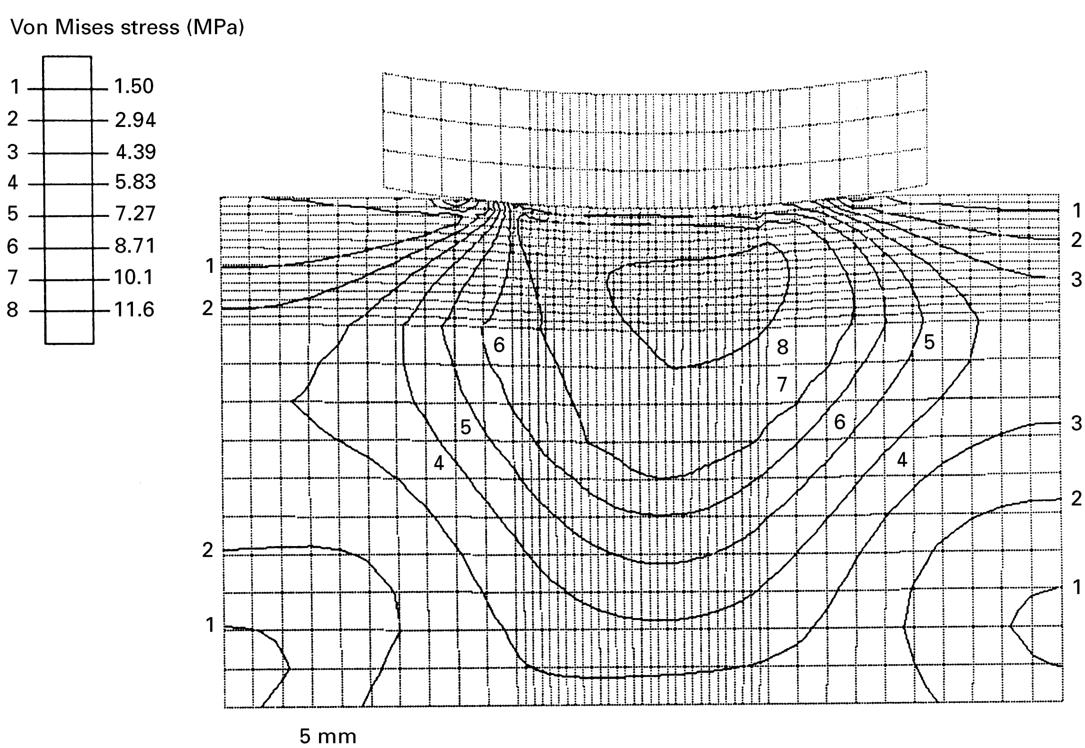

Figure 13 Von Mises stress contours for metal pin on polymer plate test configuration under 160 N load and relative sliding.

which may lead to the generation of microcracks and fatigue failure. Cracks may form where the principal tensile strain is greatest (on the plate surface, at the trailing edge of the contact) by a type I surface crack, or by a type II crack below the surface due to high shear strains. The orthogonal shear strains are greatest below the surface at points on either side of the yielded zone and the maximum shear strains are greatest in the centre of the yielded zone. Therefore cracks may form at any of these locations but post-test examination of the plates, both on the wear surface and in sections taken through the wear scar, failed to reveal any evidence of cracking on or in the plates. It should be noted that the polymer plates were not irradiated and hence the material was not subject to oxidation effects.

4. Discussion

The wear of UHMWPE in an orthopaedic application has previously been described as occurring on two magnitudes of scale [10] in addition to delamination [14]. The removal of soft polymer material by interactions between the hard metallic or ceramic asperities was described by Cooper *et al.* [10] as microscopic metal asperity wear. On a larger scale, the repeated compression and traction on the polymer asperities leading to the release of larger polymer pieces was termed macroscopic polymer asperity wear. The final wear process, as described above, was the large scale delamination or gross structural failure of the polymer due to sub-surface fatigue cracking [14].

These wear processes can be considered as having three stages. The first involves the initial detachment of a polymer particle from the surface of the bulk material which may in severe cases occur over a single asperity interaction (i.e. abrasive ploughing of hard asperities through the soft polymer). However, when the surfaces are smooth as in these tests and undamaged prosthetic components, this is more likely to occur over a large number of asperity interactions and can be considered to be a fatigue or cyclic strain accumulation process. Once free of the surface of the polymer component, a wear particle may become trapped and processed due to mechanical or thermal actions within the contact interface. The trapped particle may then act as a protective third body layer between the hard asperities and the softer polymer surface [23]. During this second phase of the wear process, the size and morphology of the particle may become altered and hence may bear little or no resemblance to the initially detached particle. Only when the particle escapes from the interface into the surrounding lubricant can it finally be thought of as being a distinct wear particle and this release phase can be thought of as the third phase of wear. The measured wear volume will be governed by this final phase as particles trapped in the contact may become reattached to the bulk surface and therefore will not be measurable as wear.

The stress conditions may influence the overall wear process at any of the above scales or during any one of the three phases of wear. As the contact stress on the polymer pin is increased, the microscopic conformity of the polymer to metal contact will reach saturation level as the real or actual contact area tends towards the apparent or nominal contact area. Thus the severity of the metal asperity interactions will reach a maximum level and any increase in stress beyond this level will not increase the wear due to microscopic asperity interactions. Therefore, increasing the contact stress beyond this level may cause the reduction in wear volume per unit load (i.e. the wear factor) observed in this study. As the contact stress is increased above saturation level, the compressive stresses in the polymer increase which may act to inhibit deformation and fracture of the material as any microcracks that form will be prevented from propagating by these high compressive stresses [23, 24]. For example, in order for a crack to propagate in the type I (tensile–compressive) mode, the crack surfaces must be free to move apart [25] which cannot occur under high compressive stresses. Thus microcracks may only propagate in the type II (shear) mode, which does not require direct crack opening, although the high compressive stresses may act to reduce the rate of propagation by preventing the free movement of the crack surfaces. Therefore, the wear debris generation rate per unit load may again be reduced as the compressive stress is increased leading to a lower wear factor. Also, as the contact is now highly conforming, there will be limited space for a polymer particle to escape into, thus making it difficult for debris to leave the interface. This would result in a contact where loose polymer particles are being held in the contact thereby acting as a solid lubricant between the metal asperities and the polymer surface. Therefore, the inability of the wear debris to escape together with the fracture inhibition caused by the high compressive stress fields may be the reason for the reduction in wear volume per unit load (i.e. wear factor) observed in the constantly loaded polymer pin on plate experiments in this study.

The observed increase in wear factor for the cyclically loaded polymer pin on plate experiments may be due to the enhanced wear debris escape rate occurring during the unloaded phase of the load cycle. Wear will occur during the loaded phase due to the asperity interactions described above but the debris will be unable to escape due to the high surface conformity as in the constant load tests. However, during the unloaded phase, the surface conformity will decrease and this debris will be free to escape into the surrounding lubricant. Not only will the amount of measurable wear increase but any protecting effect of the debris on the bulk polymer surface will also be lost. Therefore, the overall wear volume may be increased relative to the applied load as was found by comparing the wear factors in the cyclic load tests with those in the constant load tests under similar nominal stress levels.

The much larger increase in wear factor found in the spatially varying wear experiments may again be explained by the ability of the wear debris to escape from the interface. As the metal pin passes over any point on the plate surface, wear debris will be generated due to the metallic and polymeric asperity interactions.

However, once the pin passes this point, the generated debris will be free to be washed away from the contact area by the moving lubricant and hence will immediately escape from the interface. Thus fresh polymer will be exposed to the metal pin at every pass and the overall wear will increase. In addition any point on the wear track is not under a constant stress and this may accelerate the generation of wear debris.

The significant increase in wear factor found when a spatially varying load was applied may have implications for both prosthesis design and hip simulator test configurations. If the contact zone on the polymer component of a hip or knee prosthesis remains constant throughout a cycle, the wear processes may be similar to the constant or cyclic loaded polymer pin tests. Thus debris may become trapped in the interface and act as a third body to protect the bulk polymer surface from the damaging effects of the metallic component. However, if the contact area moves significantly the cushioning layer of trapped debris will not form and fresh polymer will be exposed to the metal surface.

This suggests that the method by which hip simulator machines apply the motion to the test prostheses may affect the resulting wear processes. If the femoral head is able to form a highly polished area of highly conforming polymer (as has been observed in explanted prostheses), then wear processes similar to those found in the constant or cyclic polymer pin on plate experiments may occur. However, if the contact area on the polymer surface moves continuously, then no such area will form and debris may be lost to the surrounding lubricant during every cycle. Thus the wear processes that occur with this configuration will be more akin to those of the spatially varying metal pin on polymer plates which have been shown to generate significantly greater wear.

5. Conclusions

This study has shown that the wear rate and wear factor are both significantly affected not only by the contact stress magnitude but also by the manner in which the stress is applied. The wear rate has been shown not to be directly proportional to the applied load as assumed in simple wear theory and the wear factor actually decreases with increasing load and contact stress. The wear factor can be somewhat increased by applying a cyclic load over a constant polymer contact area and it may be much more greatly increased by moving the contact area across the polymer surface. These configurations may alter the rates at which debris is generated, processed in the interface and subsequently released into the surrounding lubricant. Only when the debris has been released from the interface will it be measurable as wear.

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