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CHAPTER 3

CREEP ANALYSIS FOR UHMWPE

3.1 Introduction

As noted, the literature review in Chapter 2 revealed that the creep properties of UHMWPE under different conditions have not been clearly established. Creep data for UHMWPE is found (Engineering Materials Handbook, 1987; Lee & Pienkowski, 1998; Meng Deng & Latour, 1998), but all these tests were done at room temperature. Tests at elevated temperatures were performed by Meng Deng and Latour (1998) but this study did not include tests on crosslinked or gamma-irradiated material. Therefore, the effect of sterilisation and crosslinking on the creep properties of UHMWPE could not be found in the literature.

The purpose of this part of the study is not to undertake an in-depth study of the creep properties for UHMWPE under various conditions, but rather to show that the effect of elevated temperatures, gamma sterilisation and crosslinking on creep properties of UHMWPE is substantial and has a pronounced effect on wear characteristics. If the data is to be used for design purposes, more tests will have to be done to enable statistical analysis of the data.

3.1.1 Test protocol

The investigation into the creep properties of UHMWPE was broken down into various stages to obtain the data required within available cost constraints. The following investigations were performed:

a. Clamping effects

b. Investigation of anisotropic effects

c. The effect of temperature on virgin material

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d. The effect of temperature on sterilised material

e. The effect of temperature on crosslinked material.

3.2 Clamping effects

This investigation was done to establish the effect of the clamping force between the test piece and platen (see Figure 3.1). The expected effect is that with the test piece being too short the lateral restraining force from the platen is going to restrain the material from plastically flowing sideways at the interface between the platen and the test piece.

3.2.1 Purpose of test

The purpose of this test was to establish the influence of the clamping effects, due to test piece length, on the creep values for UHMWPE. The effect is illustrated in Figure 3.1. The lateral restraining force between the platen and the test piece limits the amount of plastic flow at the interface between the platen and the test piece. The shorter the test piece, the more dominant this effect is in influencing the achieved results. From the literature survey, there is an indication that the material is anisotropic and visco-elastic (Engineering Materials Handbook, 1987).

According to the Engineering Materials Handbook (1987), *anisotropic behaviour* can be defined as: "The material exhibits different properties when tested along axes in different directions." The material is therefore non-isotropic.

Visco-elasticity (Engineering Materials Handbook, 1987) can be defined as a property involving a combination of elastic and viscous behaviour. A material having this property is considered to combine the features of a perfect elastic solid and a perfect fluid. Visco-elasticity is a phenomenon of time-dependence, in addition to elastic deformation (or recovery) in response to load.

According to ASTM D2990 (1990), to enable tensile, compressive and flexural creep and creep rupture of plastics to be tested, the creep test piece must be 12.56 mm square with a slenderness ratio between 11 and 14. This means that the ratio of length to a minimum radius of gyration must be between 11 and 14. The radius of gyration is defined as 0.2887 x the width of the specimen (ASTM D2990, 1990). The test piece dimensions, as required by ASTM D2990 (1990), are shown in Figure 3.2. Based on these parameters, the test piece must have a minimum length of 40 mm.

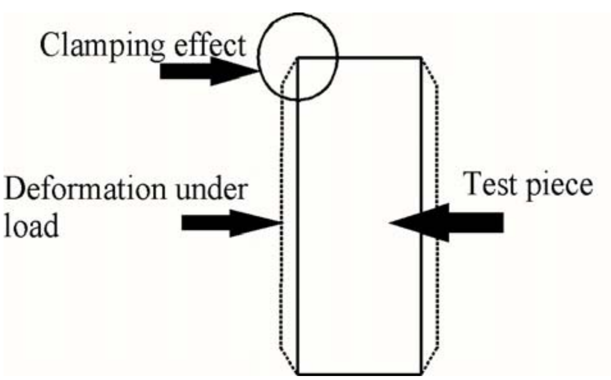

Figure 3.1: Illustration of clamping effect

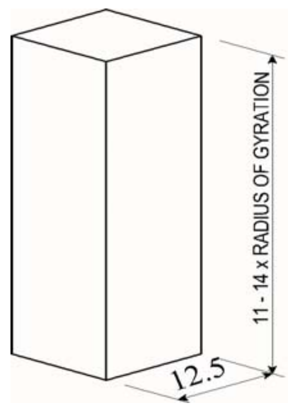

Figure 3.2: Size of an ASTM test piece according to ASTM D2990 (1990)

The stock material from which acetabular cups are manufactured is Φ65 mm as manufactured and imported from Poli Hi Solidur. A 40 mm test piece cannot be cut out at different orientations when testing the anisotropic behaviour of the material. The aim of this test was therefore to find the shortest test piece that

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would still give reliable results.

3.2.2 Test procedure

Test pieces were manufactured from a bar of Chirulen® (lot nr. B15331081) material manufactured and imported from Poli Hi Solidur. The test blocks were 12.5 mm square and the lengths were 10, 20 and 40 mm. The orientation of the test pieces in the virgin material before machining is shown in Figure 3.3.

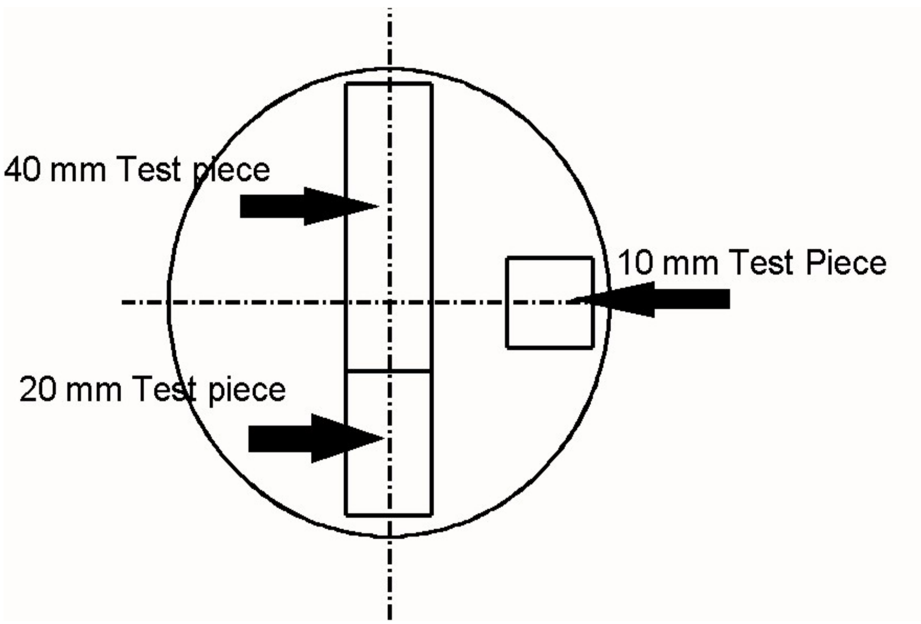

Figure 3.3: Orientation of test pieces in virgin material

The test pieces were placed, individually, in a Schenk testing machine (100 kN) and loaded to the equivalent of 8 MPa in compression. (See Figure 3.4 for the test configuration in the Schenk Hydro-pulse testing machine.) With this machine, it is possible to load a test piece in tensile and compression under computerised control. The load applied to the test piece was determined as follows: the most common size femoral head that is used is 28 mm in diameter. The maximum projected area in the

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acetabular bearing will then be:

$$Area = \frac{\pi . D^2}{4} = 0.000616 m^2$$

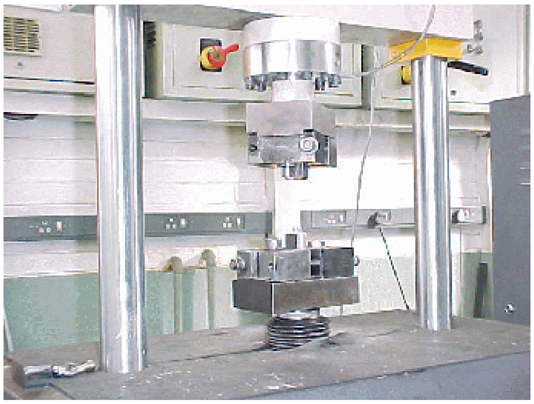
The maximum load applied to the bearing is on average six times the body weight (Paul, 1976), and if the weight of an average person is taken as 70 kg (95% percentile) (Adult data, 1988), the maximum load on the bearing is 4 800 N resulting in a compressive stress of:

$$\sigma = \frac{force}{area} = 8 MPa$$

This compressive stress of 8 MPa also correlates with load case as applied by Meng Deng and Latour (1998) and Lee and Pienkowski (1998). The load to be applied on the 12.5 mm square test piece can then be calculated as follows:

$$Load = \sigma . area = 8.(12.5)^2 = 1250 N$$

The displacement was measured by making use of a calibrated clip-on extensometer, while the load was measured with a calibrated 500 kg load cell. According to the ASTM standard (ASTM D2990, 1990), the load was applied within three seconds and kept on the test piece for one hour. The displacement data was recorded and plotted. The data was sampled at a rate of 50 Hz resulting in 1.8 x 10^5 data points over a one-hour period.



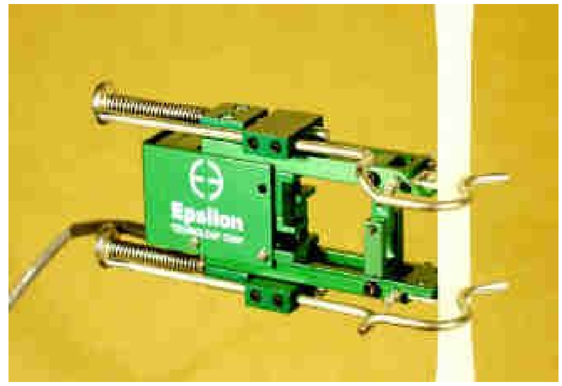


Figure 3.4a: Test set-up in Schenk testing machine

Figure 3.4b: Clip-on extensometer

3.2.3 Results

The data presented in Figure 3.5 represents the strain plotted against time for the three different lengths, 10, 20 and 40mm as shown in Figure 3.3. An increase in the creep rate of the 10mm test piece is visible if compared to the plotted data of the 20 and 40mm test pieces. This difference can be attributed to the restraint to lateral movement caused by the platen faces, namely the barrel shape effect. Another reason for this deviation can be explained by looking at Figure 3.3. The 10 mm test piece was machined from the bar right at the edge of the material. If there is any non-homogeneity, across the material, as was later proved to be the case the material will behave differently during these tests. This effect will have to be investigated further.

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From the data presented in Figure 3.5, the strain plotted against time for creep in the 20 and 40mm test pieces is very similar. The two plots actually meet as the test progresses. The conclusion that can be drawn from these tests is that the clamping or restraint effect on a test piece of 20 mm long is almost negligible. If test data is compared with the work of Lee and Pienkowski (1998) and Meng Deng and Latour (1998), the trend of the plots is the same for testing at room temperature with a loading of 8MPa.

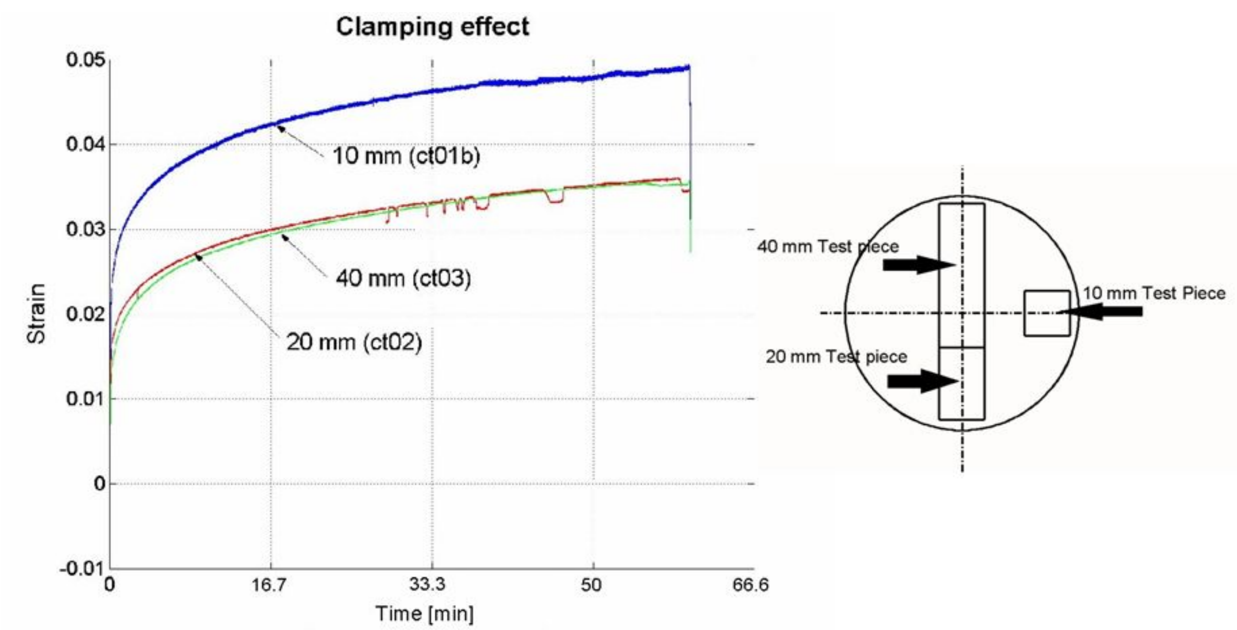

Figure 3.5: Results for the test to determine clamping effect

The conclusion from this part of the investigation is that a 20 mm test piece will be used for the rest of the investigation regarding the influence of various factors on the creep behaviour of UHMWPE. The effect of non-homogeneity or anisotropic properties, as well as the effect of elevated temperatures together with sterilisation and crosslinking on the material is investigated further.

3.3 Investigation of anisotropic effects

3.3.1 Purpose of test

The creep data, as presented in paragraph 3.2.3, for a test piece cut out from the edge of the material (see Figure 3.3) differed significantly from the other results. As explained, this can be due to the clamping effects or due to anisotropic properties caused either by the extrusion process or by heat treatment of the bar. The aim is to determine the effect of test piece orientation on the creep properties of the material.

3.3.2 Test procedure

Test pieces were machined from a standard Φ65 mm stock bar at various orientations. In all, eight test pieces were manufactured. (See Figures 3.6 and 3.7 for the position and orientation of the different test pieces.)

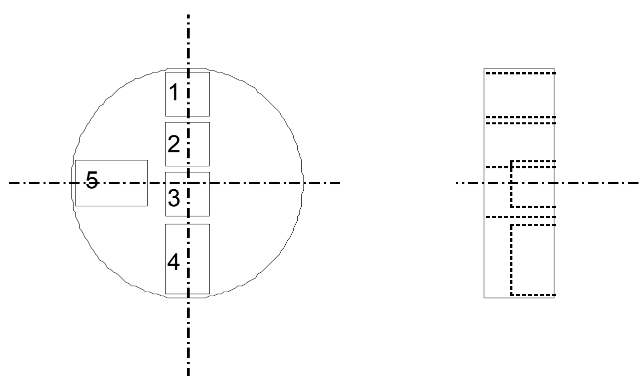

Figure 3.6: Position and orientation of test pieces 1 to 5

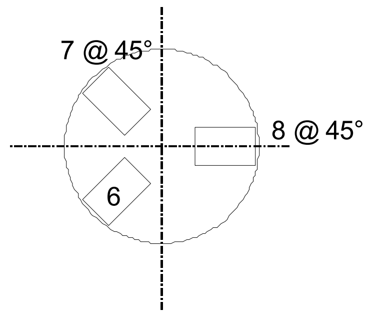

Figure 3.7: Position and orientation of test pieces 6 to 8

A slice of material, 20 mm thick, was cut from the bar stock and test pieces 1 to 5 were machined as shown in Figure 3.6. Test pieces 1 to 3 were cut out in the axial direction while 4 and 5 were cut out radially, perpendicular to the axial direction.

A second slice of material was used to manufacture test pieces 6 to 8. Test piece 6 is also perpendicular to the axial direction, but midway between test pieces 4 and 5 while test pieces 7 and 8 are cut at an angle of 45° to the axial plane.

The testing procedure was the same as that used to determine the clamping effects. The data sampling was again done at a frequency of 50 Hz. However, for test number 3, running for 18 hours, the sampling rate was brought down to 25 Hz. The test was done to ascertain the amount of creep that can be expected over a longer period. As a result of the amount of data that is gathered, the sampling was paused after one hour, keeping the load in place. The sampling was resumed after 16 hours to observe

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the long-term effect.

3.3.3 Test results

The results, plotted in Figure 3.8, show a substantial difference in creep between the outside and the inside of the raw material in the axial direction (tests 1 and 3). The difference in the creep values between these two tests is 32.43% or 0.24 mm. From this data, it appears that the centre of the virgin bar is the most creep-sensitive and that it is less creep-sensitive towards the outside.

The orientation of the test piece in the stock material is crucial. As can be seen from Figure 3.6, test pieces 3 and 4 were at different orientations. The difference in the creep values between these two test pieces is 25% or 0.18 mm. The differences between the test pieces cut out radially (4, 5, and 6) are given in Table 3.1

Table 3.1: Creep value differences for various test pieces

Test pieces	**Percentage difference**	**Difference in mm**
4 – 5	7%	0.05 mm
4 – 6	14%	0.1 mm

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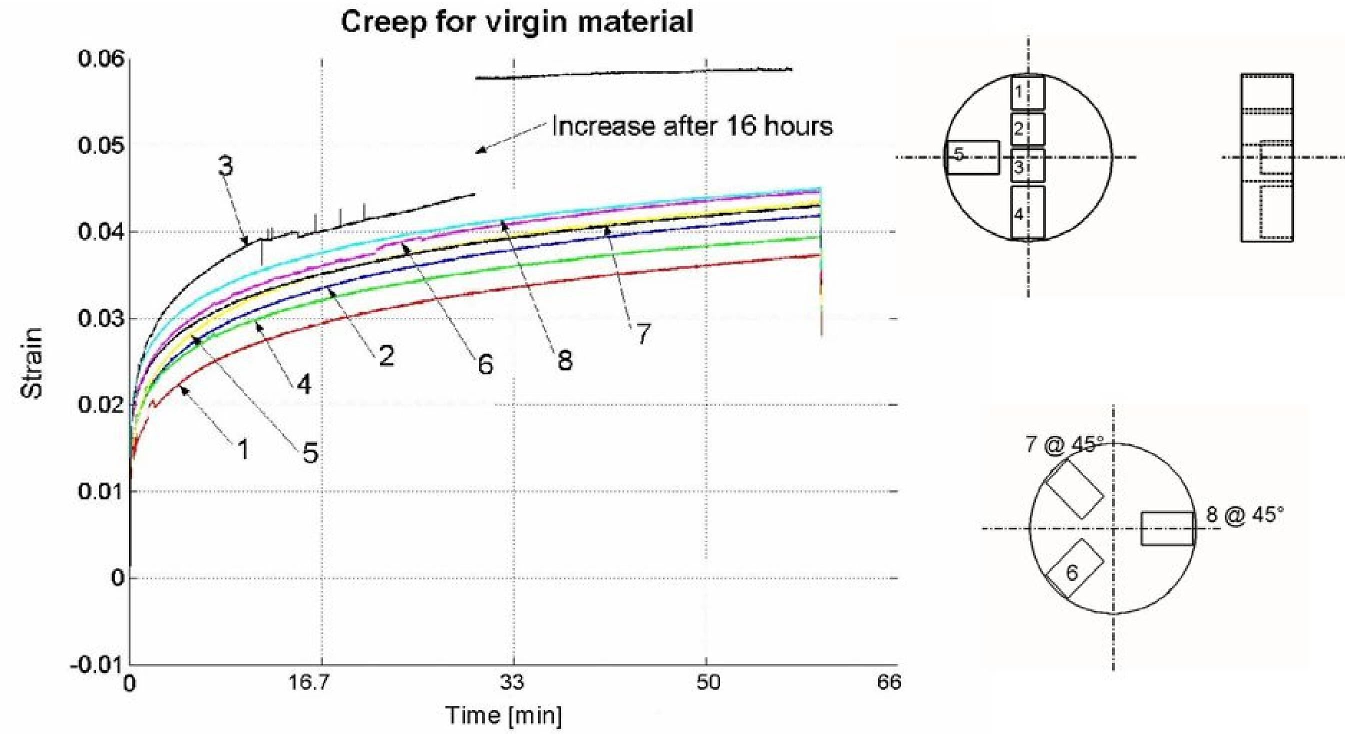

Figure 3.8: Creep in virgin material at different orientations

The creep values of the two test pieces cut out at an angle of 45°, test pieces 7 and 8, only differ 5% or 0.044 mm. What is, however, important namely is again the difference between the test piece cut out radially (4) and the rest of the test pieces that were cut out at 45° (7). The difference is 16% or 0.11 mm.

The maximum creep measured during the experiment was 1.18 mm and was measured after 18 hours of continuous loading.

The most important conclusion that can be drawn from this test is that the

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material shows anisotropic behaviour. The anisotropic properties could have been a result of the extrusion process or could be caused by insufficient or incorrect procedures used during the heat treatment afterwards.

It is, however, important that designers take note of this anisotropic behaviour during the design and manufacturing process of an acetabular cup as this anisotropic behaviour of the extruded UHMWPE could lead to severe distortion of the acetabular cup under load.

3.4 Effect of elevated temperature on the creep properties of UHMWPE

Localised elevated temperature is a severe risk in acetabular cups during motion as a direct result of friction between the two counter-bearing surfaces. The behaviour of the UHMWPE under these conditions together with gamma sterilisation and/or crosslinking is unknown.

3.4.1 Purpose of test

The purpose of the test is to determine an estimated effect of elevated temperature on the creep properties of UHMWPE. Creep tests at elevated temperatures were done by Meng Deng and Latour (1998), but these tests did not incorporate the effect of gamma irradiation and/or crosslinking as already stated. Therefore, tests on the virgin material had to be carried out to establish a baseline. It is important to note that all the creep data must be used with caution. The temperature in a cup is not homogeneous. Only small localised areas on the bearing surface will operate at elevated temperatures and the complete cup will not be subjected to the total creep effect.

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3.4.2 Test procedure

Test pieces were manufactured from a standard bar, Φ65 mm, cut out radially as shown in Figure 3.9. The test pieces were cut out and marked to enable correlation with the creep tests done at room temperature. Tests were then performed at temperatures of 40, 50 and 60°C respectively.

The temperature was monitored by placing a thermocouple down the centre of the test piece, measuring the core temperature of the test piece. This was done to ensure that the complete test piece was at the specified temperature and not only the outside. The test piece was heated up by circulating hot water around the test piece until the core had reached the desired temperature. The test set-up is shown in Figure 3.10. The rest of the test procedure remains as described earlier.

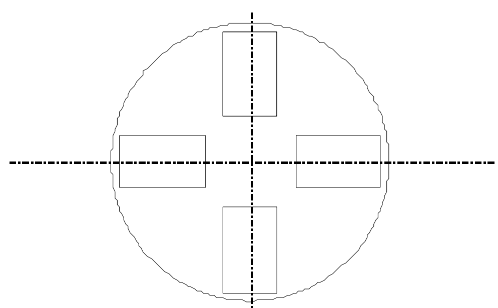

Figure 3.9: Orientation of test pieces machined from bar stock for tests at elevated temperatures

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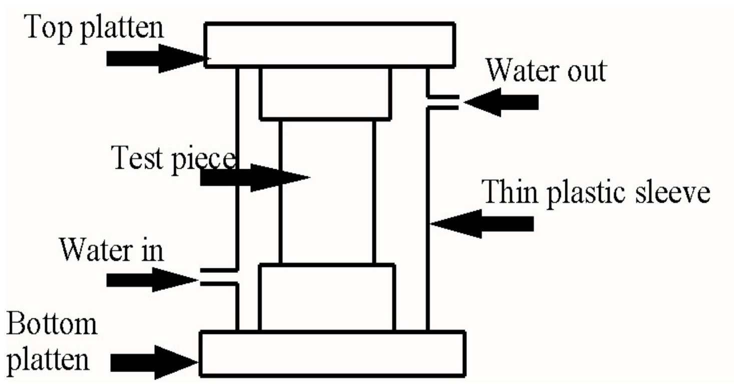

Figure 3.10: Test set-up for tests at elevated temperatures

The summary of the results of the tests at elevated temperatures are shown in Figure 3.11

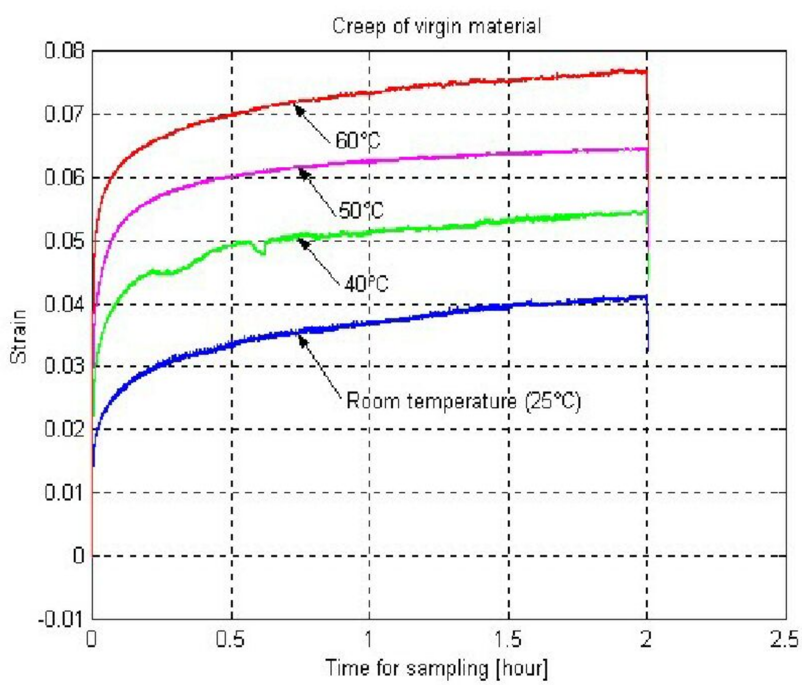

Figure 3.11: Summary of creep results at elevated temperatures

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Table 3.2: Summary of creep values after 2 hours

Test	Virgin material creep after 2 hours
Creep at room temperature	0.79 mm
Creep at 40°C	1.08 mm
Creep at 50°C	1.26 mm
Creep at 60°C	1.536 mm

From the data as presented in Figure 3.11 and Table 3.2, it can be seen that there is a substantial difference in the creep properties of UHMWPE at room temperature and at 60°C. The difference in the creep values done at room temperature and at 60°C is 87% or 0.716 mm as measured over a two-hour period. The total amount of creep, at 60°C, after two hours was 1.5 mm.

The test data as presented above correlates with the data presented by Meng Deng and Latour (1998). Although Meng Deng and Latour (1998) do not present actual data values they report an increase in the creep values of 80% if the temperature is taken from 37ºC to 62ºC. The creep test data illustrates that at elevated temperature the material softens to such an extent that extrusion of material in the local hot spot areas will be possible.

3.5 Effect of sterilisation on the creep properties of UHMWPE

3.5.1 Purpose of test

Gamma sterilisation is the industry standard used for the sterilisation of medical components. From the relevant literature (Saum, 1994; Rimnac et al., 1994; Trieu & Paxson, 1995), it can be seen that the gamma

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sterilization causes free radicals to form. These free radicals can cause an increase in oxidation that can have a negative effect on the mechanical properties of UHMWPE. The purpose of this test was to determine the effect of gamma sterilisation on the creep behaviour of UHMWPE.

3.5.2 Test procedure

Test pieces were manufactured, as described in paragraph 3.4.2. The test pieces were gamma-irradiated using three different methods to simulate sterilisation:

a. Irradiated with 25 kGy in air
b. Irradiated with 25 kGy in a nitrogen atmosphere
c. Irradiated with 25 kGy in air and heat-treated at 80°C to get an annealing effect.

The gamma irradiation and crosslinking were done by Gammatron CC using commercially available processes.

The tests were performed at room temperature to enable a comparison with data available in this study as well as with data available in the literature.

3.5.3 Test results

The test results to determine the effect of gamma irradiation are shown in Figure 3.12 (irradiation in air), Figure 3.13 (irradiation in nitrogen) and Figure 3.14 (irradiation in air and heat-treated to achieve annealing).

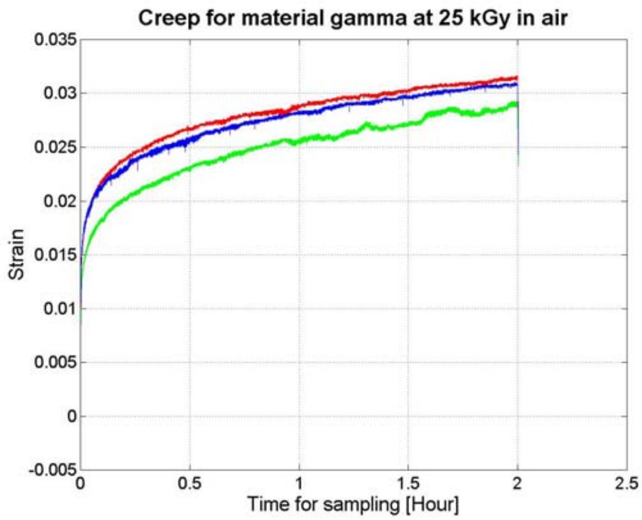

Figure 3.12: Creep properties of material irradiated in air

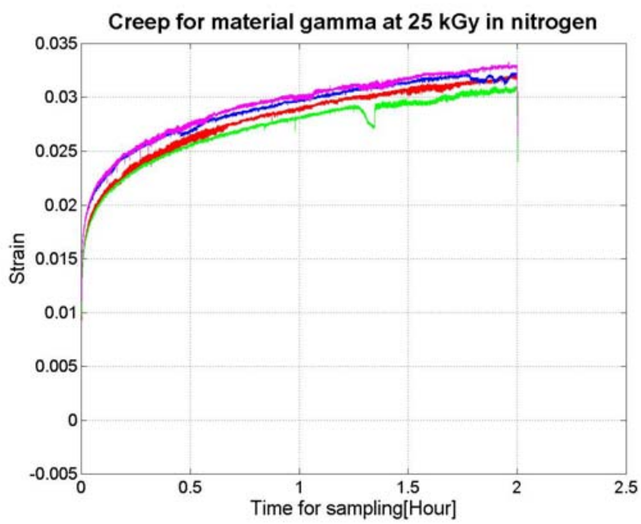

Figure 3.13: Creep properties of material irradiated in nitrogen atmosphere

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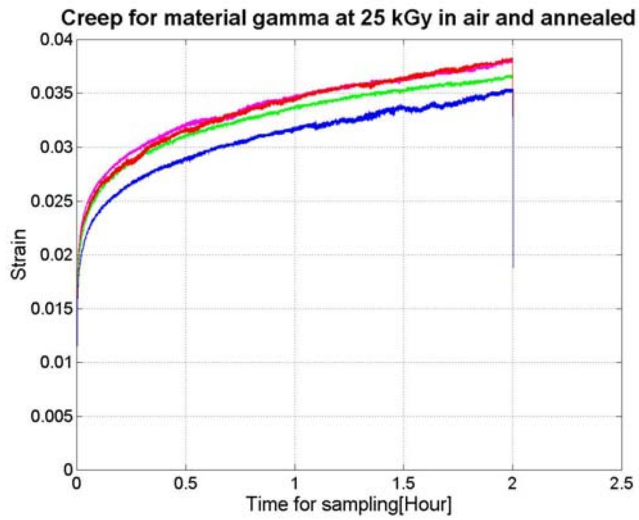

Figure 3.14: Creep properties of material radiated in air and heat-treated at 80°C and tested at room temperature

If the data as presented in Figures 3.12 to 3.14 is compared to the creep property data in the literature (Lee & Pienkowski, 1998; Meng Deng & Latour, 1998) and taking the data from paragraphs 3.2 and 3.4 into account, it can be seen that there is a slight decrease in the creep values for UHMWPE. However, the annealed material showed a substantial increase in the amount of creep (see Table 3.3).

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Table 3.3: Summary of creep after gamma irradiation

Test (average)	**Gamma-irradiated creep after 2 hours**
Test 4 (paragraph 3.2 and 3.4): Creep at room temperature (virgin material)	0.79 mm
Material radiated in air	0.6 mm
Material radiated in nitrogen	0.65 mm
Material radiated in air and then heat-treated at 80°C to achieve annealing	0.75 mm

From the data presented in Table 3.3, it can be concluded that the effect of gamma irradiation on the creep properties of UHMWPE is negligible. In this test, the biggest contributing factor to excessive creep was the annealing of the material after manufacturing, which is an indication that this is not a good manufacturing practice although the intention is to create a material with less anisotropic behaviour.

3.6 Effect of crosslinking on the creep characteristics of UHMWPE

3.6.1 Purpose of test

The latest tendency, in the manufacturing, is to crosslink the UHMWPE to achieve better wear characteristics, although there is a reported decrease in fracture toughness (Du Plessis et al., 1977). This was discussed in Chapter 2. The purpose of this test is to determine the effect of crosslinking in an acetylene atmosphere on the creep properties of

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UHMWPE at an elevated temperature.

3.6.2 Test procedure

Test pieces were manufactured from a standard Φ65 mm bar as described in paragraph 3.4.2. The test pieces were then crosslinked in an acetylene atmosphere with gamma irradiation at 125 kGy. Three different tests were performed, namely:

a. Creep at room temperature
b. Creep at 50°C
c. Creep at 60°C.

The same test procedure was used as described earlier. Again, the crosslinking was done by Gammatron CC with commercially available processes.

3.6.3 Test results

The test results of the gamma crosslinked test pieces are shown in Figure 3.15 (room temperature), Figure 3.16 (creep at 50°C) and Figure 3.17 (creep at 60°C).

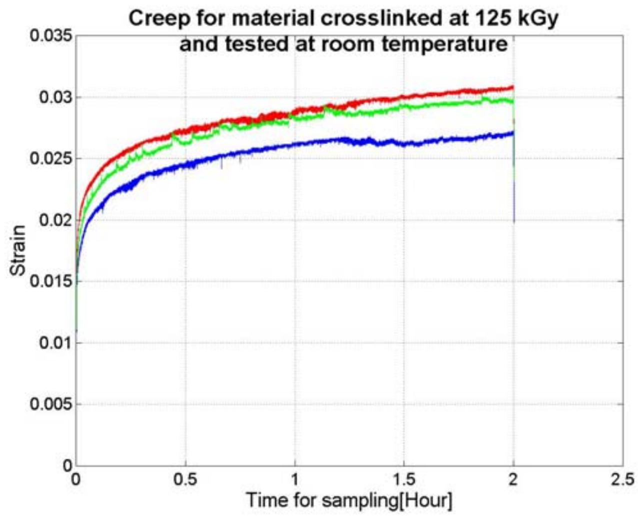

Figure 3.15: Creep properties of crosslinked UHMWPE at room temperature

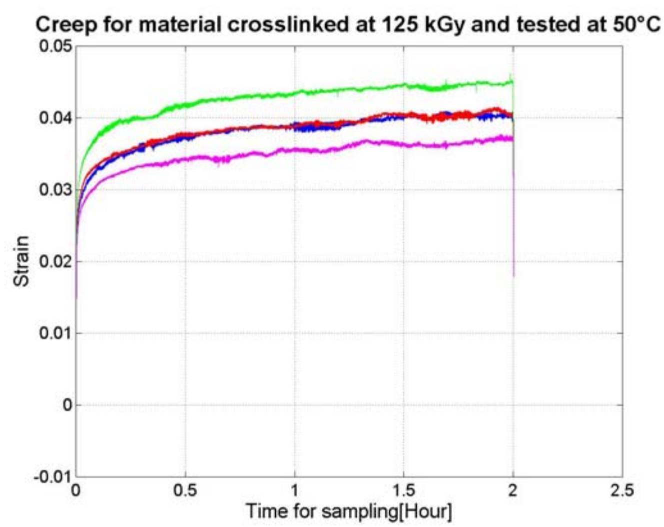

Figure 3.16: Creep properties of crosslinked UHMWPE tested at 50°C

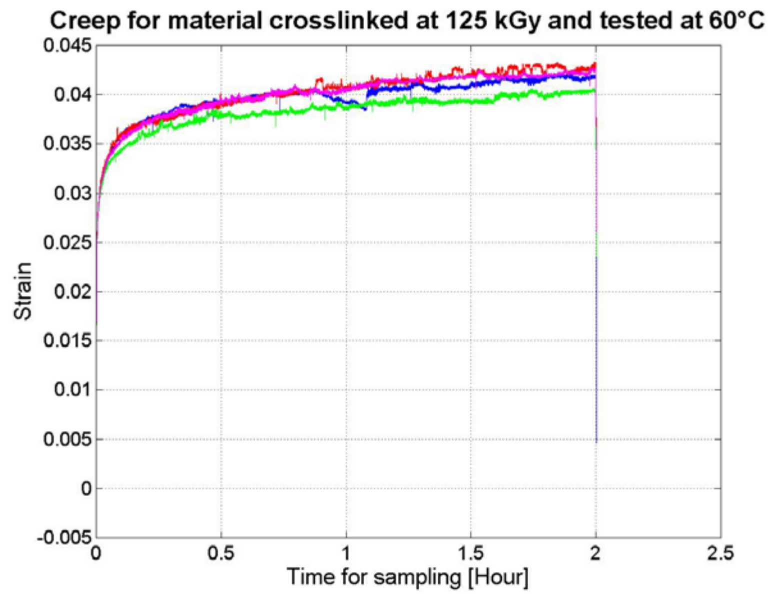

Figure 3.17: Creep properties of crosslinked UHMWPE tested at 60°C

The summary of the test data compared to the data of virgin material can be seen in Table 3.4. The creep data is average values.

Table 3.4: Summary of creep values after 2 hours

Test	**Virgin material** **Creep after 2 hours**	**Crosslinked** **Creep after 2 hours**	**Difference**
Creep at room temperature	0.79 mm	0.58 mm	-36%
Creep at 50°C	1.26 mm	0.8 mm	-58%
Creep at 60°C	1.536 mm	0.84 mm	-83%

From the data presented in Table 3.4, it can be concluded that there is a

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significant decrease in the amount of creep after crosslinking. This is to be expected if the decrease in impact strength, as explained in Chapter 2, is taken into account. This decrease in the creep properties will result in a lower tendency for plastic flow to occur in the local hot spots, on the bearing surface, in the acetabular cups.

3.7 Proposed use of creep data in cup design

The tests show that the manufacturing process, material heat treatment, orientation and temperature all play a part in the creep characteristics. If this creep tendency is to be incorporated into future designs, more tests will have to be done to enable statistical determination of the creep properties to be used in the design process.

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CHAPTER 4

PRELIMINARY INVESTIGATION OF RETRIEVED ACETABULAR CUPS

4.1 Introduction

Product failure represents one of the most persistent and expensive problems in the cost structure of any company. In the case of hip implants, the cost of these failures is carried by the health care sector and the patient. Therefore, with aseptic loosening due to wear-induced osteolysis as the principal cause of product failure (Claus et al., 2001; Dumbleton et al., 2002; Manley et al., 2002; Foguet et al., 2003; Oakley et al., 2003; Wilkinson et al., 2003), it is essential that the root cause for mechanical failure in UHMWPE acetabular cups is properly understood, especially in view of the fact that UHMWPE acetabular cups are the most commonly used in the industry (Mallchau et al., 2000; Davidson et al., 2002; Davidson et al., 2003).

The information obtained from acetabular cups retrieved during revision surgery is invaluable. The purpose of this preliminary investigation was to try and obtain a broader perspective on the defects seen in retrieved acetabular cups in order to formulate the possible failure criteria and the methodology to be used during the detail investigation of this study.

In engineering failure analysis, all possible analytical tools are used to conduct a scientific investigation to provide a better understanding into the root cause of mechanical failure. However, the classification found in some of the literature (Schmalzried et al., 1999), namely mode 1 to mode 4 wear, is vague and inadequate for a root cause failure analysis. A more comprehensive classification will have to be established to enable an engineering failure

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analysis.

In ISO 12891-3 (2000), a guideline of defects for polymeric retrievals is provided. This section was not included in the literature survey in Chapter 2 of this study as it is most suited here where the new proposed criteria are presented. The ISO 12891-3 guideline, is applicable in general to all polymeric retrievals and include the following:

a. Wear
b. Discolouration
c. Material transfer
d. Scratching or pitting
e. Embedded particles
f. Cracking
g. Warping
h. Change of shape
i. Burnishing
j. Mechanical damage
k. Tissue attachment
l. Macro porosity
m. Dimensions.

All the abovementioned defects are listed in the ISO specification, as a guideline, but no detailed description of the various defects is provided and these defects are therefore, open to interpretation by the user.

The methodology used to establish a set of failure criteria, applicable to acetabular cups, was arrived at by studying more than 100 retrieved components and by observing the defects present in these cups. The defects found were then categorised enabling the formulation of a set of failure criteria for an engineering failure analysis. The retrievals studied were all received from one

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centre. The retrievals were not clearly identified and therefore an accurate assessment of in-vivo service could not be made. Nonetheless these retrievals provided research material for an initial assessment of the failure mechanism. A detailed engineering failure analysis on retrievals for which all data is available is presented in Chapter 5.

4.2 Proposed failure criteria

After investigating the mechanical failures in more than 100 retrieved components and categorising these failures, the most common defects are listed in Table 4.1.

Table 4.1: The most common defects noticed on inside of retrieved cups

	Defect noticed	**ISO 12891-3 Items**
1	Mechanical damage	j
2	Cracks in the material	f, l
3	Plastic flow	a, g, h
4	Scratches	a, d, j
5	Adhesion wear	a
6	Wear particles embedded in base material	a, c, e,
7	Flaking	a

The visible defects, as set out in Table 4.1, are used as a classification tool to identify defects in the detailed failure analysis in this study. Scientific analytic tools, some of them suggested in ISO 12891-3 (2000), are used to establish the cause of defect formation.

4.3 Descriptive explanation of defects in acetabular cups

The defects, as listed in ISO 12891-3 (2000), are not described in detail in the specification and are therefore open to interpretation by the user. In this part of the study, the different defects, as listed in Table 4.1, are described in detail.

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This is done to ensure a clear set of criteria, which can be followed in a root cause analysis into the mechanical failure of acetabular cups.

4.3.1 Mechanical damage

Mechanical damage, predominantly caused by impingement, is normally the result of an acetabular cup not properly aligned in vivo, whether during implantation or during rotation after aseptic loosening. The mechanical damage is normally a result of the neck of the femoral stem making contact with the rim of the acetabular component. Impingement can also occur after excessive wear when the neck of the femoral component is making contact with the acetabular component. Impingement normally results in pieces of material (UHMWPE or cement) being ripped from the edge of the cup as seen in Figure 4.1. A schematic presentation of the defect is shown in Figure 4.2

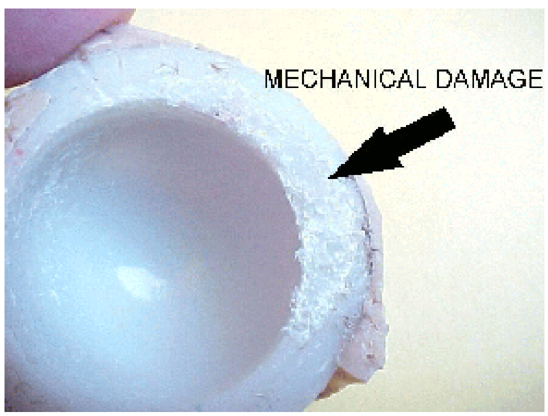

Figure 4.1: Mechanical damage on rim of cup

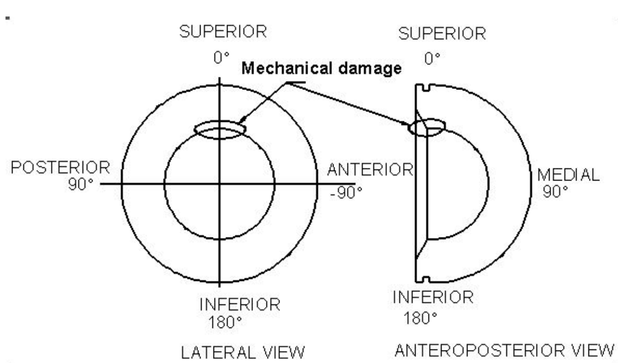

Figure 4.2: Schematic presentation of mechanical damage on rim of cup

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An initial assessment of the problem is that the pieces of material forcefully removed by the neck of the femoral component will cause large floating particles and possible loosening of the cup due to impact loading. If rotation of the cup with resulting impingement is a result of aseptic loosening, impingement will cause further rotation and discomfort to the patient.

4.3.2 Cracks in material

Cracks in the material can be caused by stress raisers and are normally expected in the high-stress or contact stress areas or on the rim of the cup as occasionally seen in the case of cups with metal backing. A typical defect is shown in Figure 4.3a and schematic presentation of the defect is shown in Figure 4.4.

Fracturing of metal backed liners can conceivably also occur as follows: If the polyethylene liner is not machine-pressed into the metal backing, but only clipped into position, the possible lack of conformity between the cup and metal backing can cause higher stresses on the rim of the cup. The resulting alternating stress can cause fatigue cracks (Figure 4.3a) and separation within the material on the rim (Figure 4.3b).

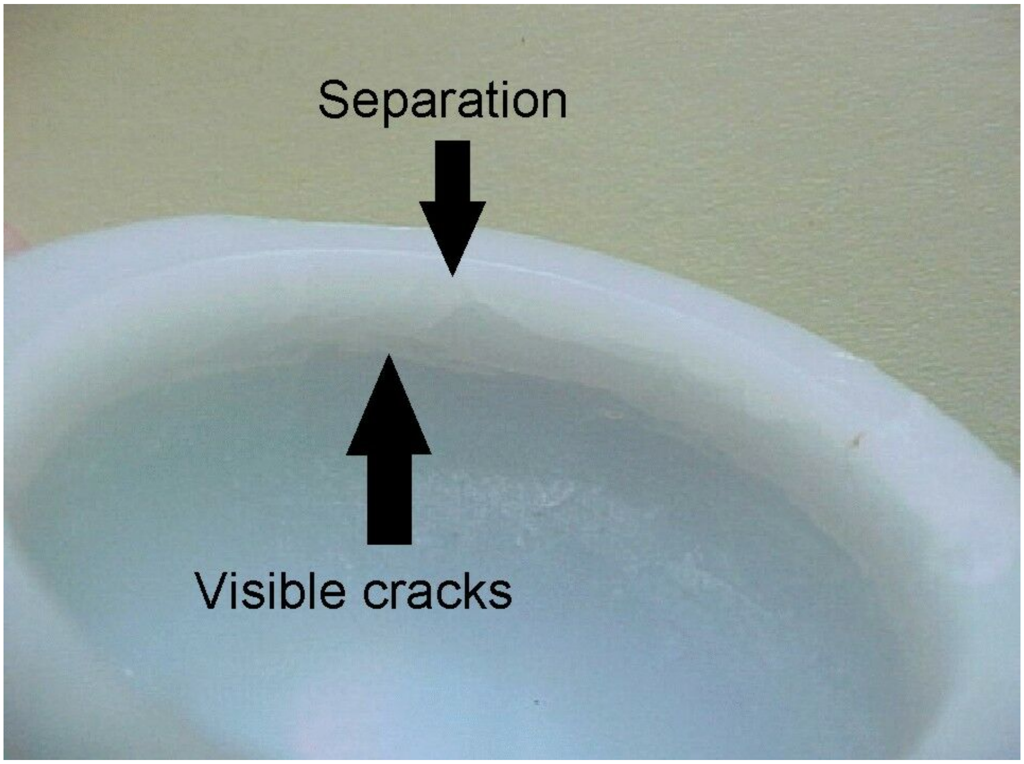

Figure 4.3a: Metal backed acetabular cup with cracks on rim

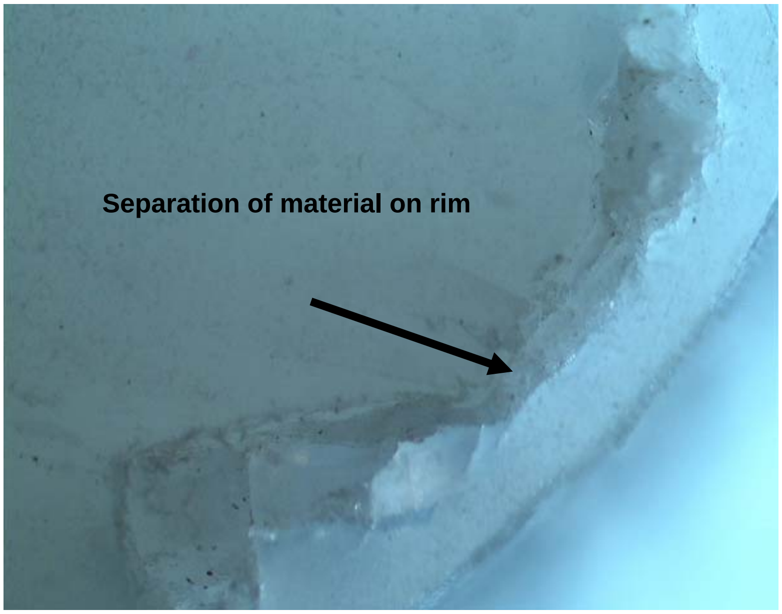

Figure 4.3b: Separation within material

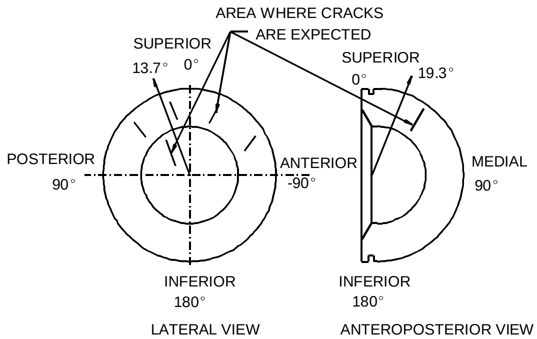

Figure 4.4: Schematic layout of areas where cracks can be expected in the area under tensile stress

4.3.3 Plastic flow

When the acetabular cups are investigated by means of a magnifying glass, areas of plastic flow are visible. These areas can have different appearances. The first is the orange peel effect. The term "*orange peel*" is used to describe the surface texture and should not be related to the surface roughening encountered in forming products from metal stock that has a coarse grain size as is commonly referred to in metallurgy and in injection moulding of plastics (Gold Technology, 1990; Engineering Materials Handbook, 1987; http://www.principalmetals.com /glossary/odoc.htm). This area normally occurs just outside the area of high contact stress on the bearing surface. Visually, it seems as if "molten" material or material sufficiently softened to be extruded was expelled from the area of high contact stress and transferred to an area where the contact stress is less intense. A typical defect is shown in Figure 4.5 with a schematic presentation of the defect shown in Figure 4.6.

A further example of this defect is plastic flow on the rim of the cup. An example of this defect can be seen in Figure 4.3b. This defect presents as if the compressive stress, on the bearing surface in the cup, exceeded the maximum limits resulting in an outward flow and/or creep of the material.

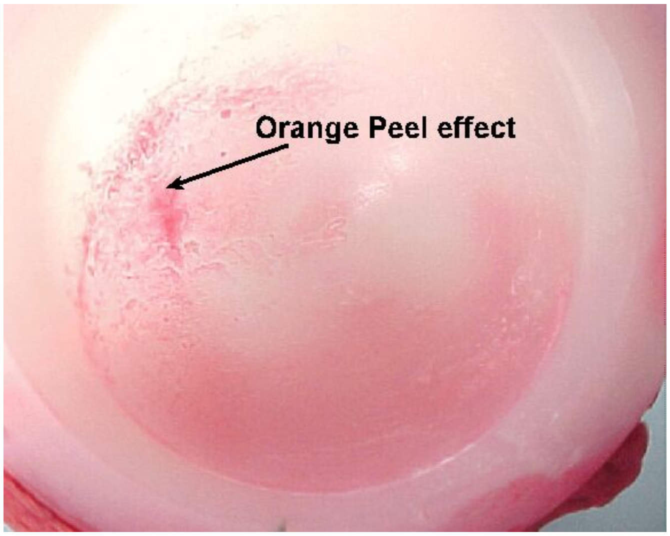

Figure 4.5: Cup treated with dye penetrant showing “orange peel” effect indicating plastic flow of material

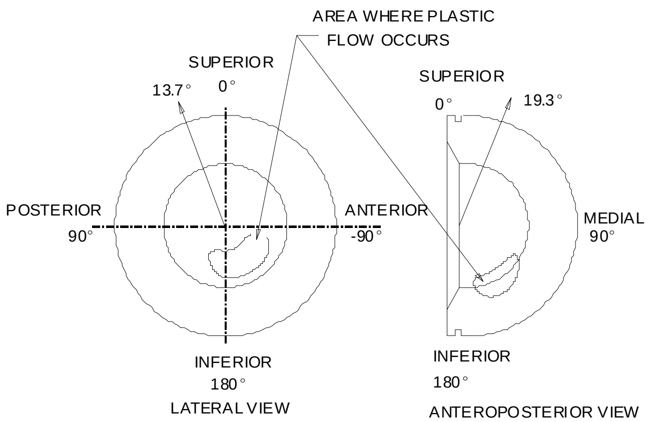

Figure 4.6: Schematic layout of expected plastic flow in acetabular cups

The defect, classified as plastic flow, in the acetabular cups appears similar to the defects found in the work of Kukureka et al. (1995), where acetal was tested in unlubricated rolling-sliding contact. At this early stage of the investigation, it

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would appear that there is an underlying problem with the available lubrication in the acetabular joint.

4.3.4 Scratches

During examination of the retrieved cups, scratches were found in some of them. Although scratches on a micro scale have been reported in the literature (see Chapter 2), scratches visible with the naked eye are also present. These large scratches will be synonymous with third-body wear, independent of what caused the wear particles or the type of particles. The appearance of these scratches is not limited to the final wear area, but can also be created during the initial stages shortly after implantation. An example of a cup with this defect is shown in Figure 4.7.

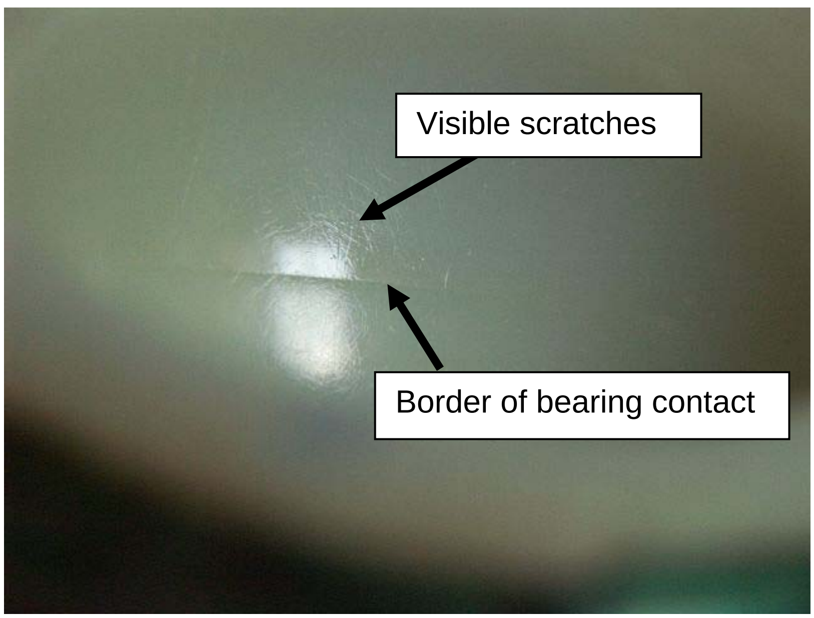

Figure 4.7: Scratches visible on inside of cup

4.3.5 Adhesion wear

Adhesion wear can be described as areas where adhesion wear, probably due to overheating and/or lack of lubrication, has taken place. This normally occurs under conditions of high frequency, short stroke, small movement (Hutchings, 1992). When bonding between asperities on the two surfaces in contact occurs and subsequent movement causes the asperities of the softer surface to be torn out, rather than breaking the bond between the asperities, the process is called *adhesion wear,* typically the areas present as rough patches and are seen in the high contact stress areas where lubrication is the poorest. An example of an acetabular cup with signs of adhesion wear is shown in Figure 4.8 and a schematic presentation of the defect is shown in Figure 4.9.

Figure 4.8: Adhesion wear on inside made visible with dye penetrant treatment

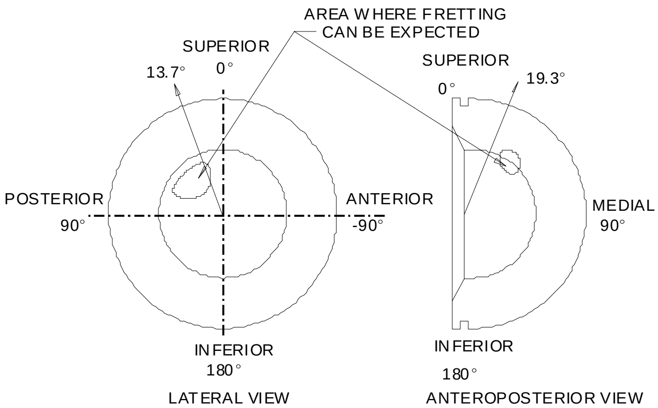

Figure 4.9: Schematic presentation of expected adhesion wear marks

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4.3.6 Wear particles embedded in base material

During the examination of some of the acetabular cups, wear particles were found embedded in the base material. Although wear products from the base material are also embedded in the base material, the most common particle found embedded was poly methacrylate (PMMA) cement used for the fixation of the implant as well as UHMWPE wear particles. An acetabular cup with PMMA particles embedded is shown in Figure 4.10.

Figure 4.10: Acetabular cup with embedded PMMA particles

4.3.7 Flaking

Flaking (delamination) can be defined as areas where pieces of material separate from the base material. This defect presents either as craters or areas of delamination. A cup with serious delamination is shown in Figure 4.11. This type of defect, although not common, is normally associated with a defect within the material and occurs in the high stress or contact stress areas.

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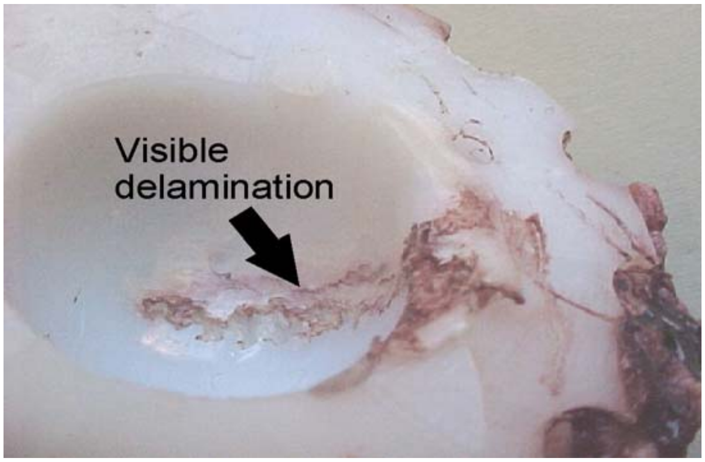

Figure 4.11: Acetabular cup with serious delamination visible.

The following question can now be raised: Can the defect present in the acetabular cup in itself cause the end of useful life? The influence of the most common defects as listed in Table 4.1 on the functional life of the acetabular cups can be seen in Table 4.2.

Table 4.2: Common defects present in acetabular cups with possible effect on useful life

	Defect	**Question: Could the defect in itself cause the end of useful life**
1	Mechanical damage	Yes
2	Cracks in the material	Yes
3	Plastic flow	Yes
4	Scratches	Possible — dependent on the severity
5	Adhesion wear	Yes
6	Wear particles embedded in base material	Possible — dependent on severity
7	Flaking	Yes

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4.4 Statistical analysis of retrieved acetabular cups

After the completion of the preliminary study, a more detailed set of defects, as given in Table 4.1, was compiled, compared to the defects as listed in ISO 12891-3 (2000). Making use of this proposed set of defects, a controlled retrieval study was done on 47 acetabular cups retrieved during revision surgery. All of these acetabular cups were obtained from one centre and procedures were performed by the same surgeon. All the details of the patients, duration in service and the type of femoral head were recorded as suggested by ISO 12891-3 (2000). The full failure analysis is discussed in Chapter 6 and the detail analysis of 20 cups is attached in Annexure A.

The results of the analysis, according to the proposed defects, can be seen in Table 4.3. The analysis is based on the number of occurrences per defect. Some of the acetabular cups had more than one defect present in the cup. (See Annexure A.)

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Table 4.3: Statistical analysis of 47 retrieved cups, with in total 125 defects

*The percentage is based on the number of occurrences per defect in 47 cups

Defect	**Number**	**Percentage***	**Comments**
Mechanical damage	18	38.3%	Caused by misalignment or movement after aseptic loosening
Cracks	11	23.4%	Cups with metal backing in specific series prone to cracks on rim
Plastic flow	29	61.7%	More prominent when ceramic femoral head is used
Scratches (Visual)	21	44.6%	Caused by third-body wear
Adhesion wear	23	48.9%	More prominent when ceramic femoral head was used
Wear particles embedded in base material	22	46.8%	Secondary effect or particles that originate outside the bearing
Flaking	1	2.1%	Most likely a material defect

.

From the data presented in Table 4.3, the major defects resulting in 'end of useful life' are:

a. Plastic flow: present in 61.7% of the acetabular cups retrieved. Plastic flow is more prominent in the UHMWPE/ceramic bearing couples than in UHMWPE/steel couples. The severity of the amount of plastic flow in the UHMWPE/steel bearing couples is also less.

b. Adhesion wear: present in 48.9% of the retrieved acetabular cups. Adhesion wear is also more prominent in the UHMWPE/ceramic bearing couples than in the UHMWPE/steel bearing couples. Adhesion wear was

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only found in 2 components running with UHMWPE/steel bearing couples.

The fact that plastic flow and adhesion wear are both influenced by the amount of heat generated on the bearing surface, the less frequent occurrence and severity in the UHMWPE/steel bearing couples are already an indication that there is better cooling in these bearing couples if compared to UHMWPE/ceramic bearing couples.

4.5 Conclusion

From the data presented in Table 4.3 and taking into account the results of the creep characteristics of UHMWPE at elevated temperatures (Chapter 3) it would seem that there is an underlying problem of localised excessive heat build-up on the bearing surface of the polyethylene acetabular cups. This heat build-up might at this stage be attributed to either a lack of sufficient lubrication and/or the difference in the ability of the various materials to conduct the generated heat away from the surface. This is supported by the difference in the thermal conductivity of steel (k=1.35 W/mK) (Engineering Materials Handbook, 1987) compared to the very low thermal conductivity value for ceramic (k= 0.0158 W/mK) (Engineering Materials Handbook, 1987) resulting in the generated heat being trapped between the mating surfaces.