AMPC

Suitability of Belt Materials for CO_2 Pellet Cleaning

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PREPARED BY:	The University of Adelaide and Cold Logic Pty Ltd
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TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

A common practice for cleaning of polymer-based conveyor belts in meat processing facilities includes the use of high temperature water and cleaning solvents, as well as sterilization fluids. This is a labour and energy intensive process. An alternative process that can reduce energy costs associated with water boiling, reduce the quantities of cleaning chemicals, and potentially reduce labour time is via dry ice (solid CO_2) blasting. This process is currently already used in the meat industry in Australia and internationally with ferrous metal meat rails; however, assessments of the process when used on polymer-based conveyor belts (commonly used in boning rooms) are lacking. The material properties, including mechanical strength and brittleness may be influenced by exposure to cold (-78.5°C) temperatures. The aim of the current project is to assess the possibility of using dry-ice blasting on polymer-based conveyor belts. This project continues from the work undertaken in AMPC projects 2015-1038 and 2016-1055 and the identification of surplus liquified CO_2 as useful byproduct from operations within meat processing facilities. The project included a detailed review of literature, as well as experimental testing on sample material specimens.

In the dry-ice blasting process one side of the conveyor belt material is exposed to the ambient room temperature and the other is cooled by the dry ice. This produces a thermal gradient through material. Furthermore, cyclical thermal loading, whereby the material in question is repetitively exposed to cooling and heating may also result in residual changes to material properties. To date, there are no studies that have investigated the effect of this thermal gradient, or cyclical thermal loading on the impact resistance of common conveyor belt materials. Understanding how these thermal variations influence relevant polymers, in order to assess the suitability of dry-ice blasting for meat processing conveyor belts, is the overall aim of this project.

To achieve the project aim, experiments were designed and undertaken on high-density polyethylene (HDPE), polypropylene, and acetal. Samples with thickness of 10 mm had thermocouples implanted at depths of 1 mm, 2.5 mm, 5 mm. The samples were covered with dry ice and the changes in temperatures at the three locations were measured. This allowed for analysis of thermal gradient variations.

To assess the impact resistance of the three materials, samples were cooled for predetermined and varying periods of time before being tested using an Izod impact tester. To assess the impact resistance of materials subject to cyclic thermal loading, additional samples available were subjected to increasing numbers of thermal cycles prior to being tested using an Izod impact tester. The thermal cycles included cooling for 60 seconds with dry ice, and heating for 60 seconds in boiling water. The impact tests were conducted after the sample returned to ambient temperatures.

The key findings from these experiments is that both polypropylene and acetal belts are not suitable for dry ice blasting. For both materials, the risk of material failure is high, but more so for polypropylene. However, the results from HDPE tests indicate that it is likely to be suitable for dry ice blasting as a cleaning process. Unfortunately, the number of thermal loading cycles conducted on HDPE was insufficient and further investigations would be warranted. However, this would only be useful and warranted if a production facility relied solely on HDPE-based conveyor belts.

Overall, the results indicate that dry ice blasting on non-HDPE polymer conveyor belts typically used in meat processing facilities is not suitable and therefore not recommend. The impact resistance of commonly used materials becomes unacceptably low, thus increasing the risk of material failure and hence significantly increasing the risk of production stoppages.

2.0 INTRODUCTION

To ensure food safety at all stages, meat processing rooms and slaughter areas undergo rigorous cleaning on a daily basis; some cleaning activities are conducted multiple times per day. General industry practice is to use a combination of high temperature water and cleaning solvents to remove any animal residue, with sterilising fluids sprayed on surfaces during and after the main cleaning to disinfect surfaces. Depending on the size of the facilities, this type of cleaning generally takes multiple hours, uses large amounts of energy, and is very labour intensive. In order to reduce energy costs associated with the water boiling and reduce the quantities of chemicals necessary for cleaning, dry ice (solid CO_2) blasting is proposed as an alternative method for the cleaning of conveyor belts.

Cleaning of meat rails using dry ice blasting is already an established practice in the meat industry, both in Australia and internationally. However, no investigation in the public domain has been undertaken until this point in time to consider the cleaning of meat conveyors made from polymer materials that are commonly used in boning rooms. Polymers have specific properties with regards to mechanical strength and brittleness when exposed to significant temperature changes on a repeated basis. Possible fatigue cracking could occur based on repeated cooling and heating as would be undertaken during cleaning using dry ice pellets. This project is an investigation into the effect of repeated cleaning of conveyors belts using dry ice pellets. Specifically, the project focuses on impacts on variations to material strength due to temperature variations associated with dry ice pellet impact exposure (including cyclical exposure). Overall, this project continues from the work undertaken in AMPC projects 2015-1038 and 2016-1055 and the identification of surplus liquified CO_2 as useful by-product from operations within a meat processing facility. The project included a detailed review of literature (Milestone 1), as well as experimental testing on sample material specimens (Milestone 2).

During the cleaning process using dry ice blasting, conveyor belts experience a short exposure of dry ice (temperature of -78.5°C). Cold temperature exposure combined with low thermal conductivity of the polymer materials typically used to make the belts, results in a thermal gradient through the belt material. This happens where one side of the material is at local ambient temperature and the other is cooled by the dry ice. To date, there are no studies that have investigated the effect of this thermal gradient on the impact resistance[1] of common conveyor belt materials. If dry ice blasting is to be used for the cleaning of conveyor belts, the impact resistance of the materials with a thermal gradient requires investigation. This was identified in Milestone 1 as the most likely failure mechanism of belt material during cleaning.

There has been a significant field of research testing the properties of materials at low temperatures, however, they all dealt with homogeneously cooled samples. As the dry ice blasting does not uniformly cool the material over the time it is expected that the blasting process will take place, there is a significant gap in knowledge regarding the material properties of polymers with an internal temperature gradient resulting from the blasting process. Milestone 2 focused on validation of cooling rates at varying depths in the material and impact testing of polymer samples across a range of cooling periods. Sections of polymer materials, typically used in conveyor belts, were covered in dry ice. The material temperature at three depths (1 mm, 2.5 mm, 5 mm), were measured using thermocouples connected to a data logger. Impact testing of these cooled samples was conducted using an Izod impact tester to determine their impact resistance with an internal thermal gradient. When comparing the current data for temperatures measured at 1 mm to that in literature for homogeneously cooled samples, it showed similar trends; however, there is an offset in trend, which

[1] Impact resistance is the energy required to cause the material to break due to an impact.

differs for the various materials. Accurate prediction of the offset for various materials would require significant experimentation, well beyond the scope of the current work.

A mathematical model of the thermal gradients was developed to compare the use of dry ice powder covering a sample surface in order to simulate cooling by dry ice blasting. The mathematical model of cooling from dry ice blasting produced different cooling profiles compared with the aforementioned experimental results. However, the experimental method used provided more controlled and repeatable results, and thus deemed appropriate for the current work. The results from Milestone 2 showed that covering with dry ice to cool the materials did not produce the exact temperature gradient anticipated during dry ice blasting; however, the gradient developed was sufficient for impact testing to reveal the expected behaviour.

In all cooling schedules investigated, polypropylene fell below its glass transition temperature (T_g) of 0°C and hence was brittle and exhibited low impact resistance. Whilst acetal has a T_g of -70°C, it experienced a gradual reduction in impact resistance in the temperature range investigated, as predicted in literature. The HDPE has the lowest T_g of -125°C so all impacts were carried out well above the T_g. Furthermore, as identified in literature, HDPE experiences an increase in impact resistance as T_g is approached. These results indicate that dry ice blasting may be appropriate for HDPE conveyor belts, but in the case of polypropylene or acetal belts, the potential for impact failure needs to be further investigated.

Milestone 2 of this project, in conjunction with literature, found that polymer materials where more affected by the temperature at impact testing, rather than the actual shape and thickness. However, considering the actual use of these materials, the cyclic thermal loading (freezing and reheating to room temperature at approximately 20°C) and the subsequent effects this may have on the polymer properties, a variation to project scope was made to conduct a preliminary assessment of cyclical cooling on the samples.

3.0 PROJECT OBJECTIVES

The objectives for the current project are to:

1. Provide a comprehensive review of dry ice blasting for cleaning purposes currently in use around the world and in different industry sectors.
2. Summarise of application benefits and literature of using dry ice blasting for meat rails.
3. Review literature of materials used for meat conveyors and existing knowledge into changes of material properties due to repeated sudden temperature changes.
4. Provide a summary report of experimental testing results and analysis of material specimen and real-world conveyor belt components.
5. Devise a suitable experimental testing regime to identify material property changes from dry ice blasting.
6. Use standardised material specimens for conveyor belt materials and identify changes in material properties and fatigue characteristics due to repeated dry ice blasting.
7. Use actual compound material specimens from actual conveyor belt materials and identify changes in material properties and fatigue characteristics due to repeated dry ice blasting.

8. Undertake experiments and analyse results of cyclic thermal loading (freezing and reheating to room temperature) and the subsequent effects this may have on the polymer properties.

Objectives 1–4 were undertaken as part of Milestone 1. Objectives 5–7 were undertaken as part of Milestone 2. Objective 8 is provided in the current report.

3.1 Limitations to the Project

The research has been limited to three types of materials, identified as typical materials most often used for conveyor belts used in meat processing facilities. Furthermore, testing of impact on cyclic thermal loading, (detailed in the current report) was limited to the number of existing sample in order to reduce the overall cost to AMPC (as agreed upon with a variation in contact). Finally, it is noted that to ensure scientific repeatability and accuracy, tests were conducted to isolate the affect of only cyclic thermal loading, rather than impact from DRY ICE pellet delivery.

4.0 METHODOLOGY

4.1 Materials

Following on from Milestone 2, the three materials investigated were high-density polyethylene (HDPE), polypropylene (PP) and acetal (POM). These were identified in Milestone 1 as the most common conveyor belt materials currently used in the meat processing industry. Samples of each were purchased from local suppliers in 4-mm and 10-mm thicknesses.

4.2 Temperature Variation Cycle

The cooling/heating cycle process involved samples being exposed to 60 seconds of dry ice and 60 seconds of boiling water. Whilst this is temperature variation is unlikely in a meat processing facility, it was chosen to exacerbate any thermal shock that could be encountered. Following the repetition of this cycle a (variable) number of times, once the samples were at ambient temperature, they were subjected to impact resistance measured using an Izod impact tester.

4.3 Impact Testing

Impact resistance of the polymers using an Izod impact tester is detailed in Milestone 2 report. The method follows ASTM D256 and ISO 180:2000. Each test result represents a single sample that was subjected to the specified number of cooling/heating cycles, prior to impact assessment until sample failure. Impact assessment was conducted at ambient temperature conditions.

4.4 Surface Imaging

Material surfaces were imaged under a microscope to assess potential surface variation from heating and cooling. Magnifications for each sample included 5×, 10× and 20×. These results are included in Appendix A with comparison results from literature in Appendix B.

5.0 RESULTS AND DISCUSSIONS

The results from impact testing with cyclical cooling and heating are limited due to low cyclic numbers. The results are presented in Table 1 and Figure 1. The low number of thermal cycles is due to the samples that were available. The key findings of impact resistance (in kJ/m^2) do not show significant variation to the impact resistance. Surface images, shown in Appendix A, support this hypothesis in that no clear changes occur with cycling variations. Specifically, there is no evidence of increased markings, surface flaking, pitting, or other defects. Examples of the types of defects expected as indicators of failure are shown in Appendix B and sourced from Western *et al.,* (2005), Lind *et al.,* (2015) and Liu *et al.,* (2019). Additional images can also be found in Doyle *et al.,* (1972). For both polypropylene and acetal the impact resistances do not reach the values of the respective control samples. This was not the case for HDPE.

Table 1: Impact resistance of polymer material samples after specified number of heating/cooling cycles.

Material	Number of Cycles [-]	Impact Resistance [kJ/m^2]
Polypropylene	0	10.54
	1	9.31
	2	8.11
	3	6.74
	4	8.23
	5	8.13
	6	8.13
	7	6.18
	8	6.16
	9	9.29
	10	8.35
HDPE	0	8.88
	1	10.45
	2	7.39
Acetal	0	11.94
	1	8.49

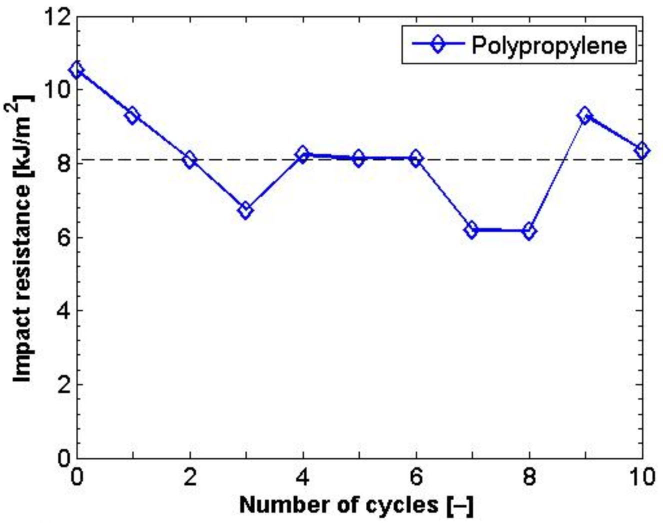

Figure 1: Impact resistance of polypropylene as a function of the number of thermal-loading cycles.

6.0 PROJECT DISCUSSION

The overall aim of the current project was to determine if dry ice blasting would be a suitable alternative to existing cleaning systems of conveyor belts used in meat processing facilities. From the literature, the major area of concern that needed investigation was the effect of low temperatures on the hardness and brittleness of the conveyor belt materials. These results were detailed in the Milestone 2 report. Subsequently, the effect of cyclic thermal loading was considered as an area of concern. This was then analysed for the current report. Experiments assessing effects of low temperature and cyclic thermal loading were conducted on three different materials: high-density polyethylene (HDPE), polypropylene (PP) and acetal (POM).

The experimental results from impact testing with cooled samples indicated that HDPE increased its impact resistance from 8.88 kJ/m² to 12.36 kJ/m² with greater exposure time to dry ice (up to 300 second exposure). This is supported by findings from Heijboer (1967). Additionally, for the conditions assessed, the temperature of HDPE did not approach its glass transition temperature. The experimental results from impact testing with thermally-loaded samples indicated that minor variations were present when compared with the control sample of HDPE that was not cooled at all. Additionally, no variations to the surface of the material were noted. The use of dry ice blasting on HDPE is not expected to result in unexpected material failure.

As polypropylene (PP) has a material glass transition temperature of 0°C, it was expected that it would become unacceptably brittle with the cooling associated with dry ice exposure. Sixty seconds of cooling with dry ice resulted in an impact resistance reduction of over 50% from 10.54 kJ/m² to 4.43 kJ/m². Interestingly, longer duration cooling up to 300 seconds did not significantly alter the reduced resistance level. The effects of thermal loading showed that raising the temperature of PP after cooling raised the impact resistance, but it was still approximately 10% below the value of a control sample not exposed to cooling or heating. Surface microscopy indicated that no significant changes occur due to thermal loading. Although impact resistance does not vary with thermal loading (for the range investigated), and the impact resistance does not change with increased dry-ice exposure time above 60 seconds, the recorded drop in resistance reduce, and the high glass transition temperature of PP indicate an unacceptable risk associated with dry-ice blasting.

The acetal samples showed similar response to dry-ice exposure as PP with a near 50% reduction in impact resistance (from 11.94 kJ/m² to 6.67 kJ/m²); however, rather than the plateau occurring after only 60 seconds, for acetal it occurred at 180 seconds. Additionally, acetal has a glass transition temperature of -70°C. This indicates that although acetal may be suitable to dry-ice blasting, the probability of material failure would need to be considered. Only one samples of acetal was available for cyclic thermal loading. After one cycle, the impact resistance was recorded at 8.49 kJ/m², compared with the control sample result of 11.94 kJ/m². This indicates that some level of degradation occurred. More experiments would need to be conducted to confirm this issue. However, these results highlight the risk associated with dry ice blasting on acetal, and therefore it is not recommended.

7.0 CONCLUSIONS/RECOMMENDATIONS

From the investigations conducted for the entire project, it is evident that dry ice blasting as a cleaning method of conveyor belts used in meat processing facilities may have some complications that render the process impractical. Polypropylene would have a high risk of material failure, as the glass transition temperature is high (0°C). Furthermore, there is a 10% reduction impact resistance after one 60-second exposure to dry ice, even after subsequent heating to 100°C and temperature stabilisation to room temperature.

Acetal fairs better than polypropylene with impact resistance at cold temperature exposure, and thermal loading; and also has a much lower glass transition temperature. However, there is still sufficient evidence to indicate high risks of material failure of acetal when cleaned using dry ice blasting.

Experiments conducted on the HDPE samples indicate that variations in impact resistance from cooling, and cyclic thermal loading from dry-ice exposure are minor and unlikely to cause material failure. This implies that dry-ice blasting on HDPE conveyor belts could be conducted. However, additional considerations could need to be made (such as other materials used on the belt construction, and operation of the cleaning equipment). Additionally, higher numbers of thermal loading cycles would need to be conducted to verify the impacts of thermal fatigue.

Overall, the results indicate that dry ice blasting on conveyor belts typically used in meat processing facilities is not suitable and therefore not recommend. The impact resistance of commonly used materials becomes unacceptably low, thus increasing the risk of material failure.

8.0 BIBLIOGRAPHY

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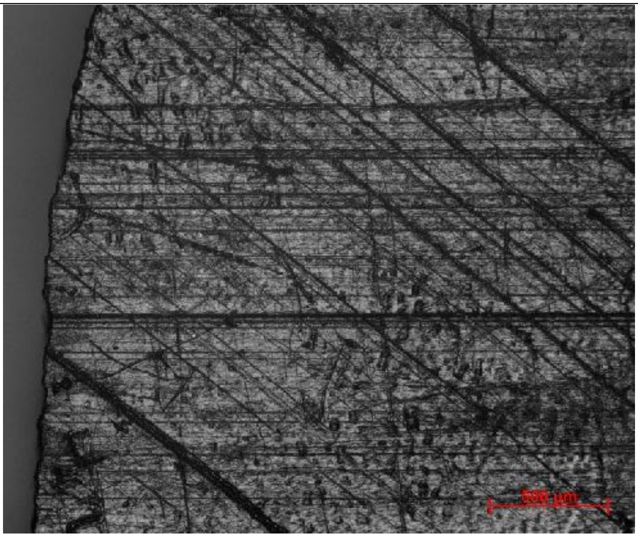
9.0 APPENDICES

The following images show the surface of various materials subject to different cooling/heating cycles. The magnification is at 5, 10 and 20 times.

9.1 APPENDIX A – MICROSCOPY IMAGES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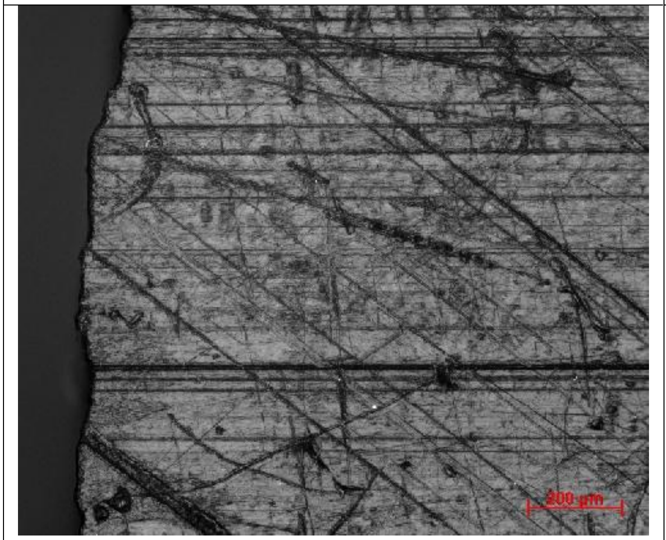	
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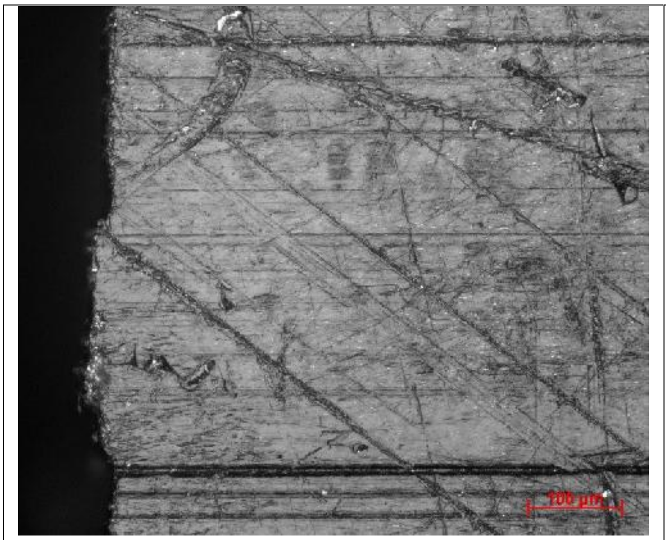	
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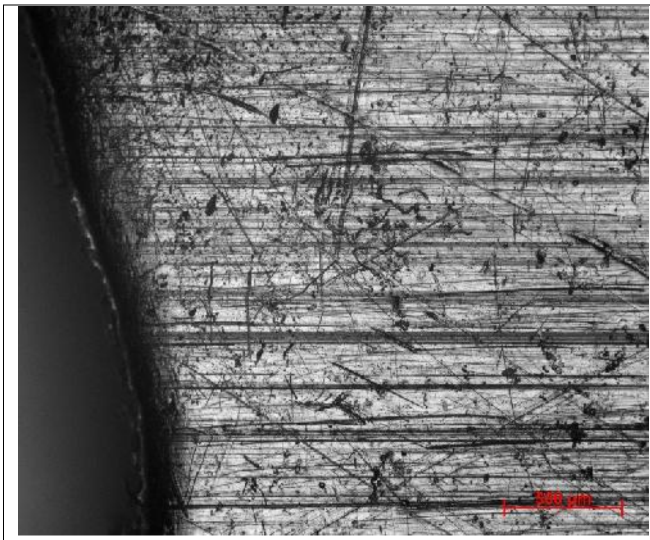
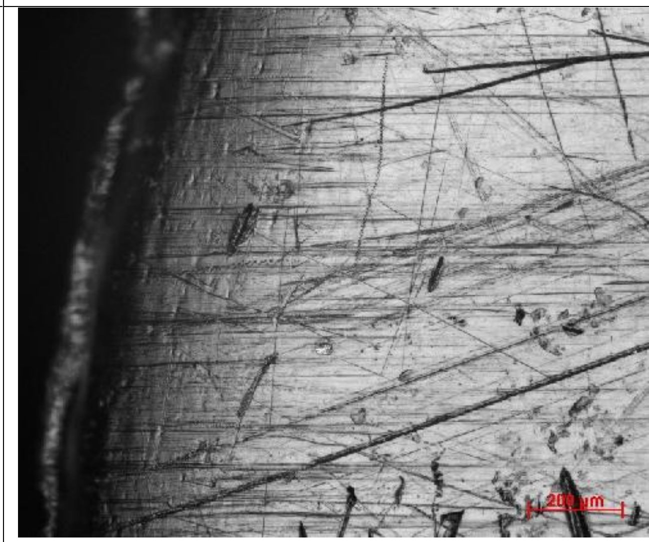
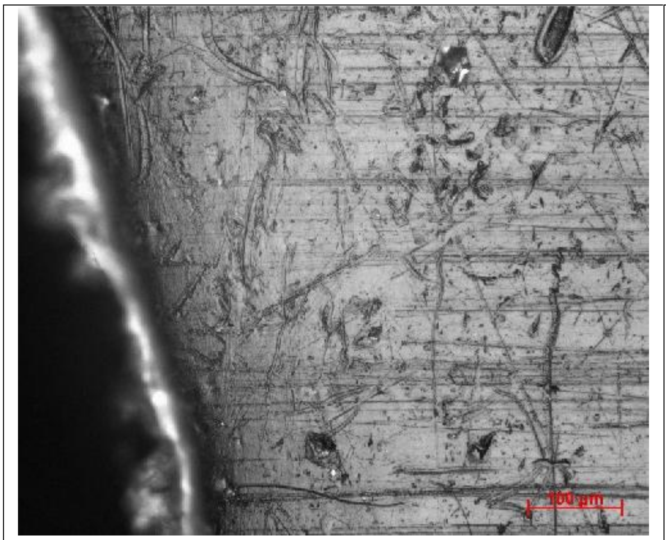
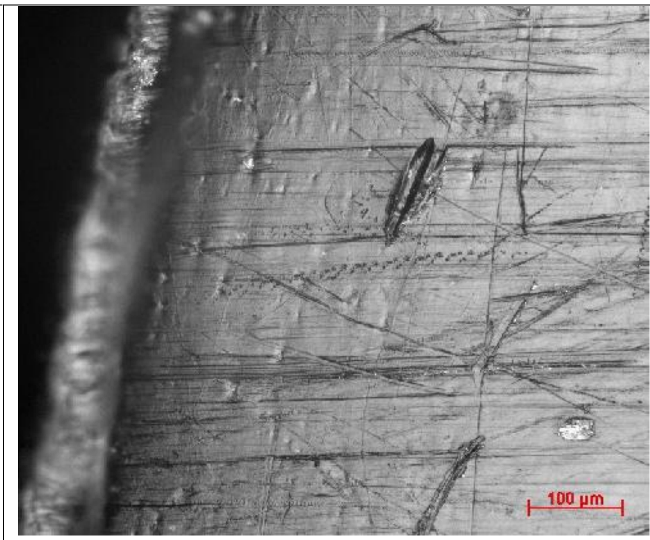
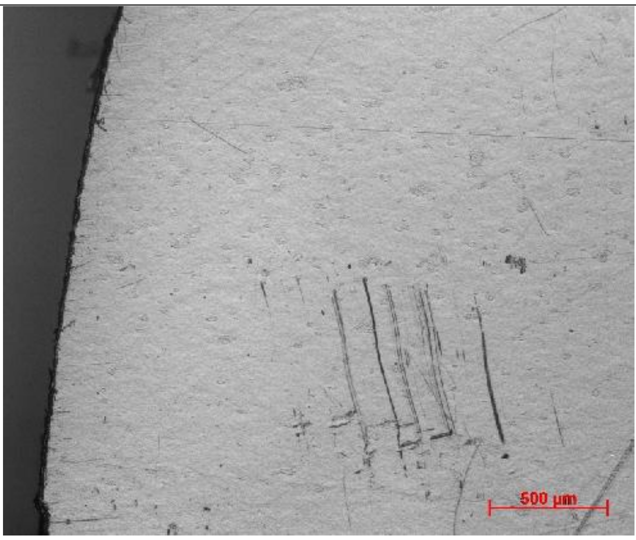
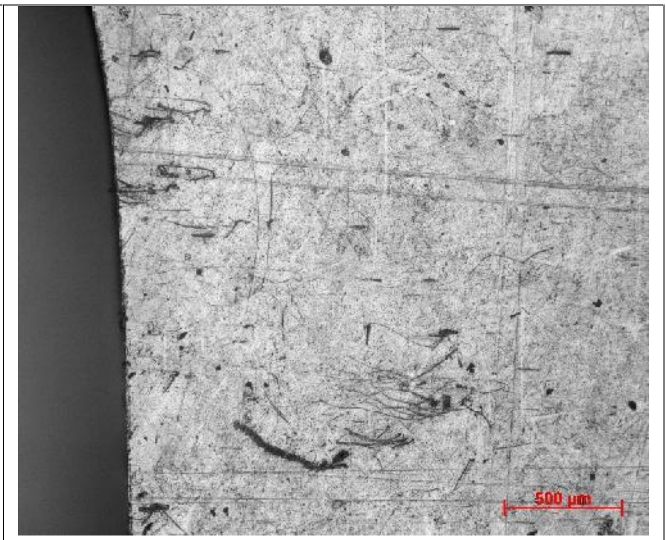
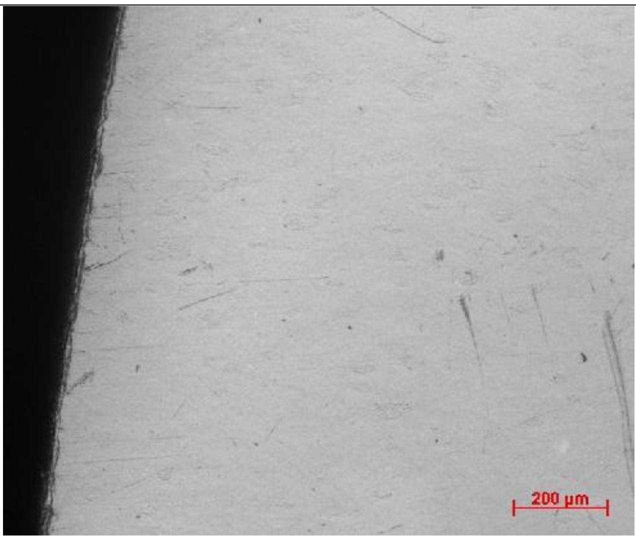
	
HDPE: 1 Cycle, 5× magnification	HDPE: 2 Cycles, 5× magnification
	
HDPE: 1 Cycle, 10× magnification	HDPE: 2 Cycles, 10× magnification

	
HDPE: 1 Cycle, 20× magnification	HDPE: 2 Cycles, 20× magnification

	
Polypropylene: 1 Cycle, 5× magnification	Polypropylene: 2 Cycles, 5× magnification
	
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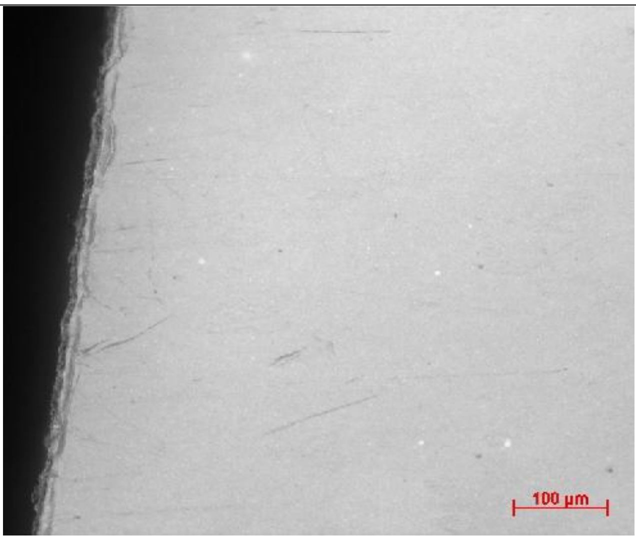	
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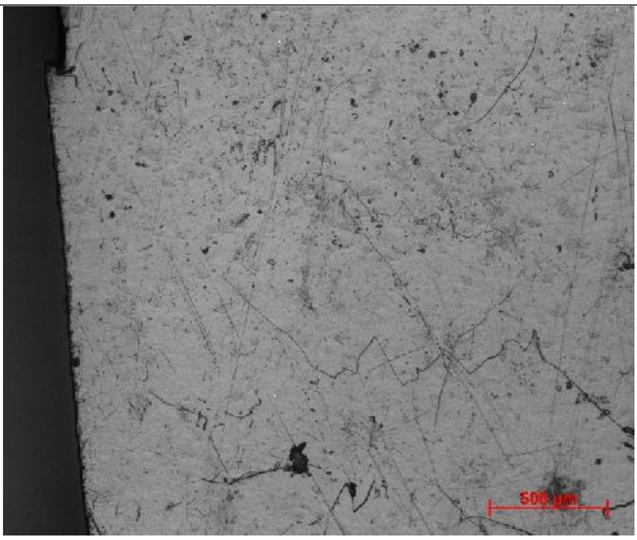	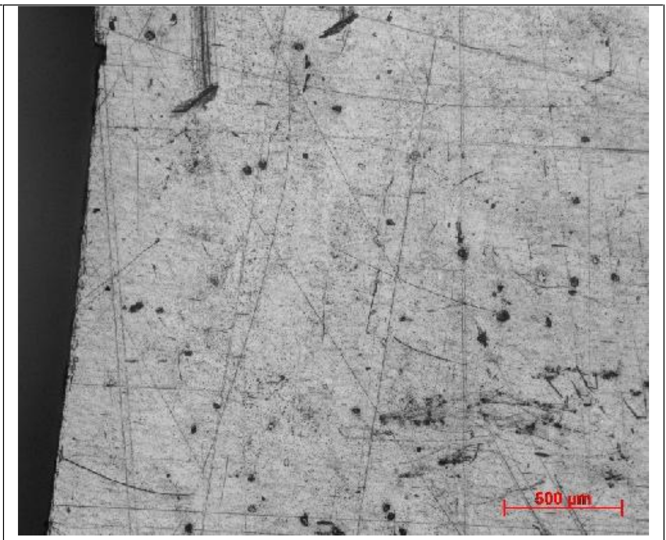
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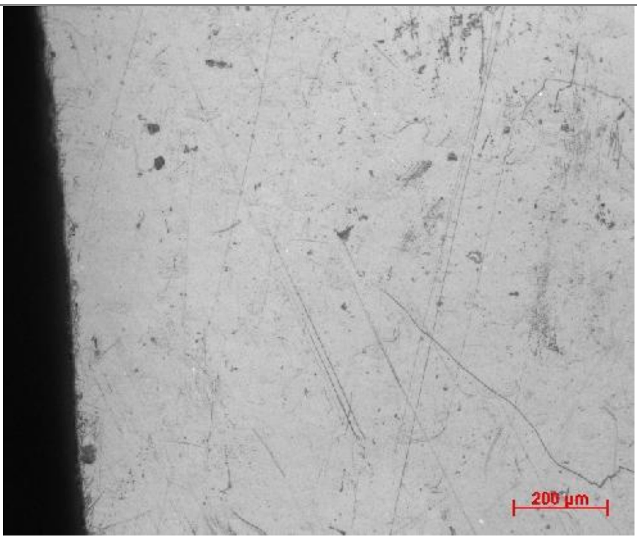
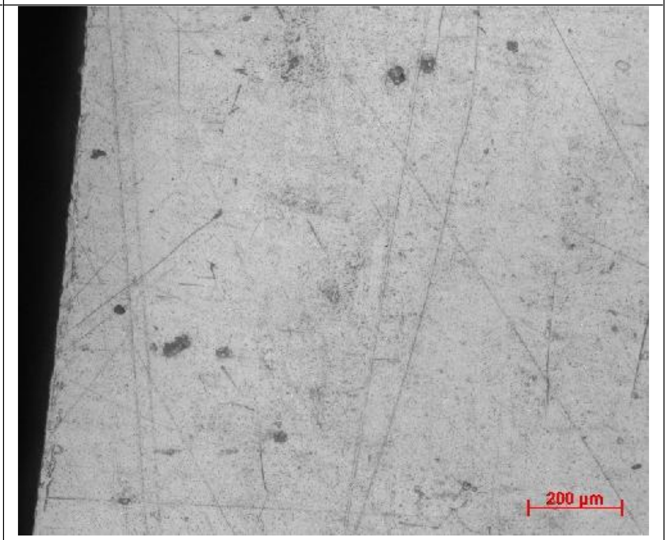
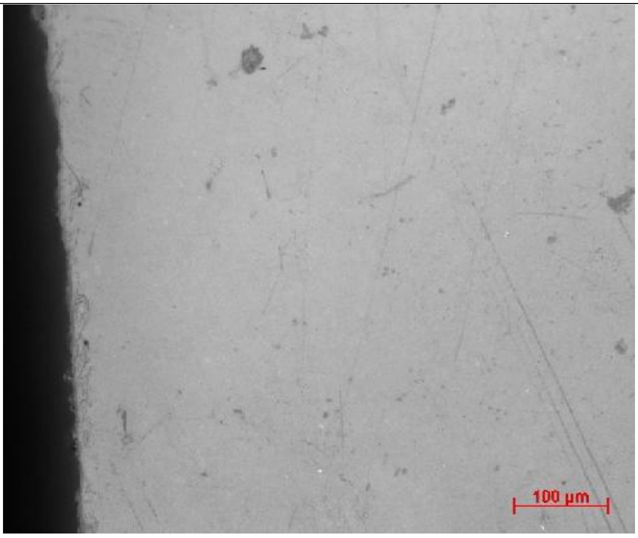
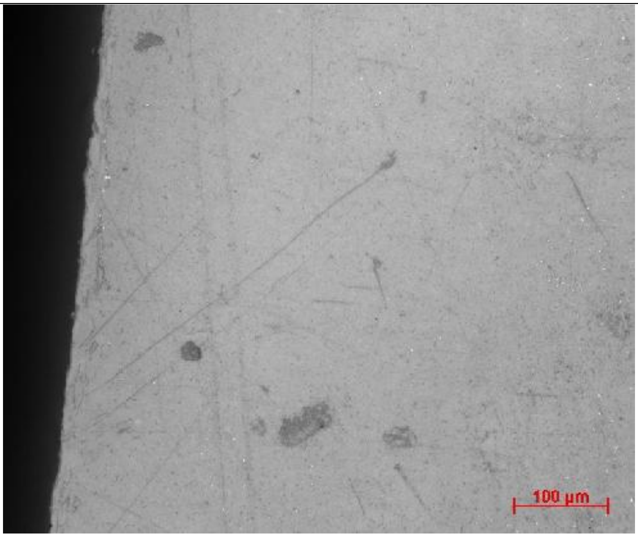
	
Polypropylene: 3 Cycles, 10× magnification	Polypropylene: 4 Cycles, 10× magnification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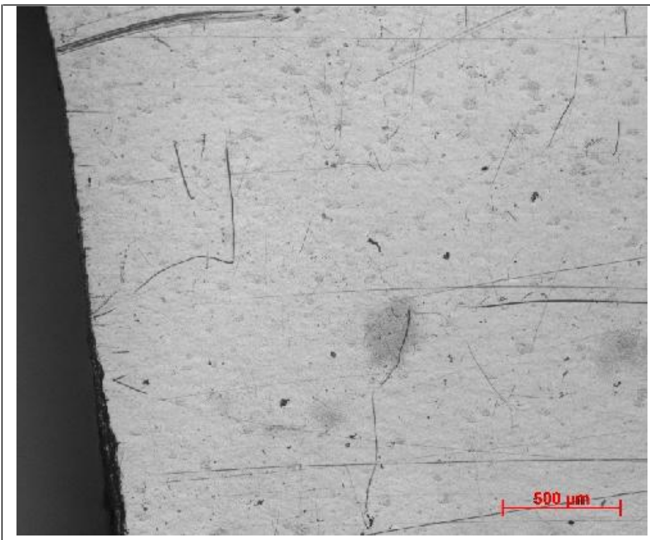
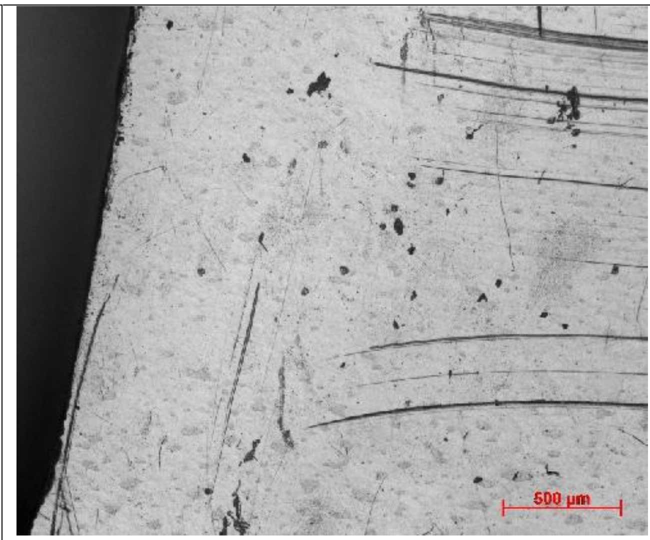
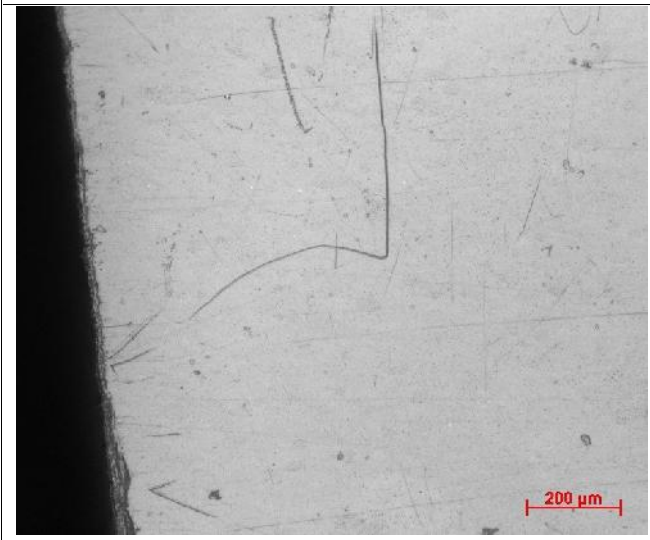
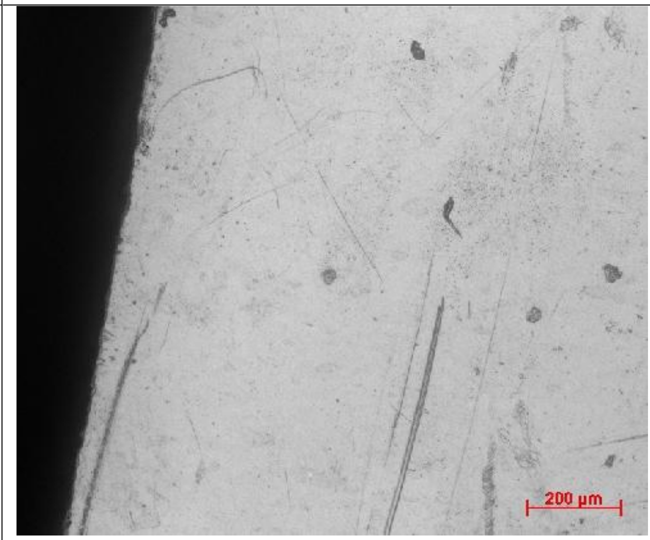
	
Polypropylene: 5 Cycles, 5× magnification	Polypropylene: 6 Cycles, 5× magnification
	
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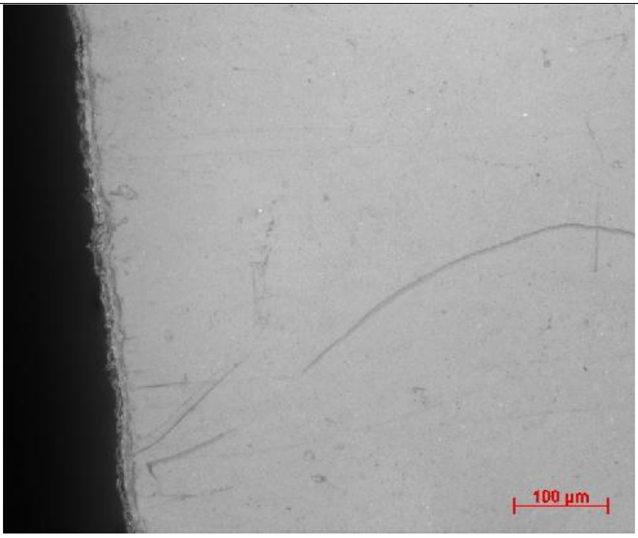	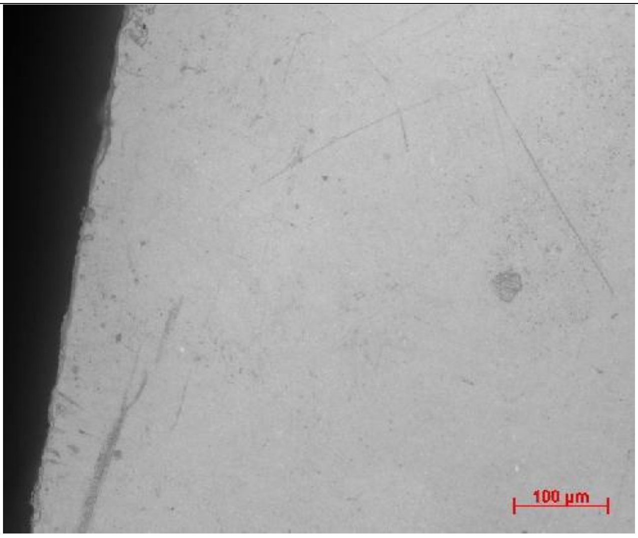
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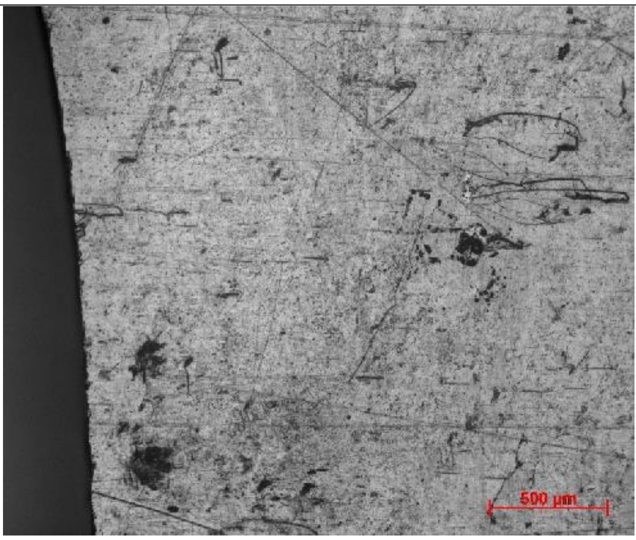
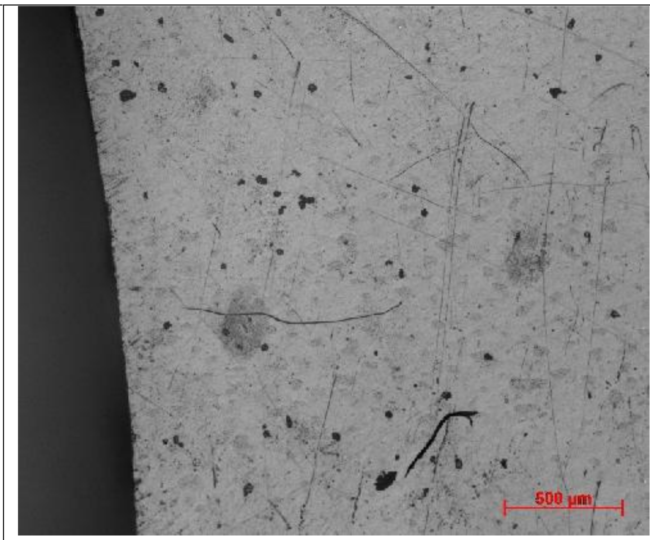


Polypropylene: 7 Cycles, 5× magnification



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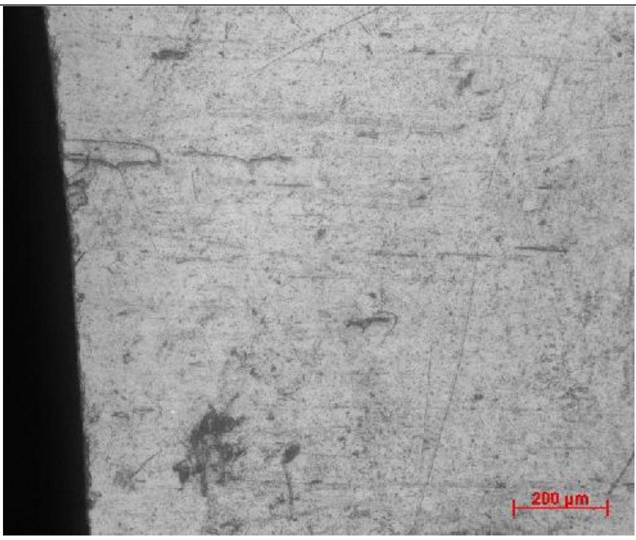
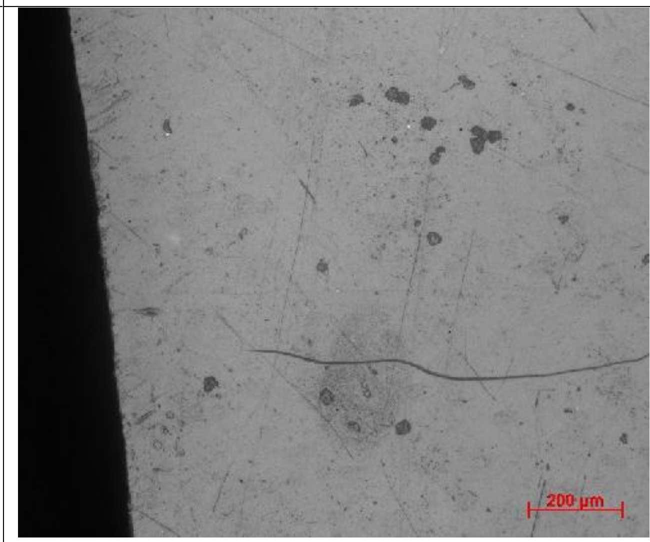
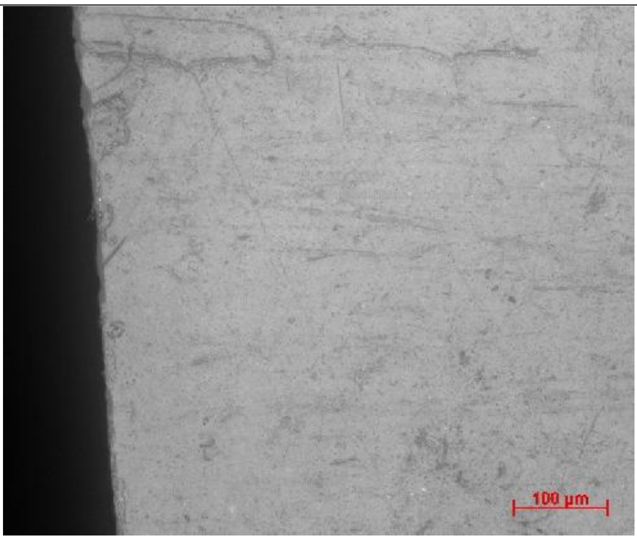
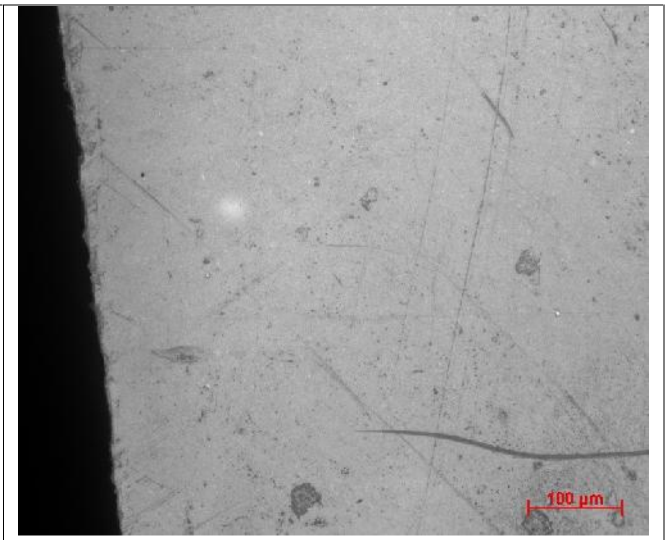
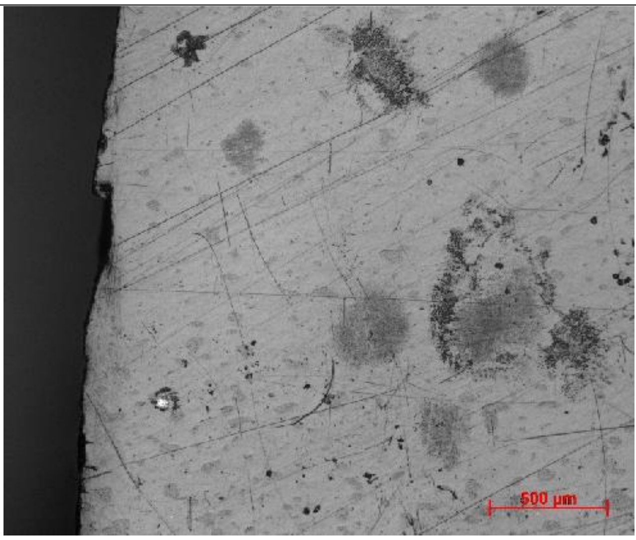
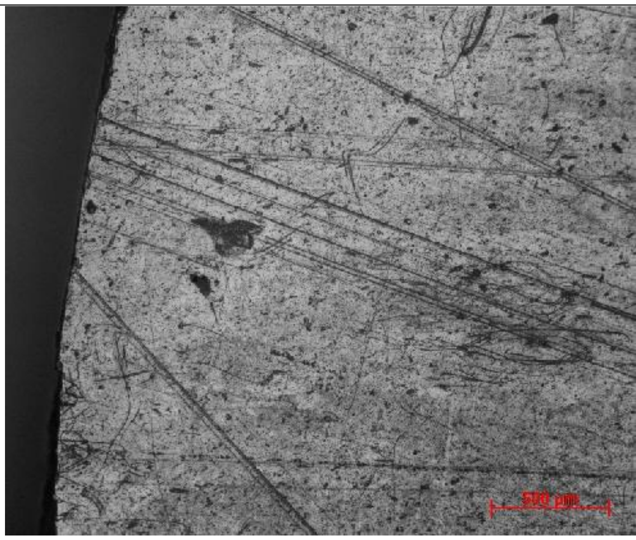
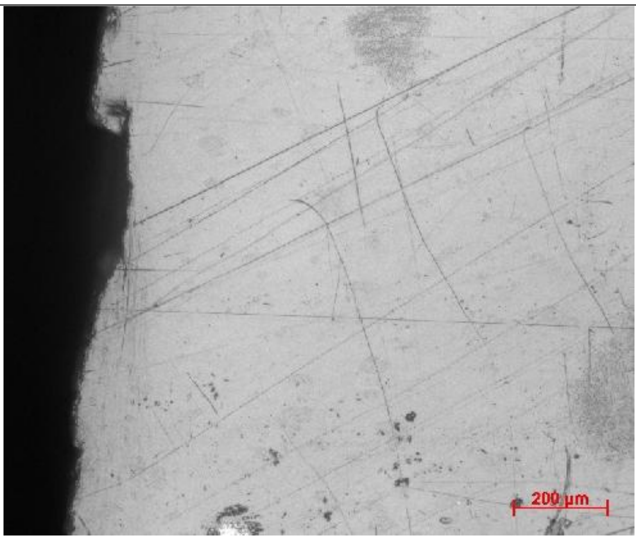
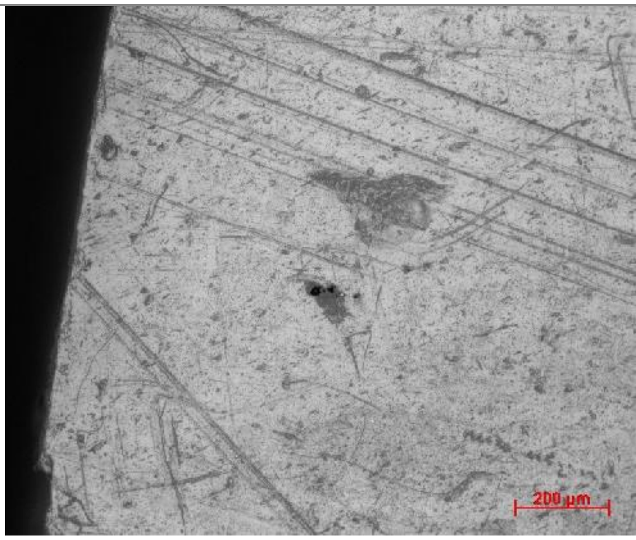


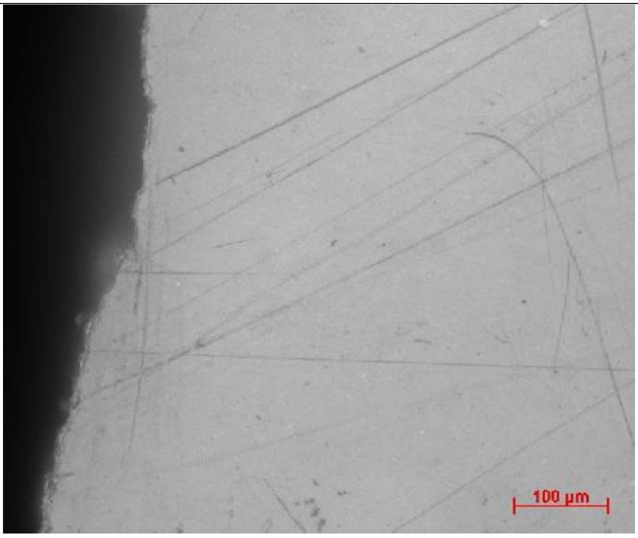
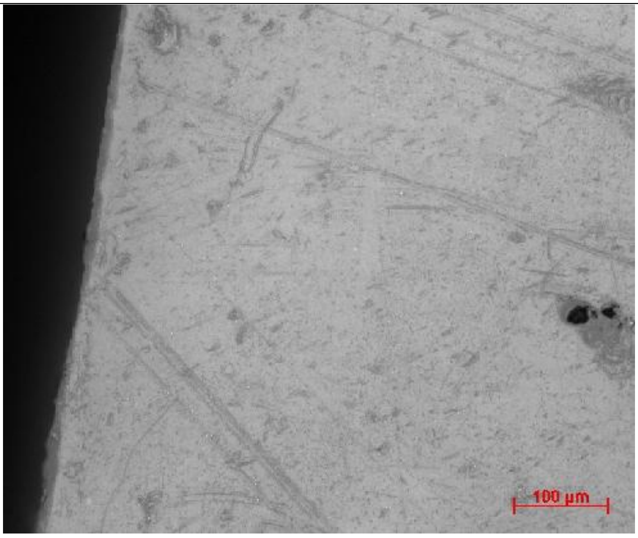
Polypropylene: 7 Cycles, 10× magnification



Polypropylene: 8 Cycles, 10× magnification

	
Polypropylene: 7 Cycles, 20× magnification	Polypropylene: 8 Cycles, 20× magnification

	
Polypropylene: 9 Cycles, 5× magnification	Polypropylene: 10 Cycles, 5× magnification
	
Polypropylene: 9 Cycles, 10× magnification	Polypropylene: 10 Cycles, 10× magnification

	
Polypropylene: 9 Cycles, 20× magnification	Polypropylene: 10 Cycles, 20× magnification

9.2 APPENDIX B – SURFACE DEFECT EXAMPLES

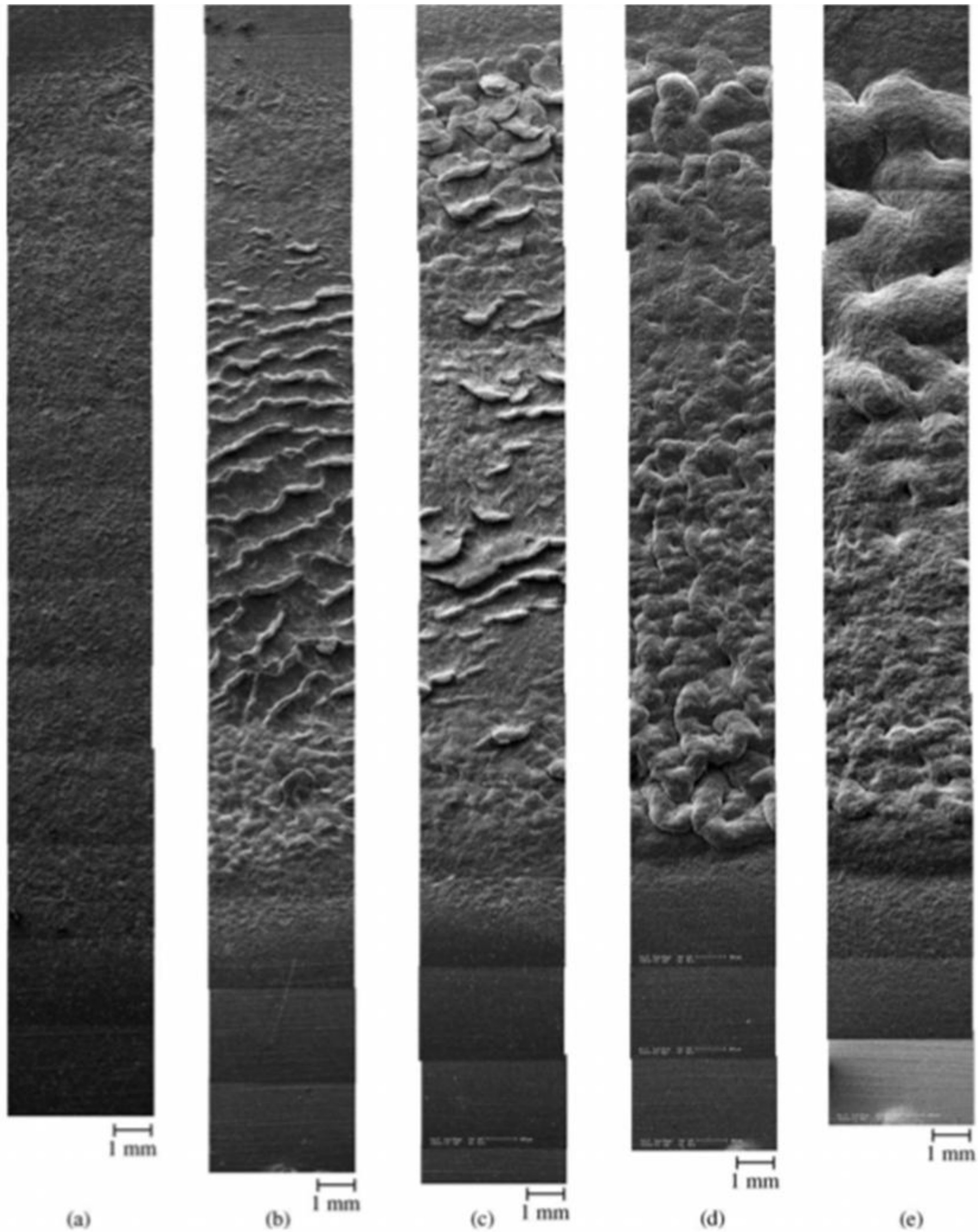


Figure B1. SEM composites of wear scares on polypropylene from Western et al (2005). Figures (b) and (c) provide examples of the precursor of potential flaking, as an indicator of possible failure.

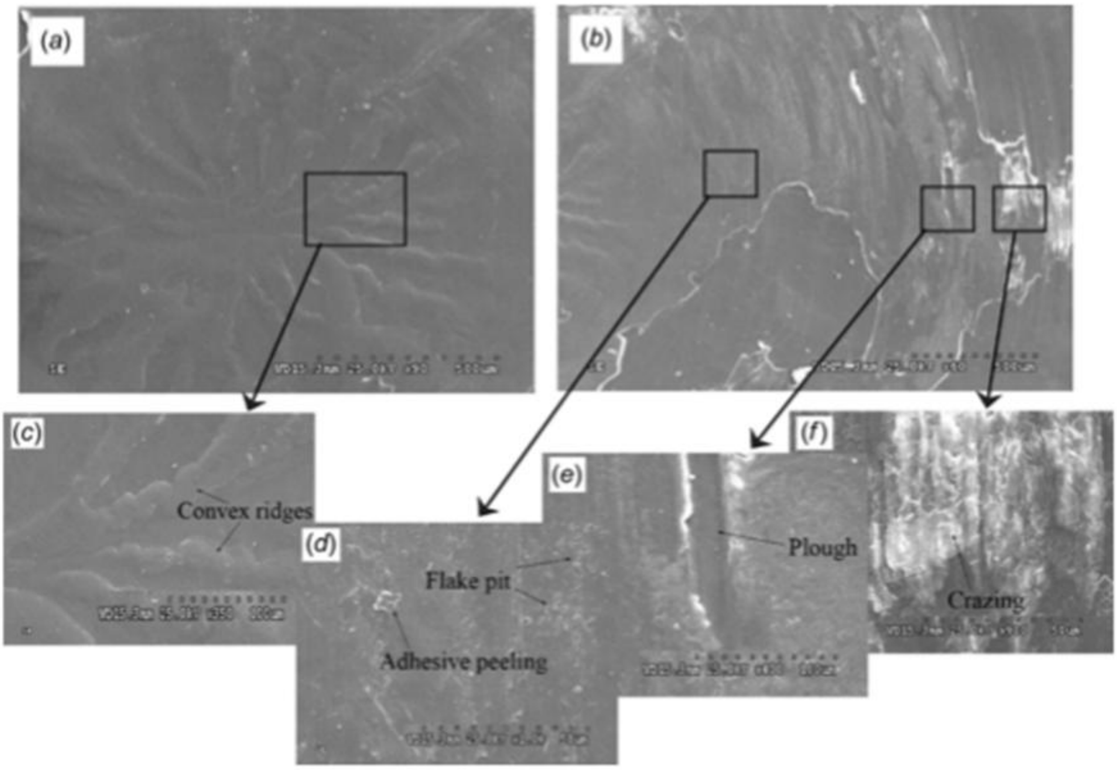


Figure B2. SEM morphologies of surface defects, including ridges (c), flaking/adhesive peeling (d), pitting/flake pit (d), pitting/plough (e) and crazing (f) (Liu *et al.,* 2019).

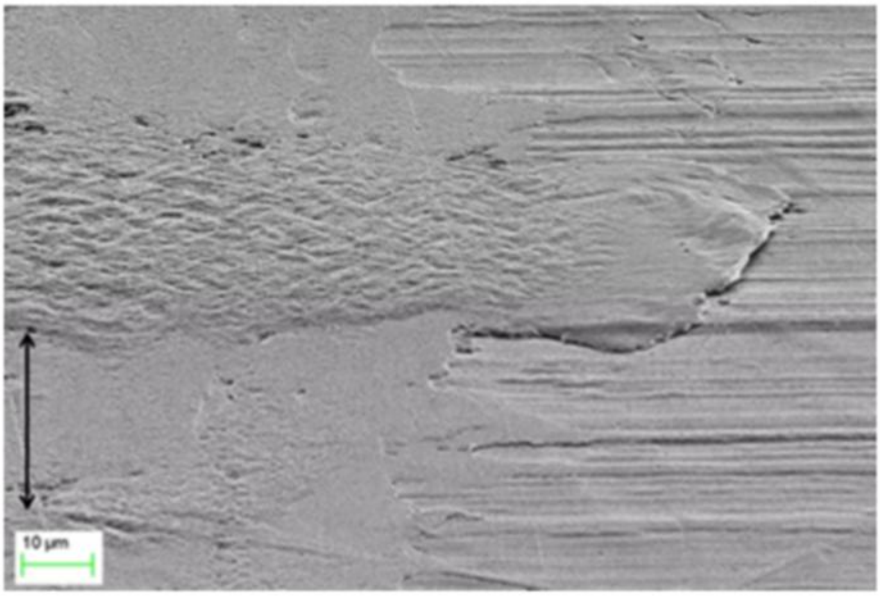


Figure B3. SEM of surface defects, including ploughing (left hand side of image) and flaking (right hand side of image) (Lind *et al.,* 2015).