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**University of Southampton**

Engineering Science unit  
Faculty of Engineering and the Environment

**Thesis supplement**

**Micro-scale Fluid Flows: The  
Application of Acoustic Streaming  
to Biomedical Research**

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Submitted for the degree of Doctor of Philosophy

July 2013

Supervised by Prof. Martyn Hill, Dr. Dyan Ankeret & Dr. Rosie Boltryk

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# 1. Percentage Range of Speed and Direction

## 1.1. Region 1

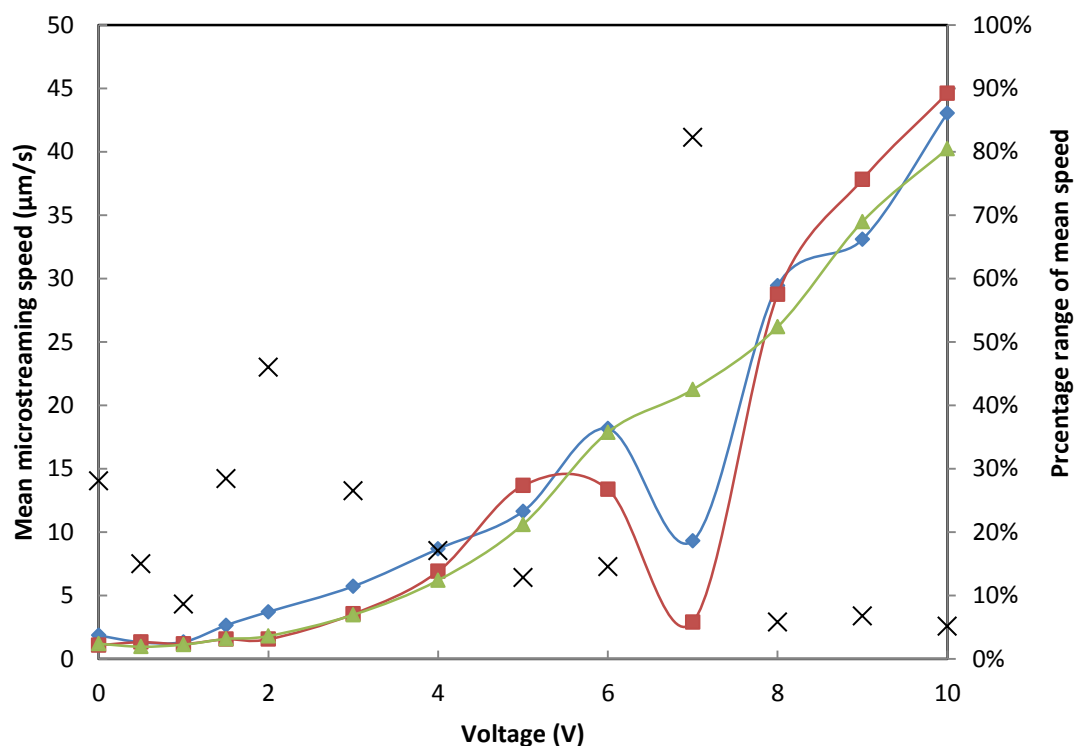


Figure 1.1: Voltage vs. mean microstreaming speed for the 3 repeats of region 1 (blue, red and green respectively) and their percentage range of mean speed (X).

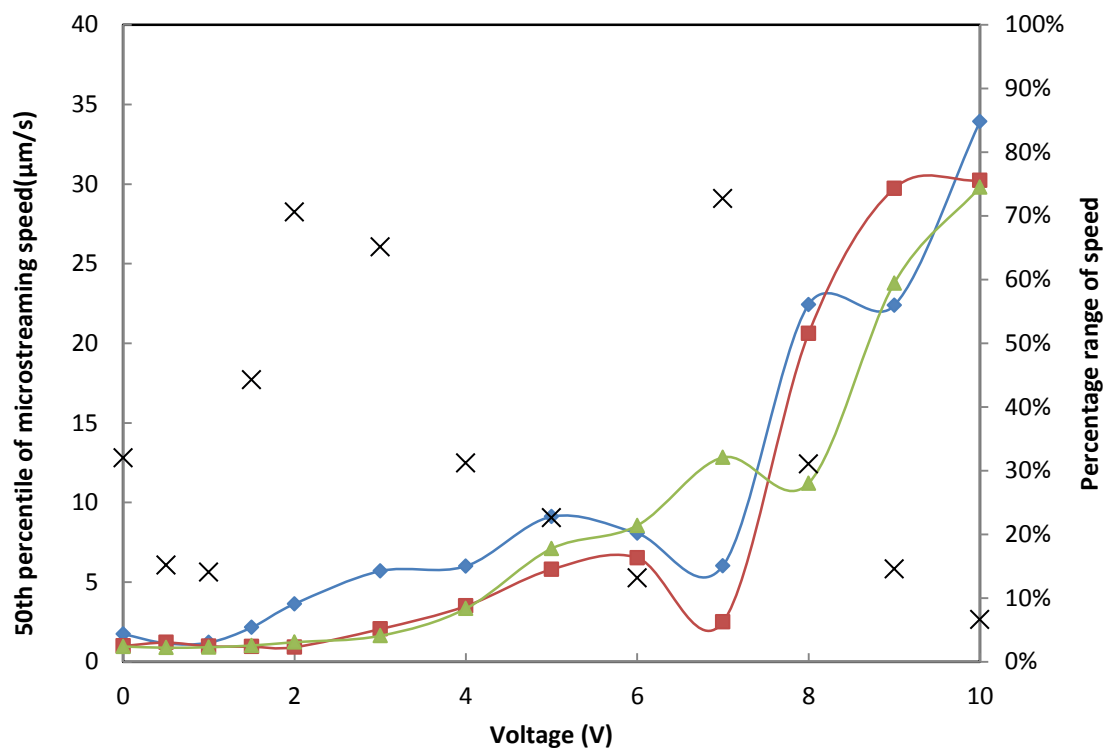


Figure 1.2: Voltage vs. 50<sup>th</sup> percentile of microstreaming speed for the 3 repeats of region 1 (blue, red and green respectively) and their percentage range of speed (X).



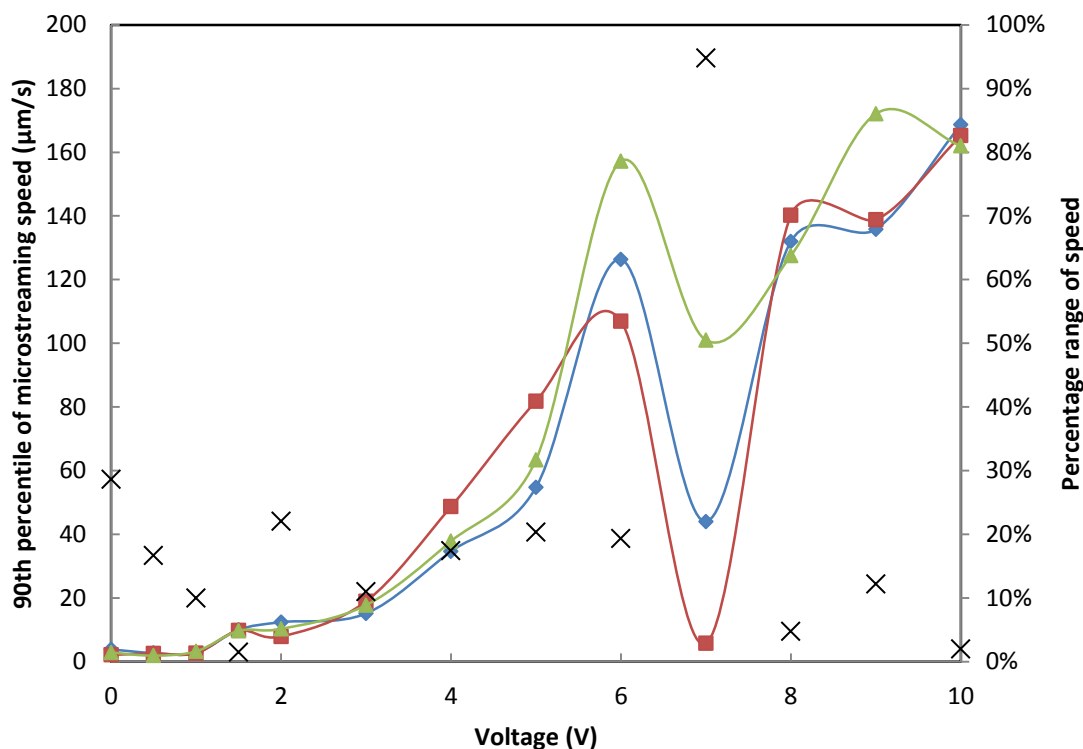


Figure 1.3: Voltage vs. 90<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region (blue, red and green respectively) and their percentage range of speed (X).

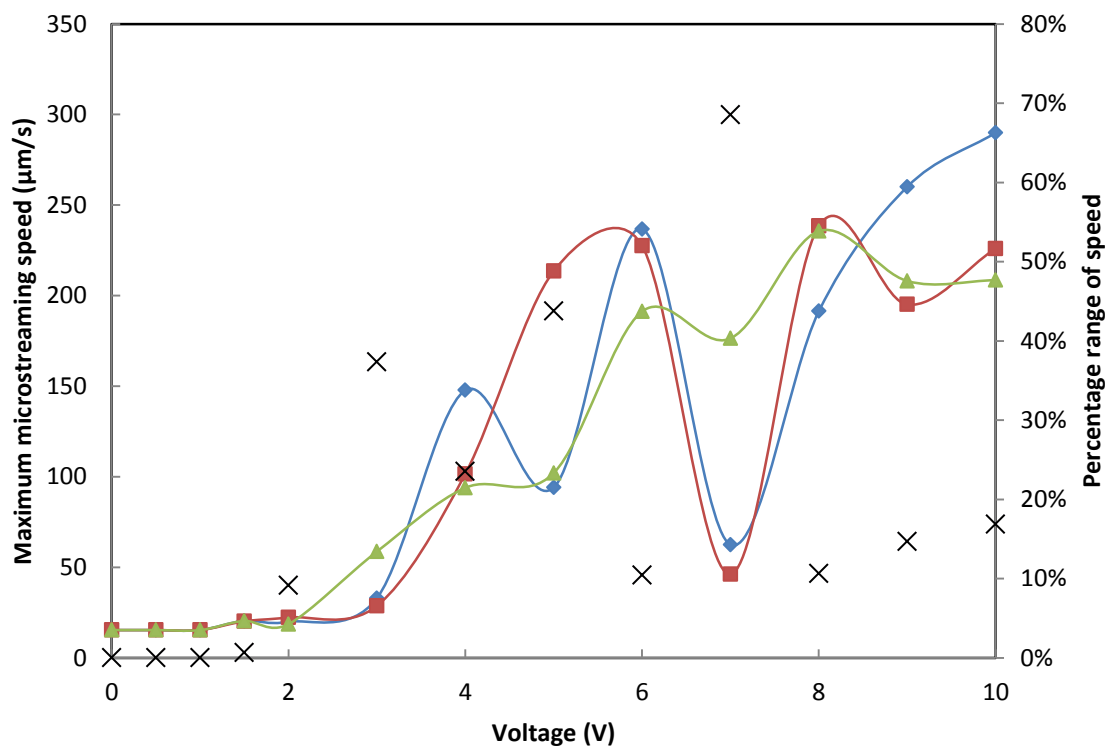


Figure 1.4: Voltage vs. maximum microstreaming speed for the 3 repeats of region 1 (blue, red and green respectively) and their percentage range of speed (X).

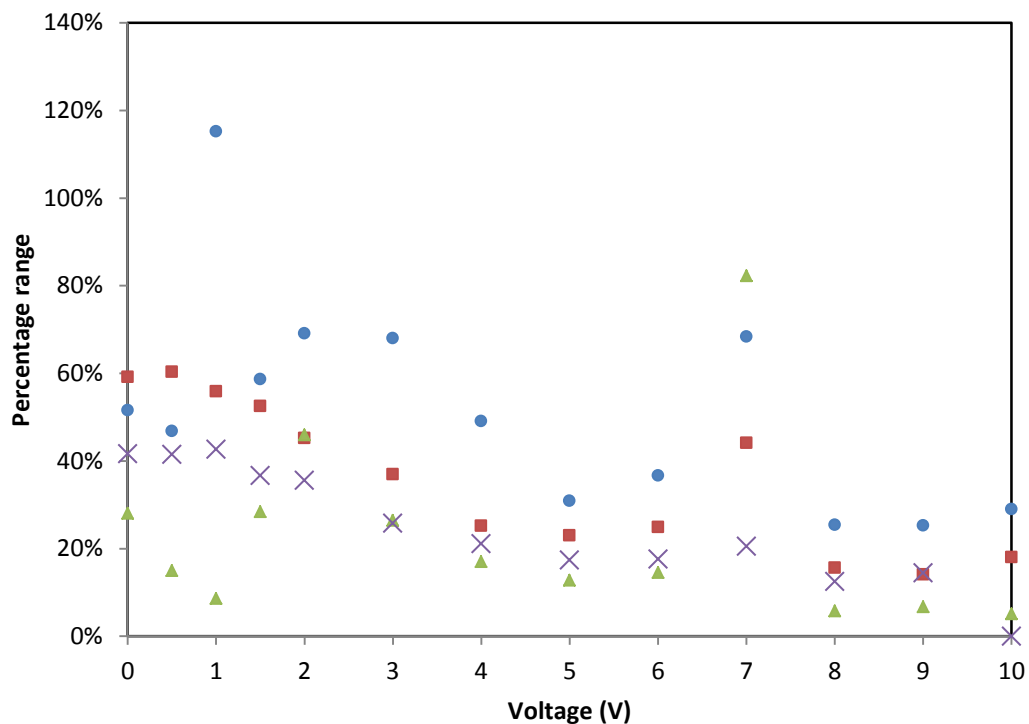


Figure 1.5: The percentage range of mean speed (triangles), pointwise percentage range of speed (circles), pointwise percentage range of direction (squares) and pointwise angular deviation (X) for region 1.

## 1.2. Region 2

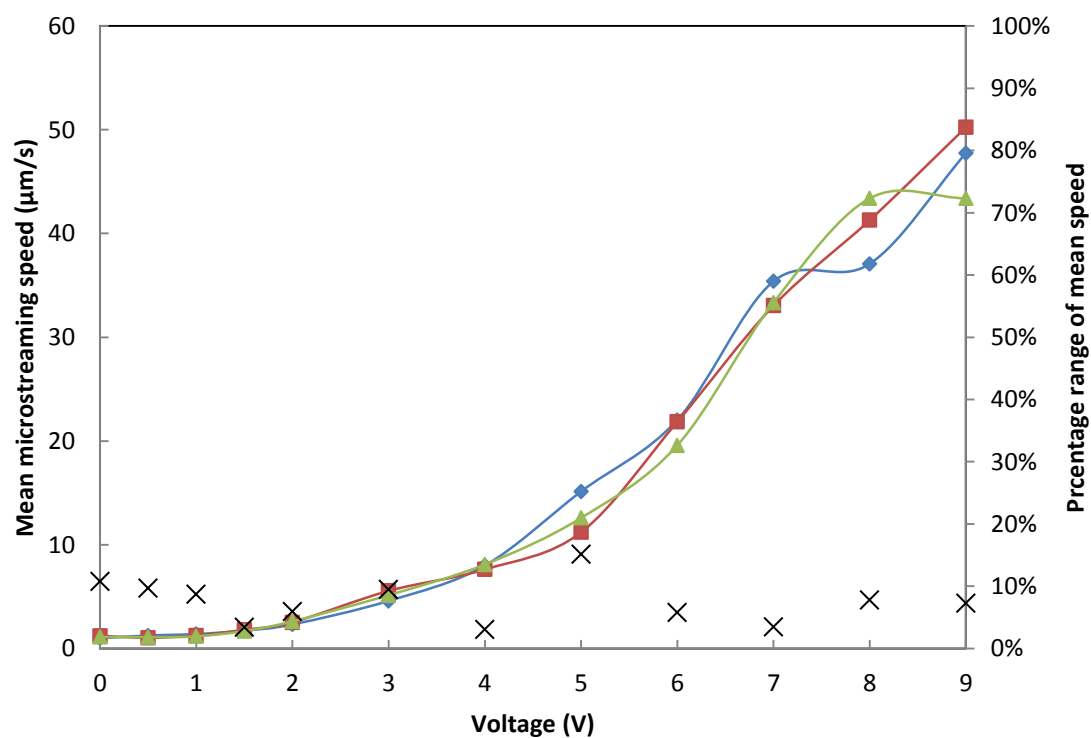


Figure 1.6: Voltage vs. mean microstreaming speed for the 3 repeats of region 2 (blue, red and green respectively) and their percentage range of mean speed (X).

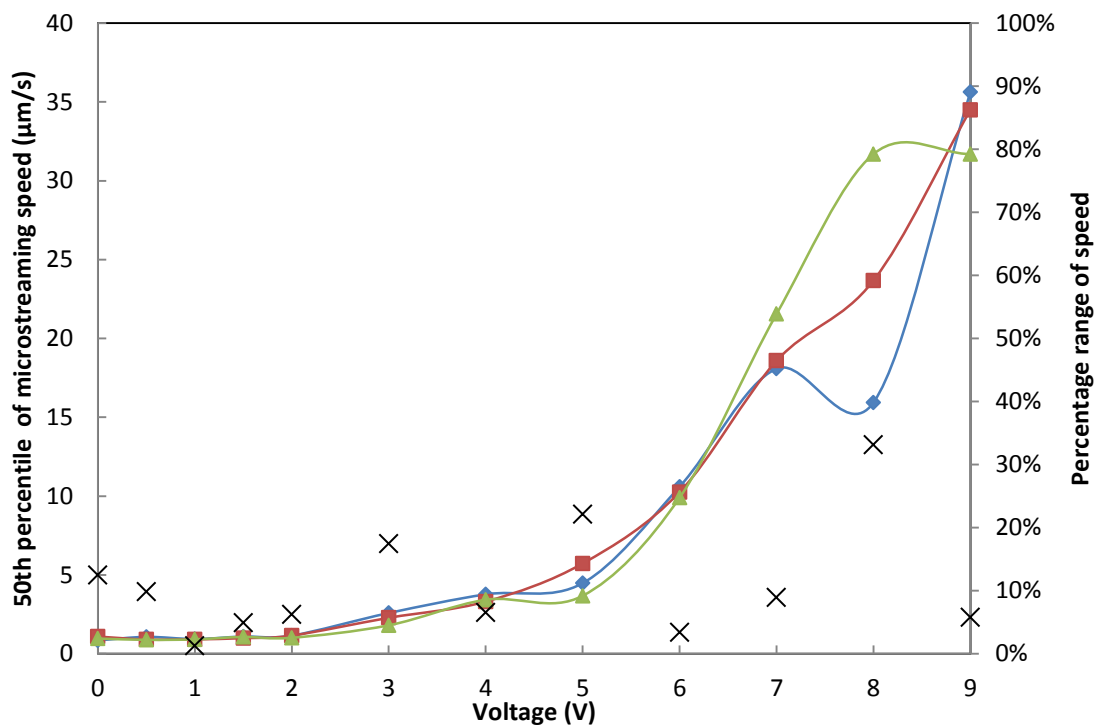


Figure 1.7: Voltage vs. 50<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 2 (blue, red and green respectively) and their percentage range of speed (X).

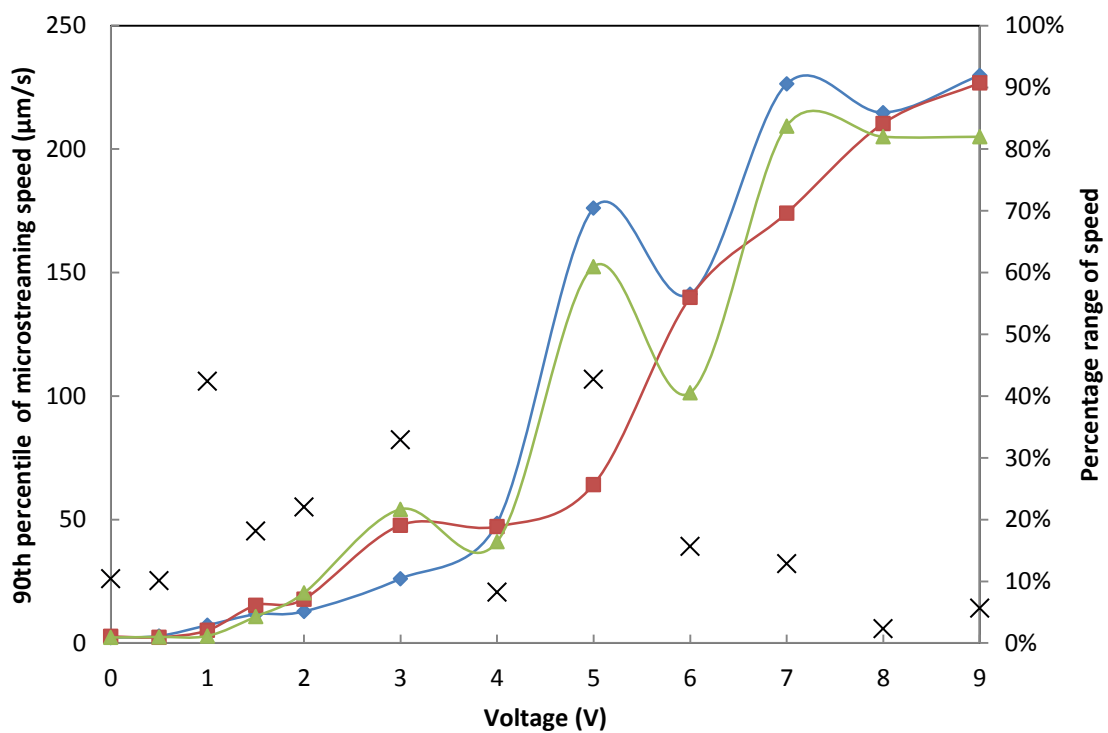


Figure 1.8: Voltage vs. 90<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 2 (blue, red and green respectively) and their percentage range of speed (X).

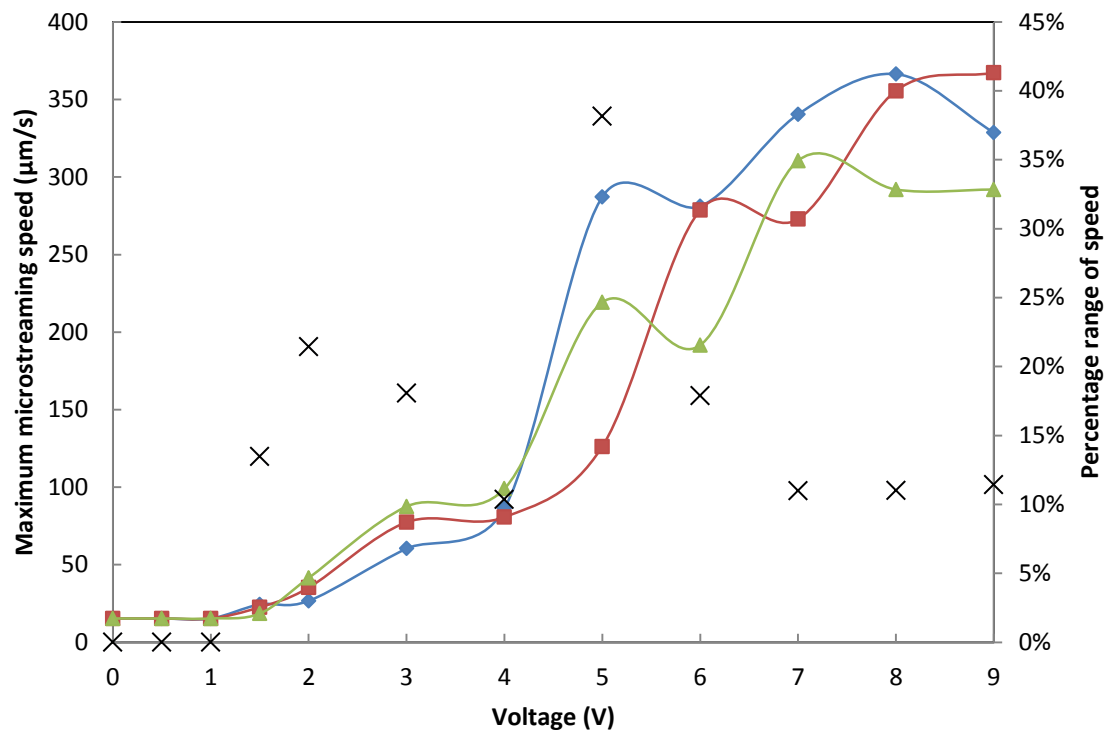


Figure 1.9: Voltage vs. maximum microstreaming speed for the 3 repeats of region 2 (blue, red and green respectively) and their percentage range of speed (X).

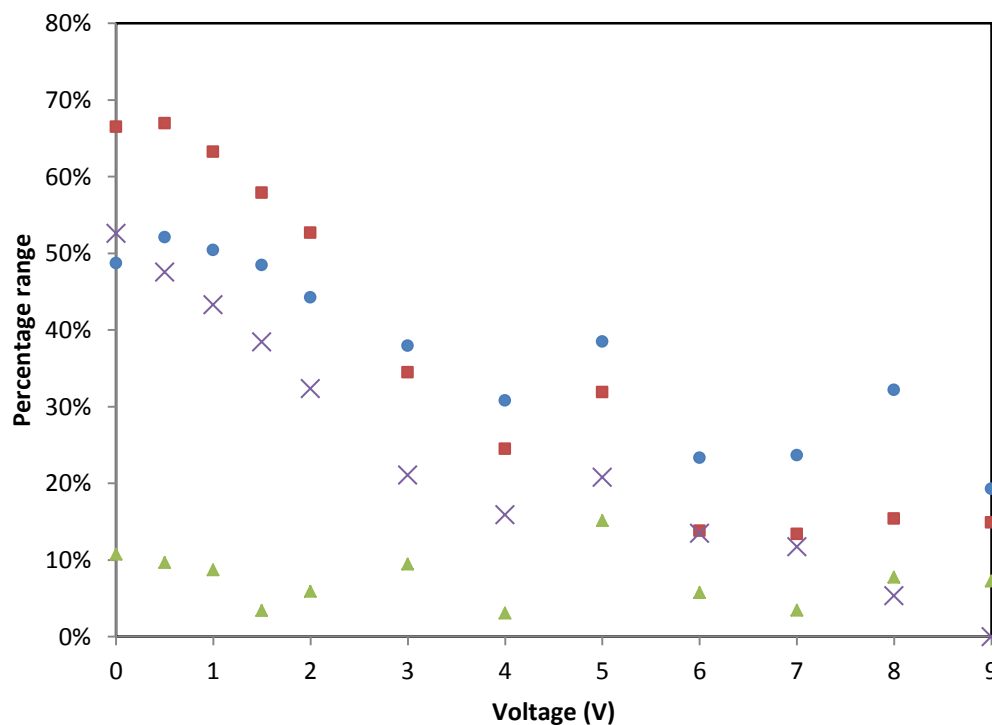


Figure 1.10: The percentage range of mean speed (triangles), pointwise percentage range of speed (circles), pointwise percentage range of direction (squares) and pointwise angular deviation (X) for region 2.

### 1.3. Region 3

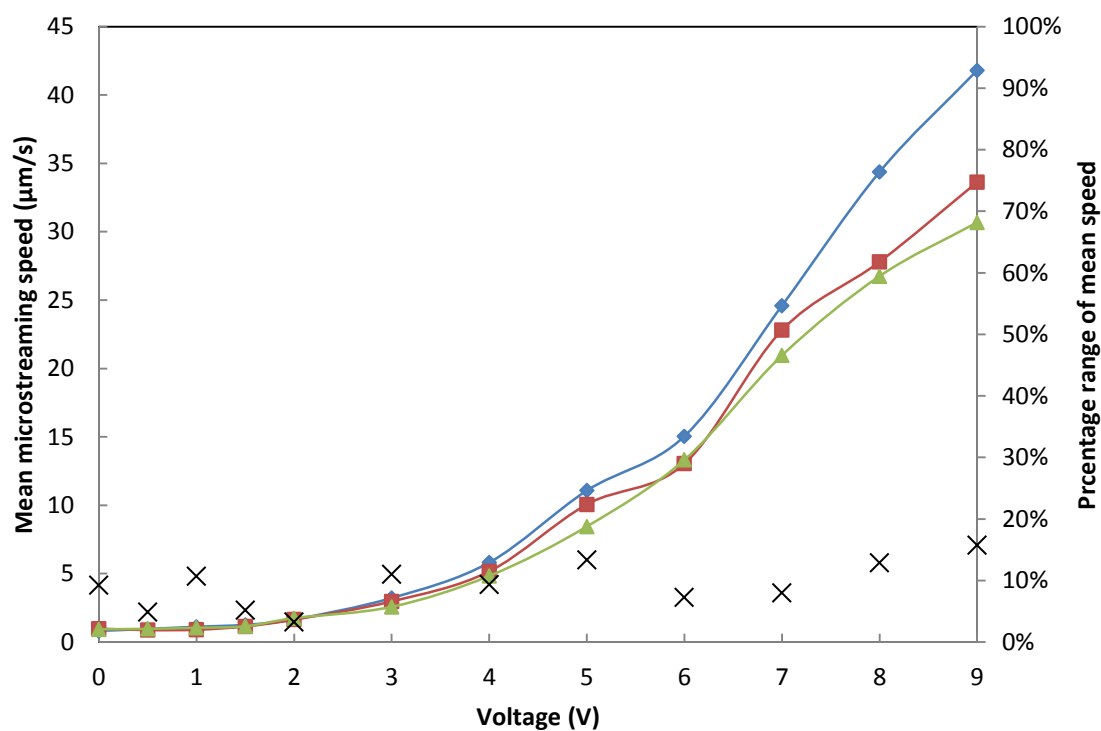


Figure 1.11: Voltage vs. mean microstreaming speed for the 3 repeats of region 3 (blue, red and green respectively) and their percentage range of mean speed (X).

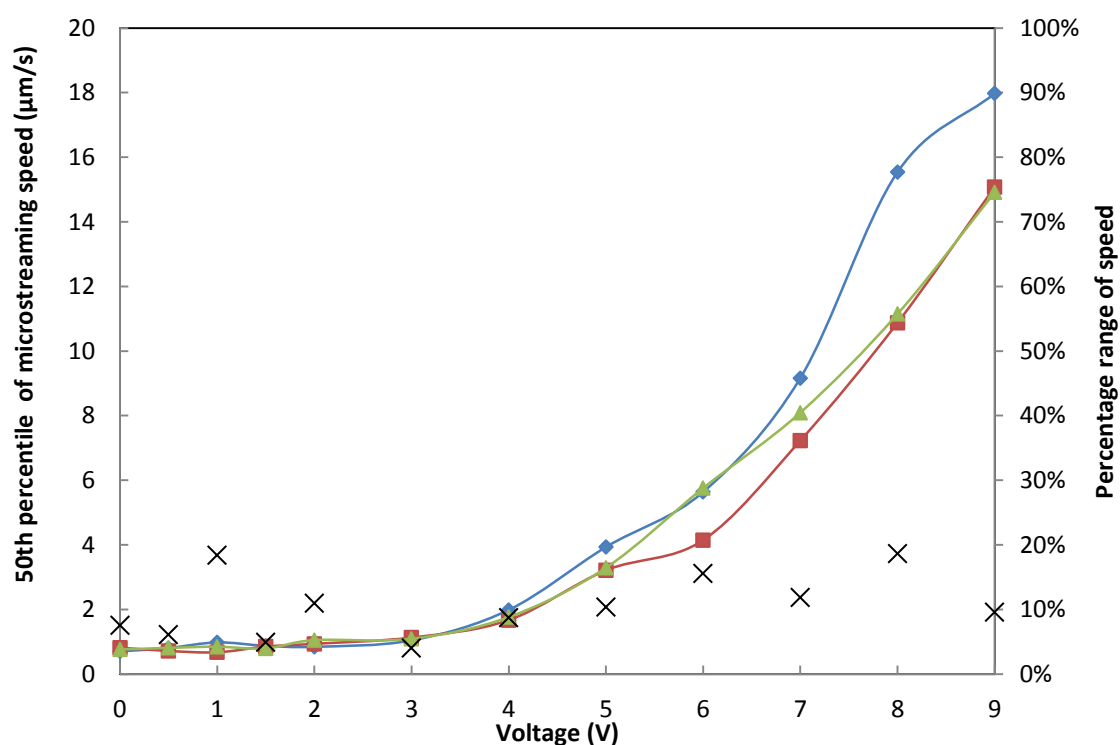


Figure 1.12: Voltage vs. 50<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 3 (blue, red and green respectively) and their percentage range of speed (X).

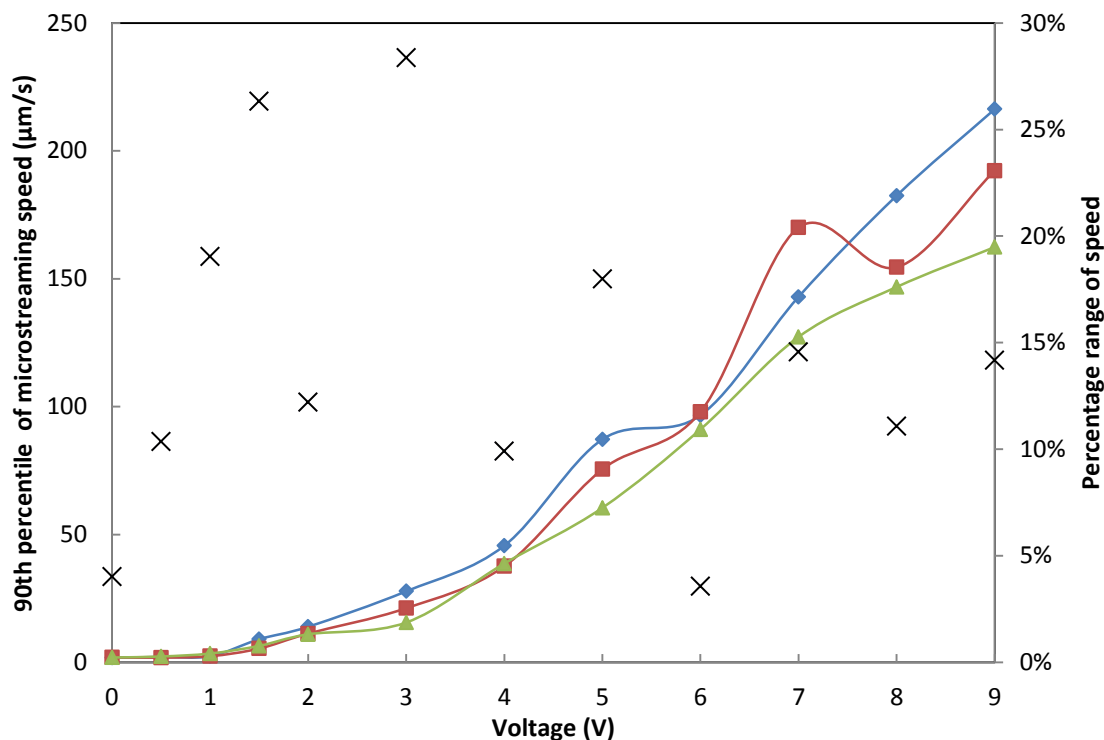


Figure 1.13: Voltage vs. 90<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 3 (blue, red and green respectively) and their percentage range of speed (X).

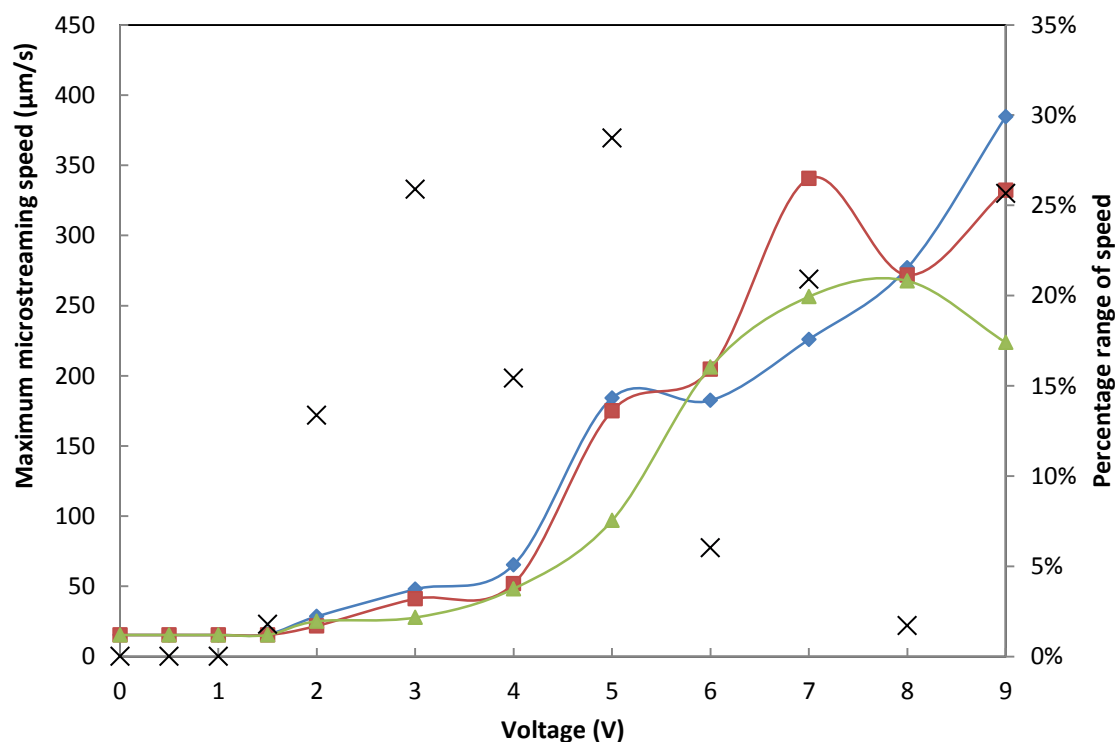


Figure 1.14: Voltage vs. maximum microstreaming speed for the 3 repeats of region 3 (blue, red and green respectively) and their percentage range of speed (X).

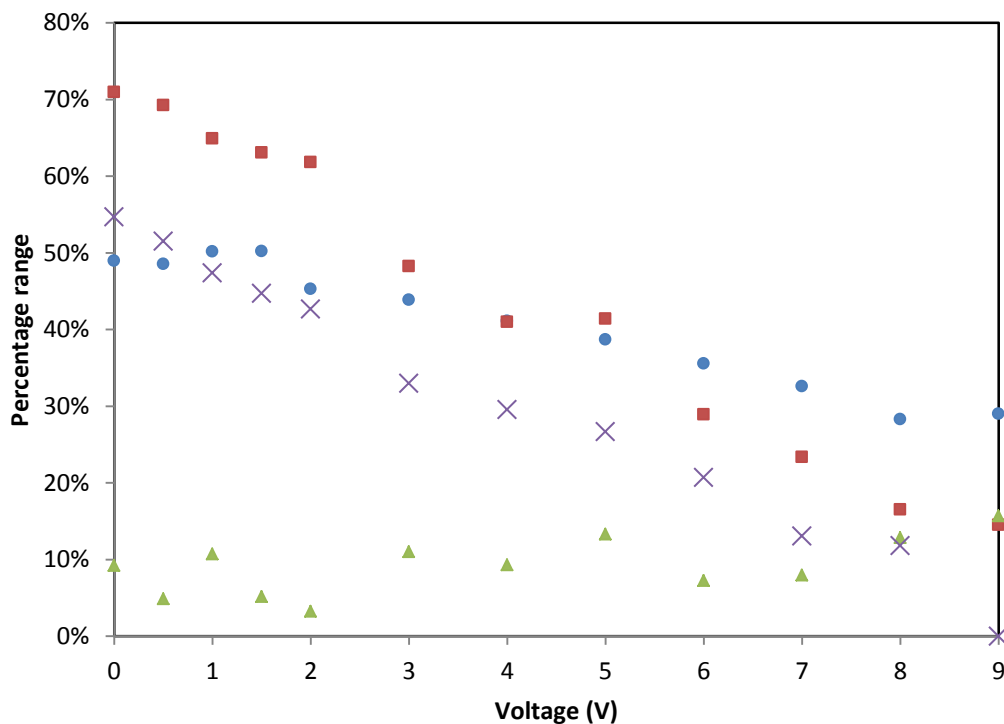


Figure 1.15: The percentage range of mean speed (triangles), pointwise percentage range of speed (circles), pointwise percentage range of direction (squares) and pointwise angular deviation (X) for region 3.

#### 1.4. Region 4

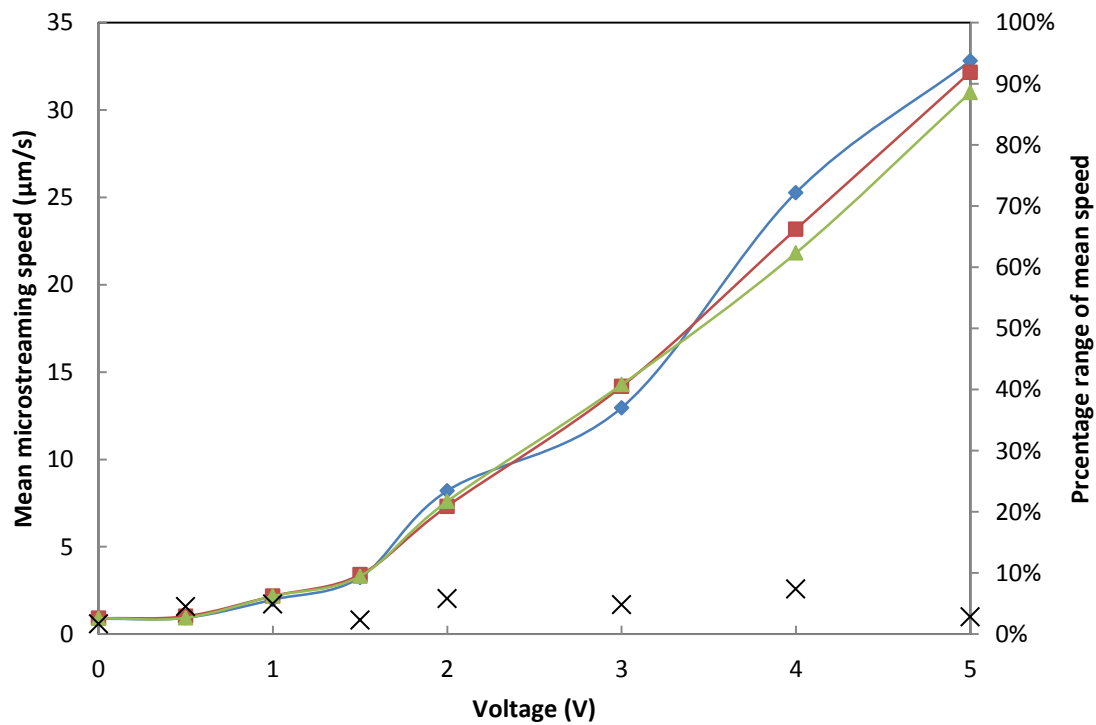


Figure 1.16: Voltage vs. mean microstreaming speed for the 3 repeats of region 4 (blue, red and green respectively) and their percentage range of mean speed (X).

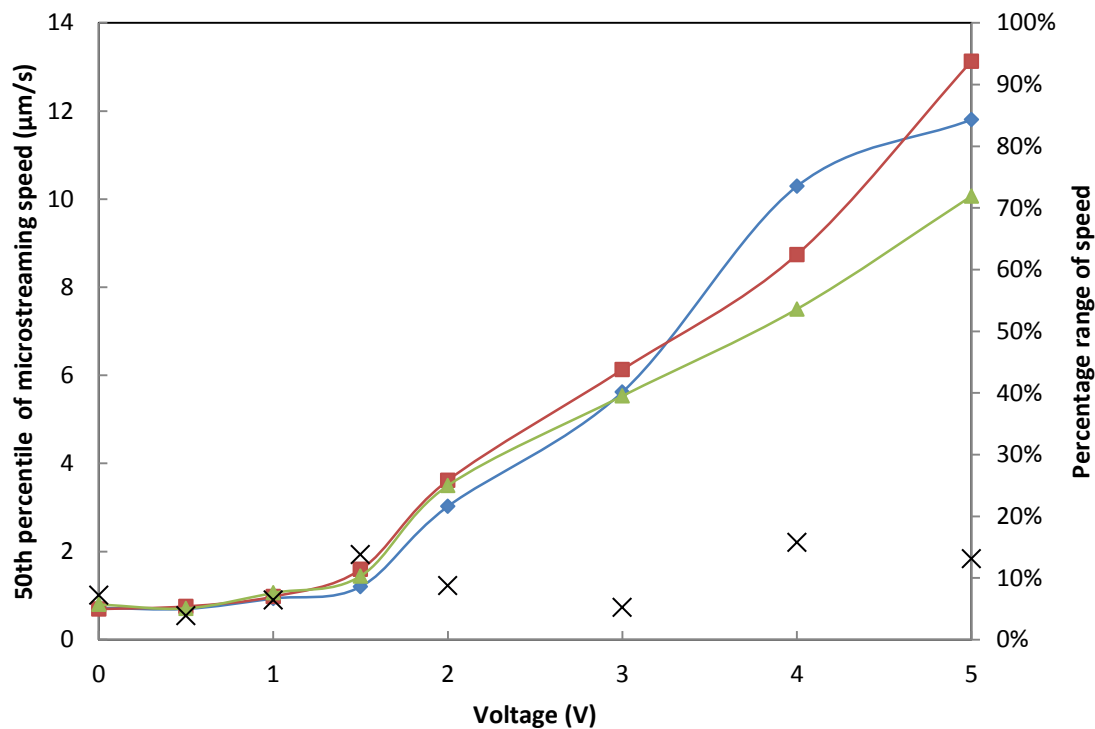


Figure 1.17: Voltage vs. 50<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 4 (blue, red and green respectively) and their percentage range of speed (X).

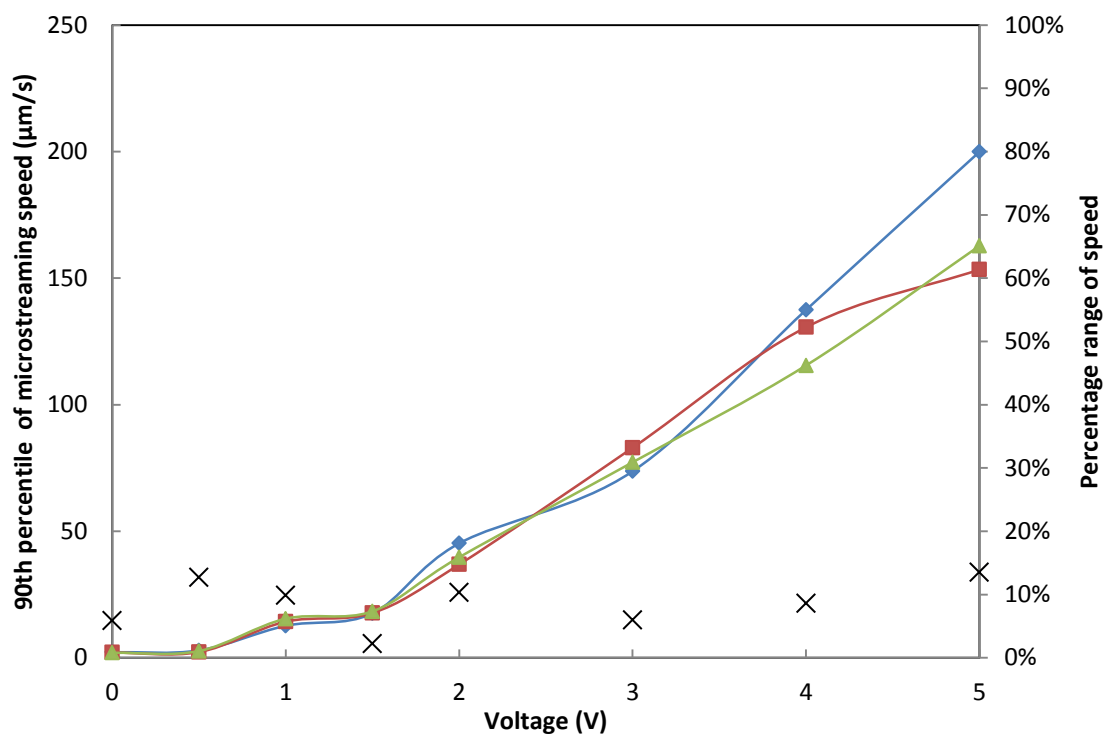


Figure 1.18: Voltage vs. 90<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 4 (blue, red and green respectively) and their percentage range of speed (X).



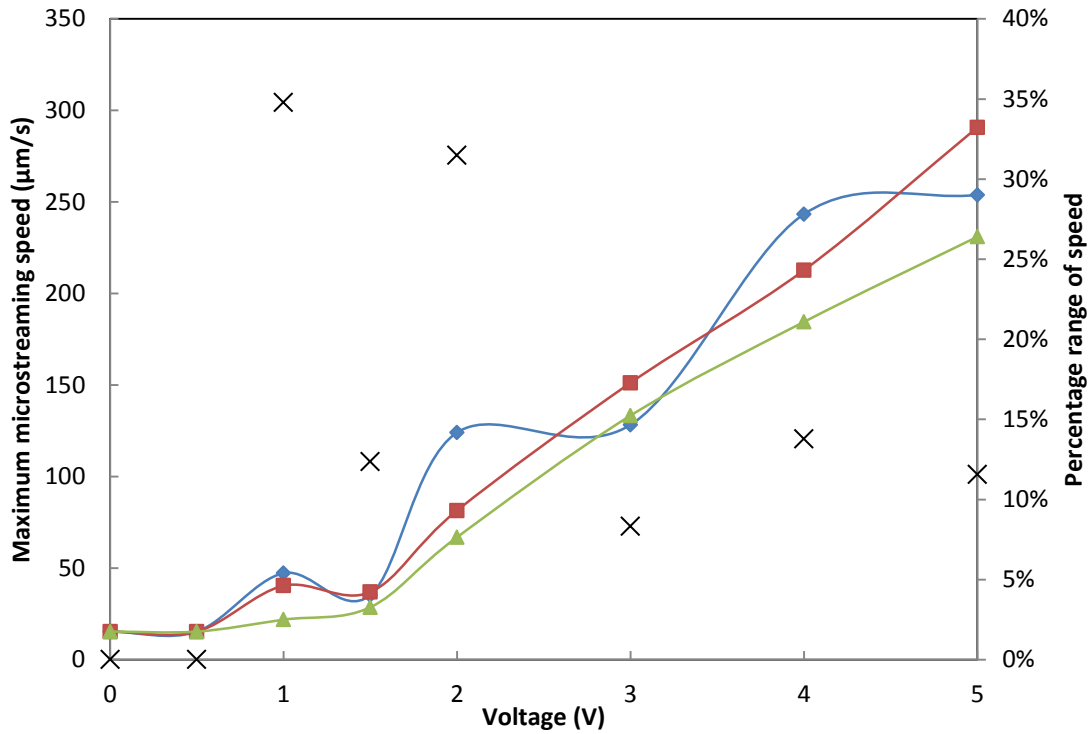


Figure 1.19: Voltage vs. maximum microstreaming speed for the 3 repeats of region 4 (blue, red and green respectively) and their percentage range of speed (X).

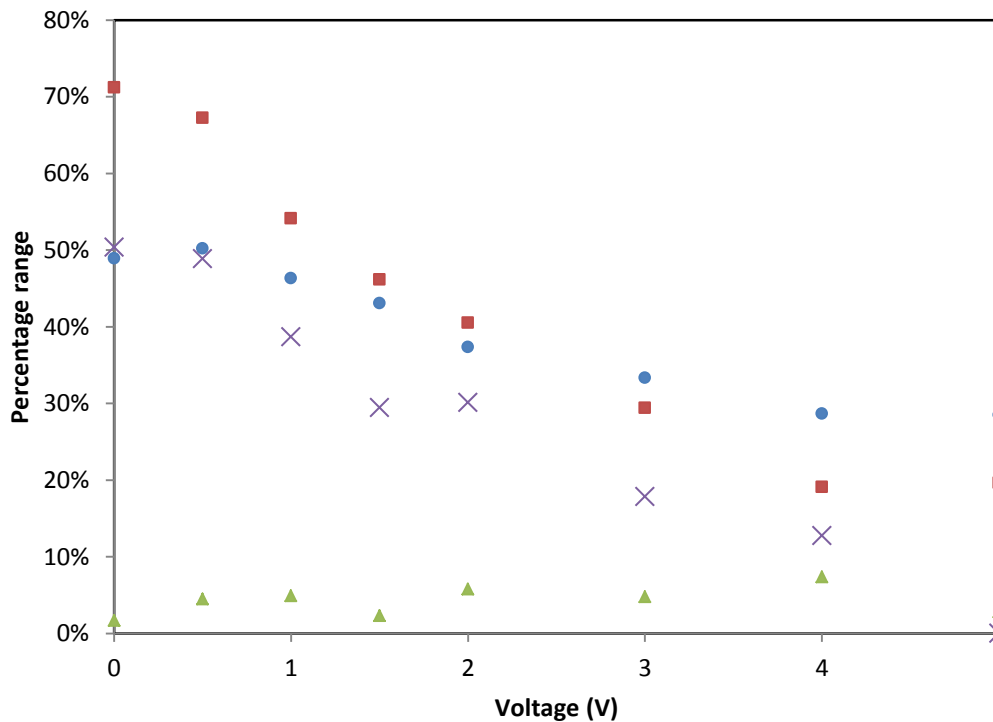


Figure 1.20: The percentage range of mean speed (triangles), pointwise percentage range of speed (circles), pointwise percentage range of direction (squares) and pointwise angular deviation (X) for region 4.

## 1.5. Region 5

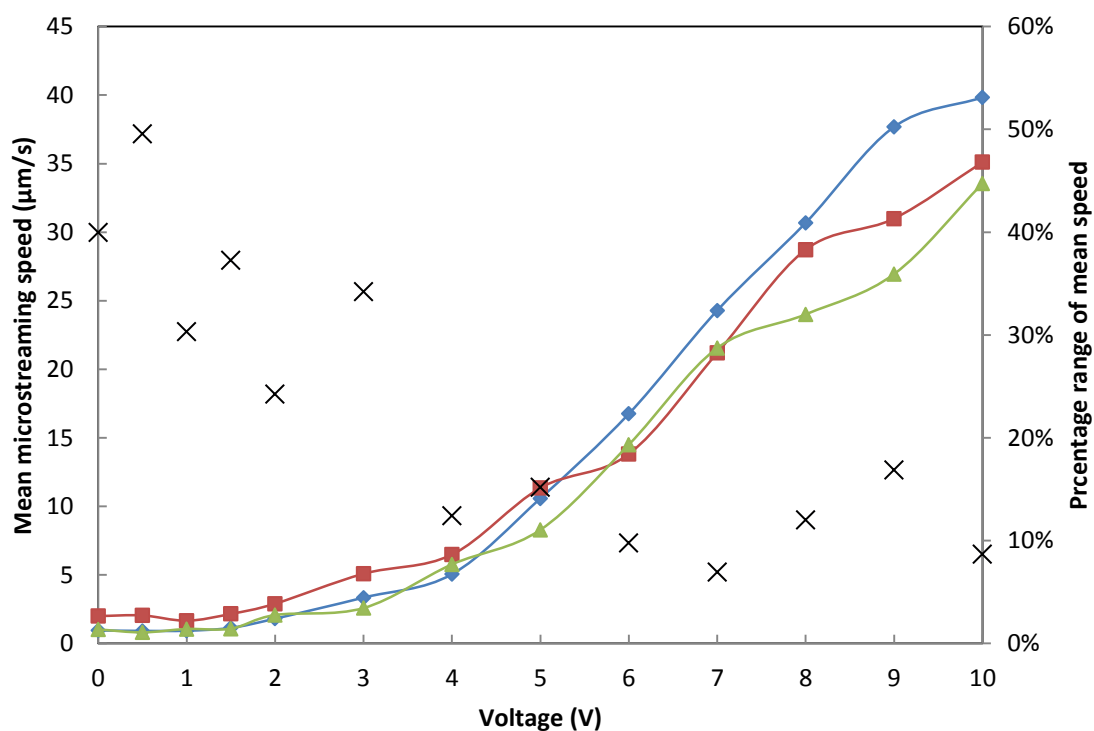


Figure 1.21: Voltage vs. mean microstreaming speed for the 3 repeats of region 5 (blue, red and green respectively) and their percentage range of mean speed (X).

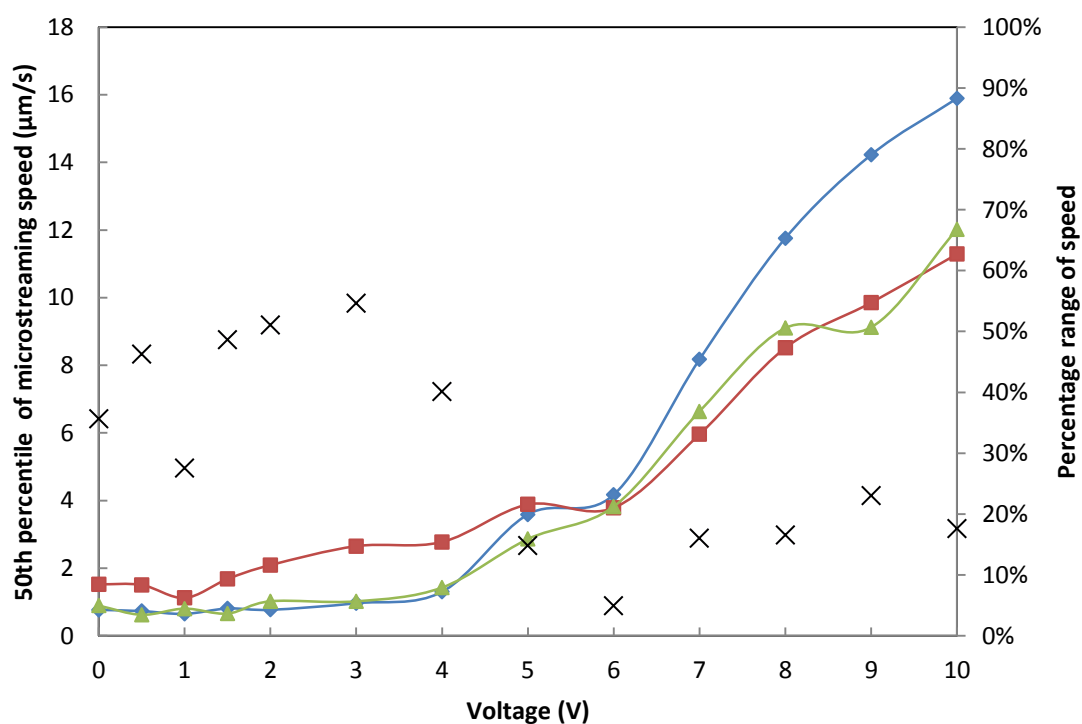


Figure 1.22: Voltage vs. 50<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 5 (blue, red and green respectively) and their percentage range of speed (X).

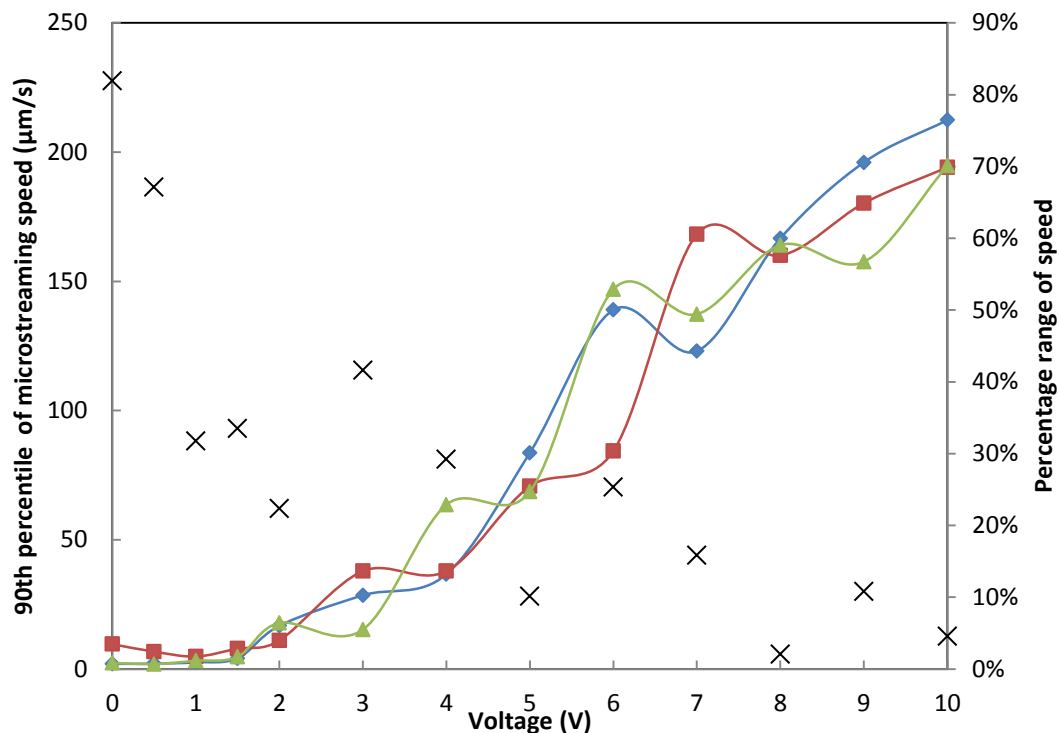


Figure 1.23: Voltage vs. 90<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 5 (blue, red and green respectively) and their percentage range of speed (X).

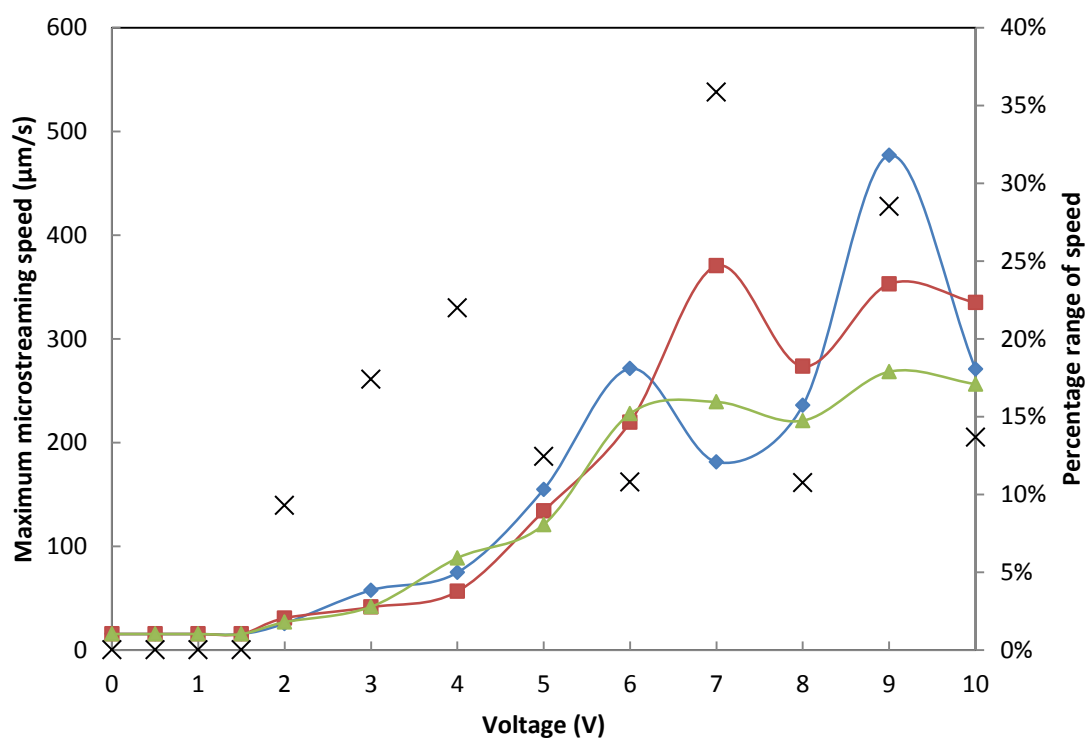


Figure 1.24: Voltage vs. maximum microstreaming speed for the 3 repeats of region 5 (blue, red and green respectively) and their percentage range of speed (X).

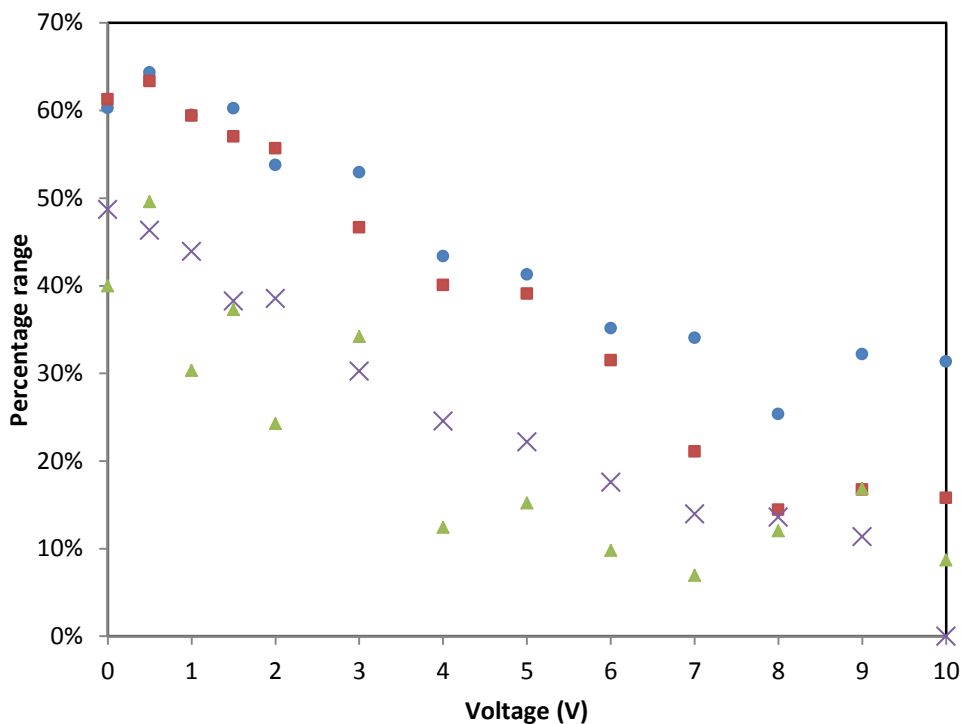


Figure 1.25: The percentage range of mean speed (triangles), pointwise percentage range of speed (circles), pointwise percentage range of direction (squares) and pointwise angular deviation (X) for region 5.

## 1.6. Region 6

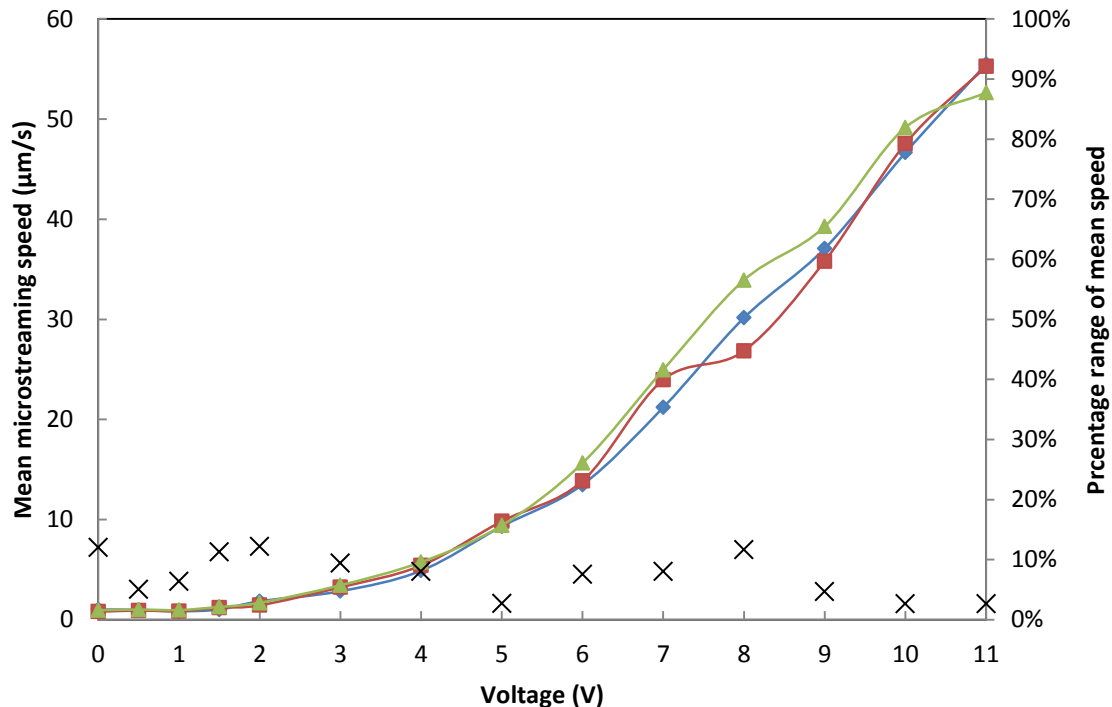


Figure 1.26: Voltage vs. mean microstreaming speed for the 3 repeats for region 6 (blue, red and green respectively) and their percentage range of mean speed (X).

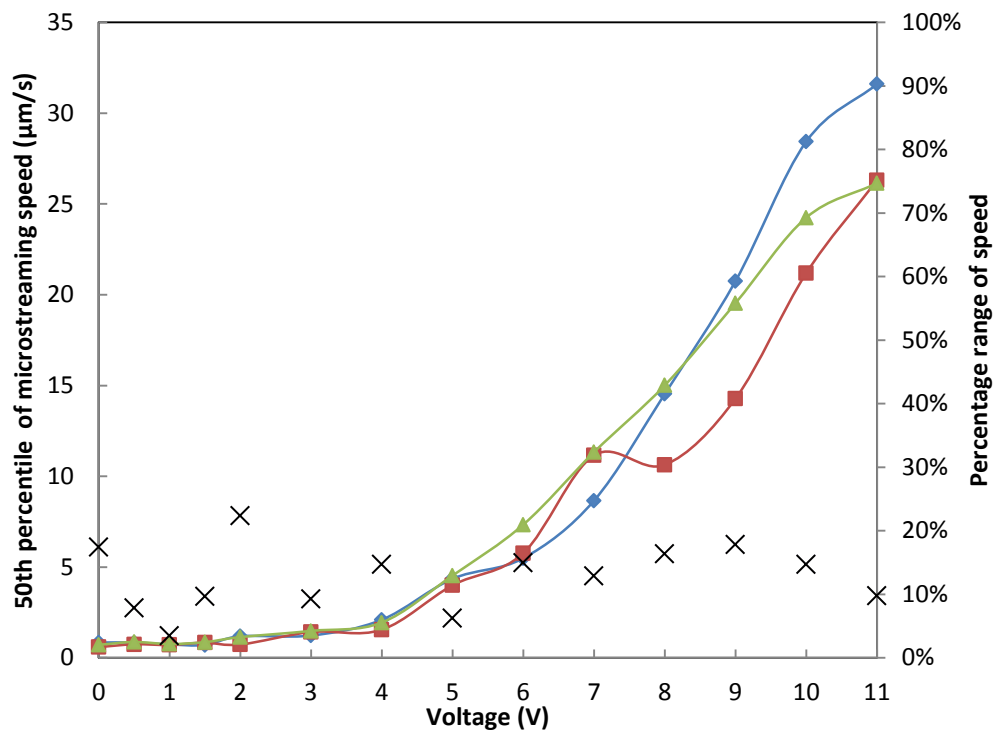


Figure 1.27: Voltage vs. 50<sup>th</sup> percentile of the microstreaming speed for the 3 repeats for region 6 (blue, red and green respectively) and their percentage range of speed (X).

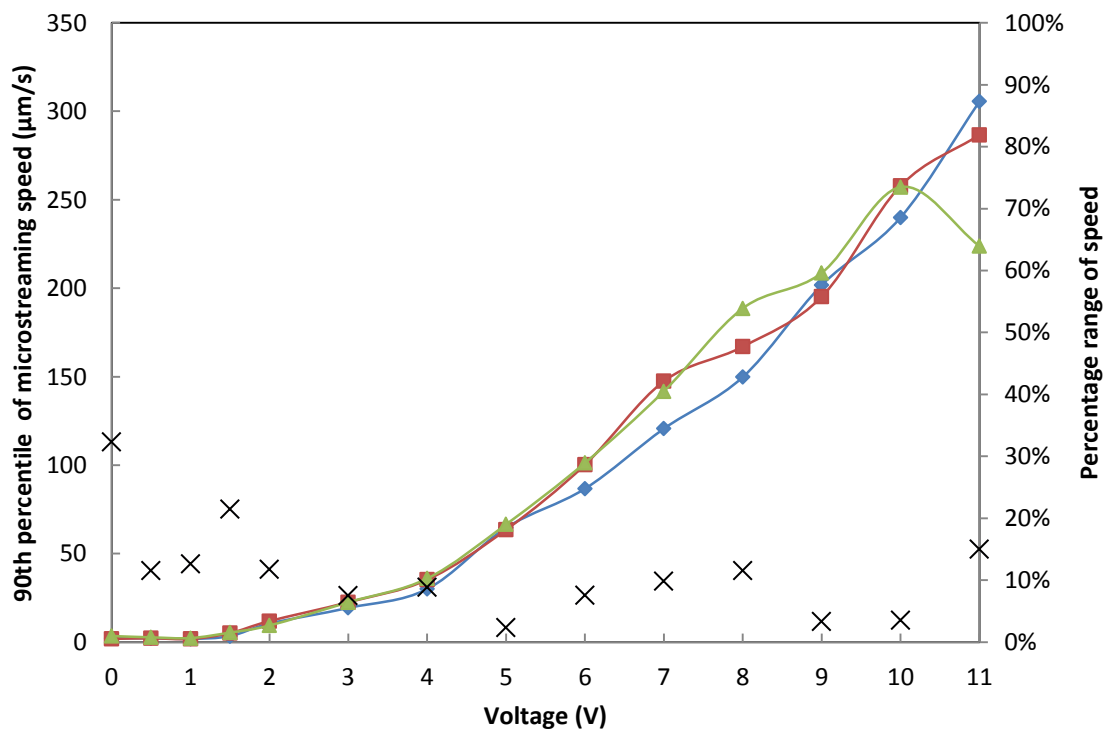


Figure 1.28: Voltage vs. 90<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 6 (blue, red and green respectively) and their percentage range of speed (X).

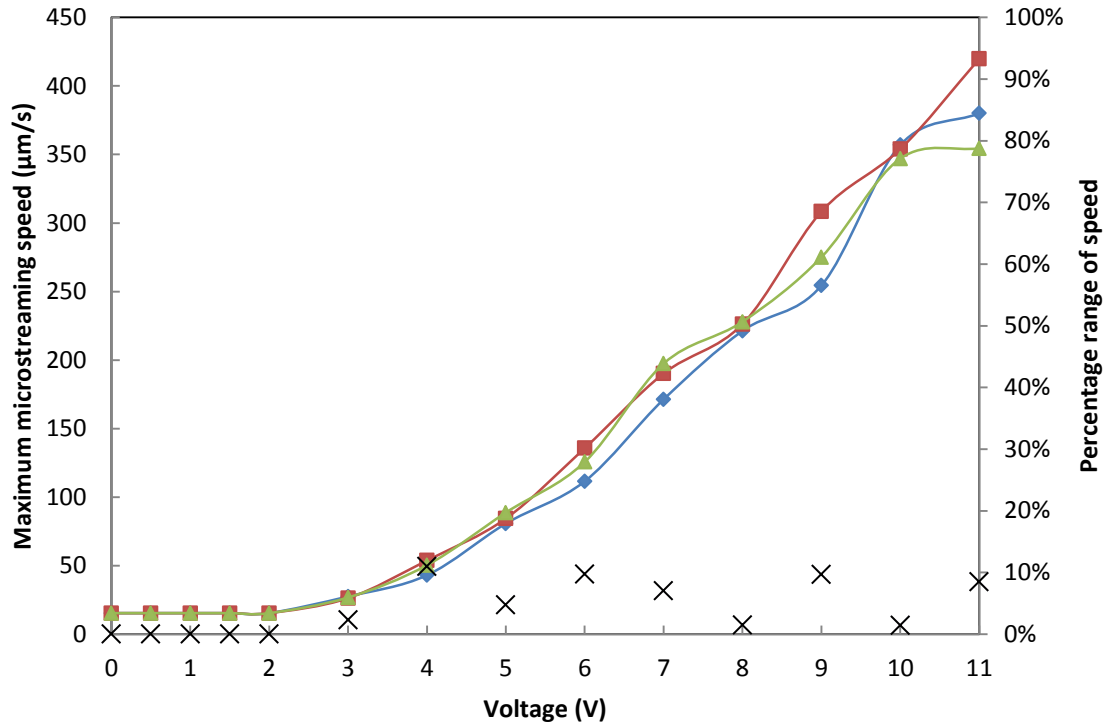


Figure 1.29: Voltage vs. maximum microstreaming speed for the 3 repeats of region 6 (blue, red and green respectively) and their percentage range of speed (X).

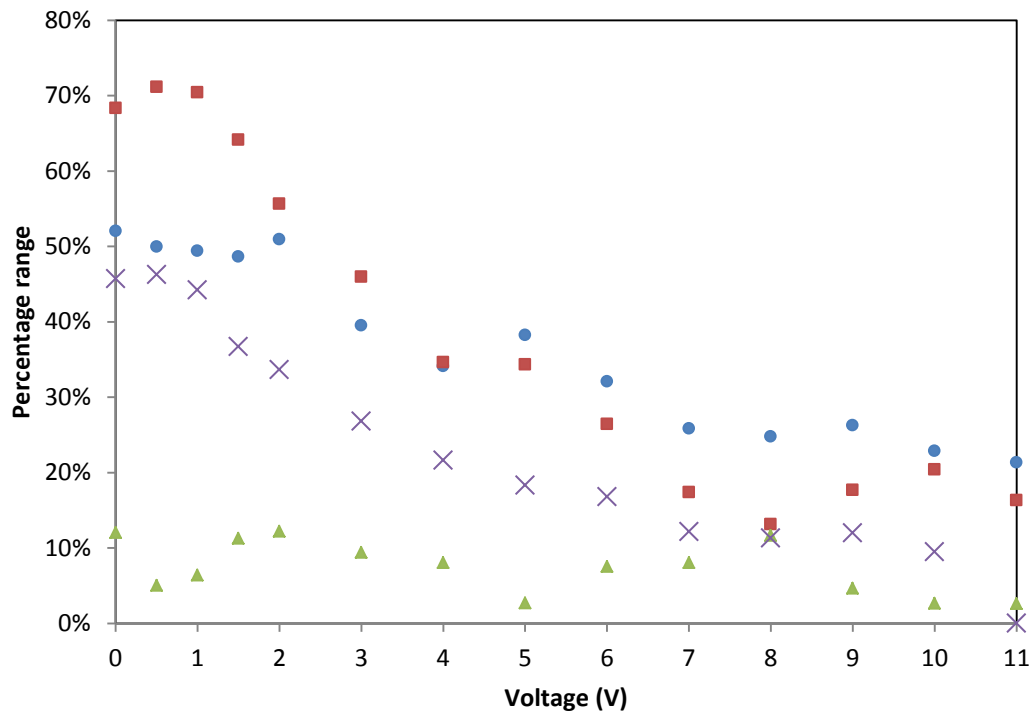


Figure 1.30: The percentage range of mean speed (triangles), pointwise percentage range of speed (circles), pointwise percentage range of direction (squares) and pointwise angular deviation (X) for region 6.

## 1.7. Region 7

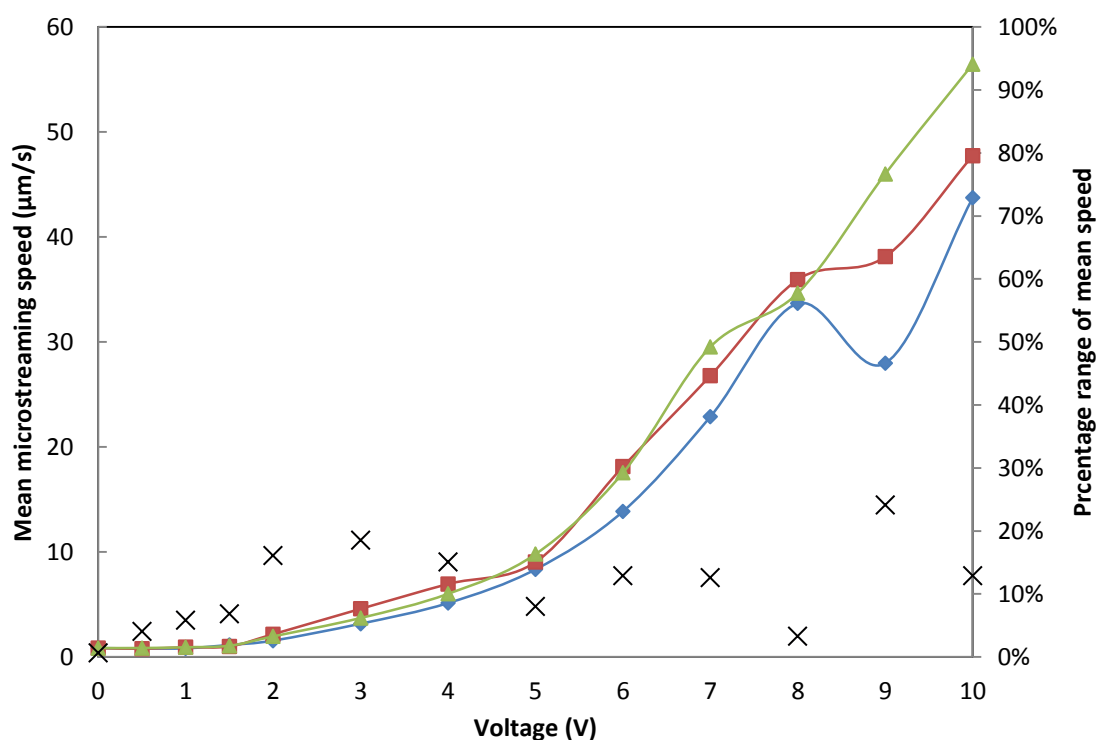


Figure 1.31: Voltage vs. mean microstreaming speed for the 3 repeats of region 7 (blue, red and green respectively) and their percentage range of mean speed (X).

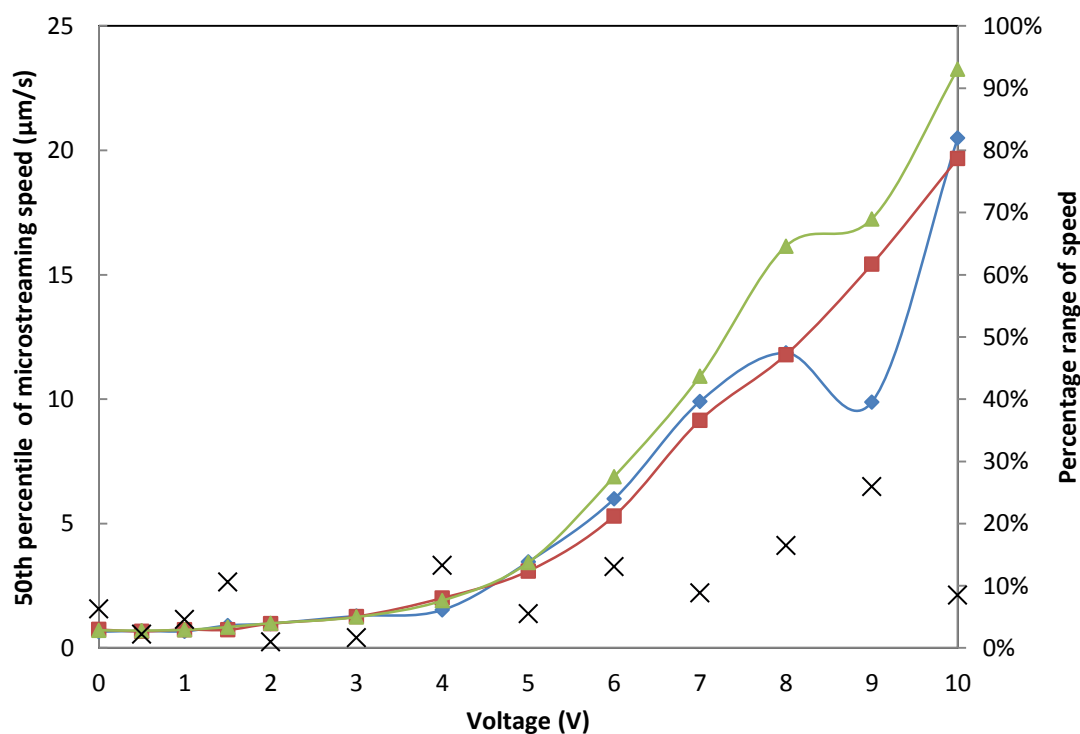


Figure 1.32: Voltage vs. 50<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 7 (blue, red and green respectively) and their percentage range of speed (X).

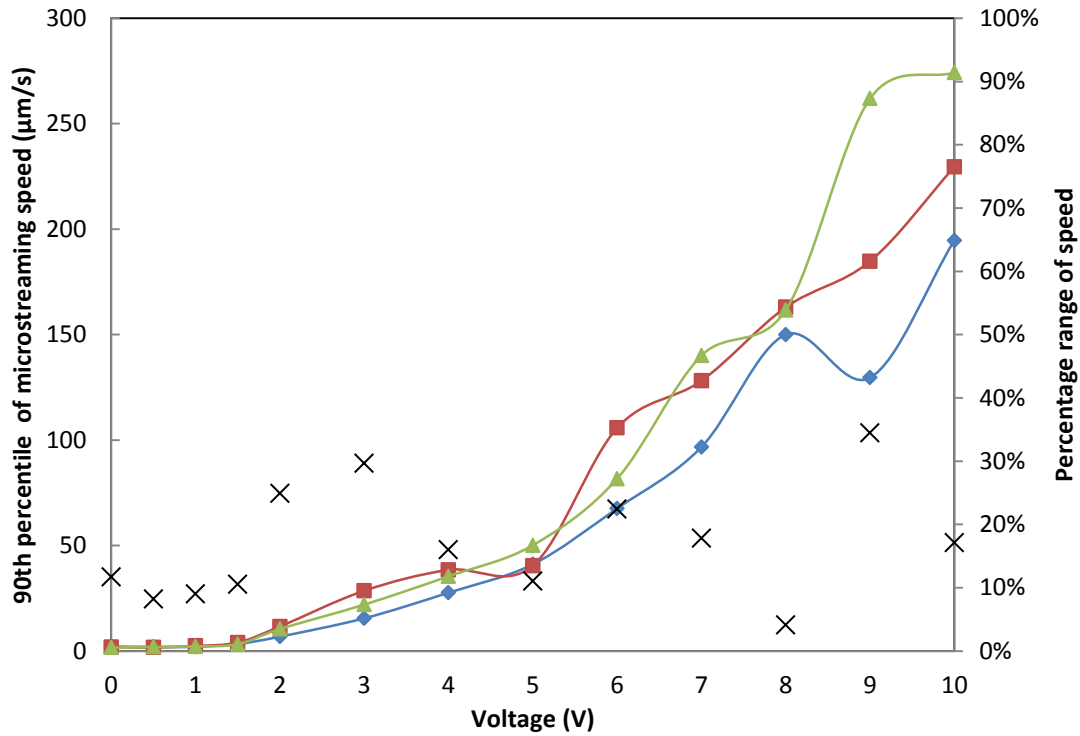


Figure 1.33: Voltage vs. 90<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 7 (blue, red and green respectively) and their percentage range of speed (X).

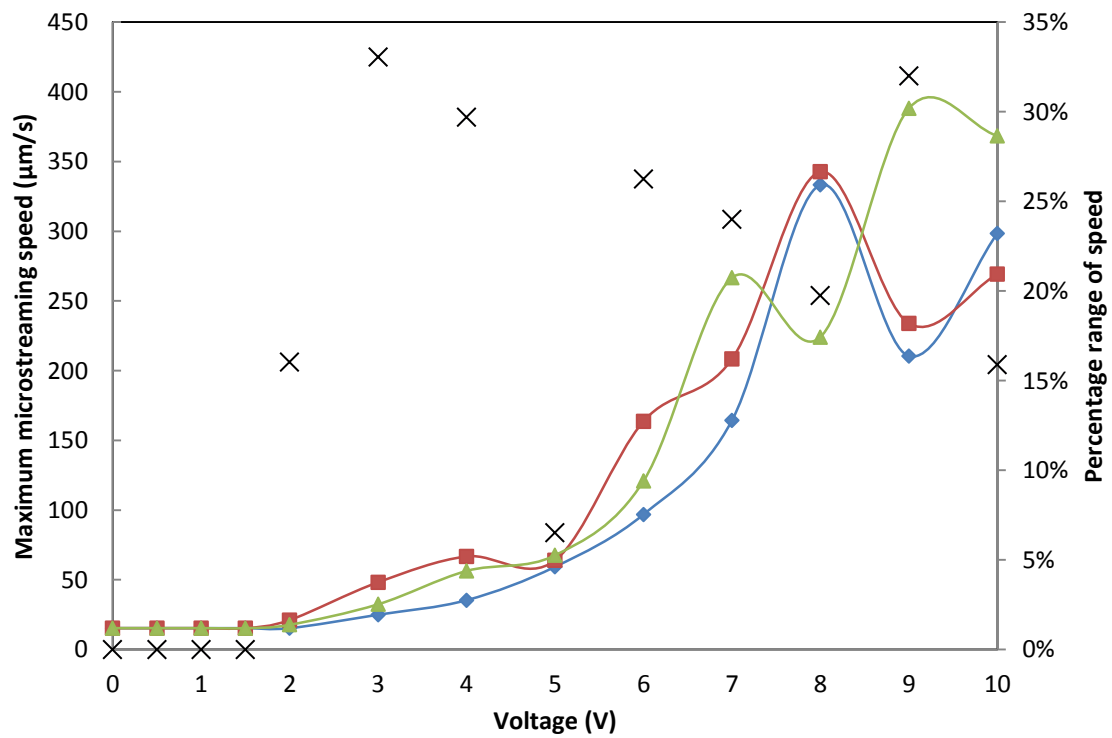


Figure 1.34: Voltage vs. maximum microstreaming speed for the 3 repeats of region 7 (blue, red and green respectively) and their percentage range of speed (X).



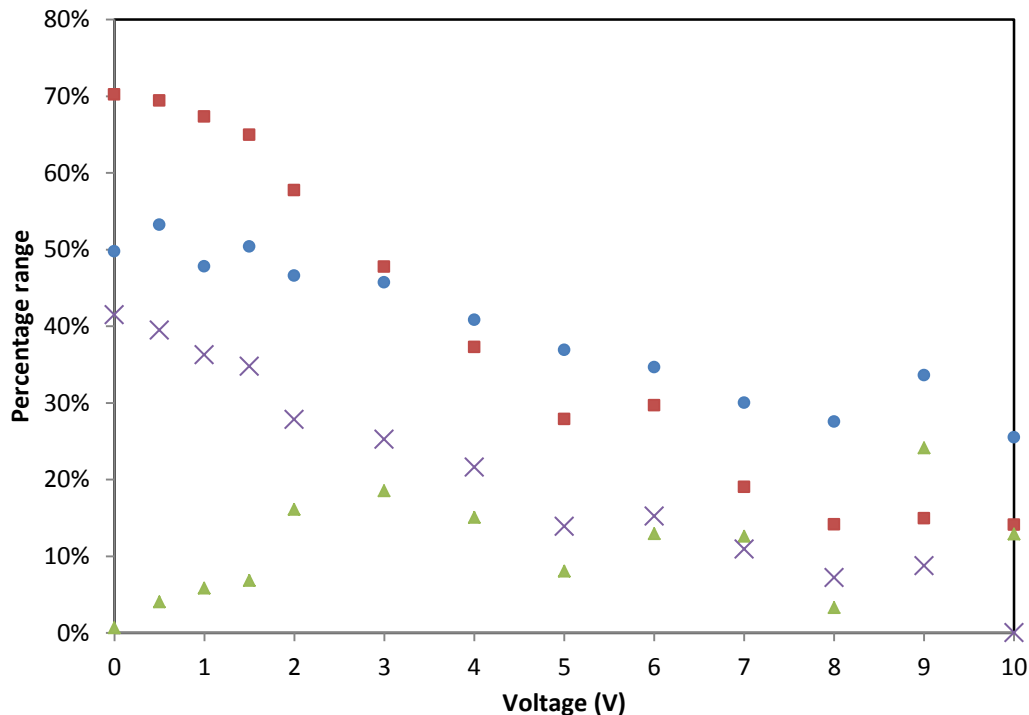


Figure 1.35: The percentage range of mean speed (triangles), pointwise percentage range of speed (circles), pointwise percentage range of direction (squares) and pointwise angular deviation (X) for region 7.

### 1.8. Region 8

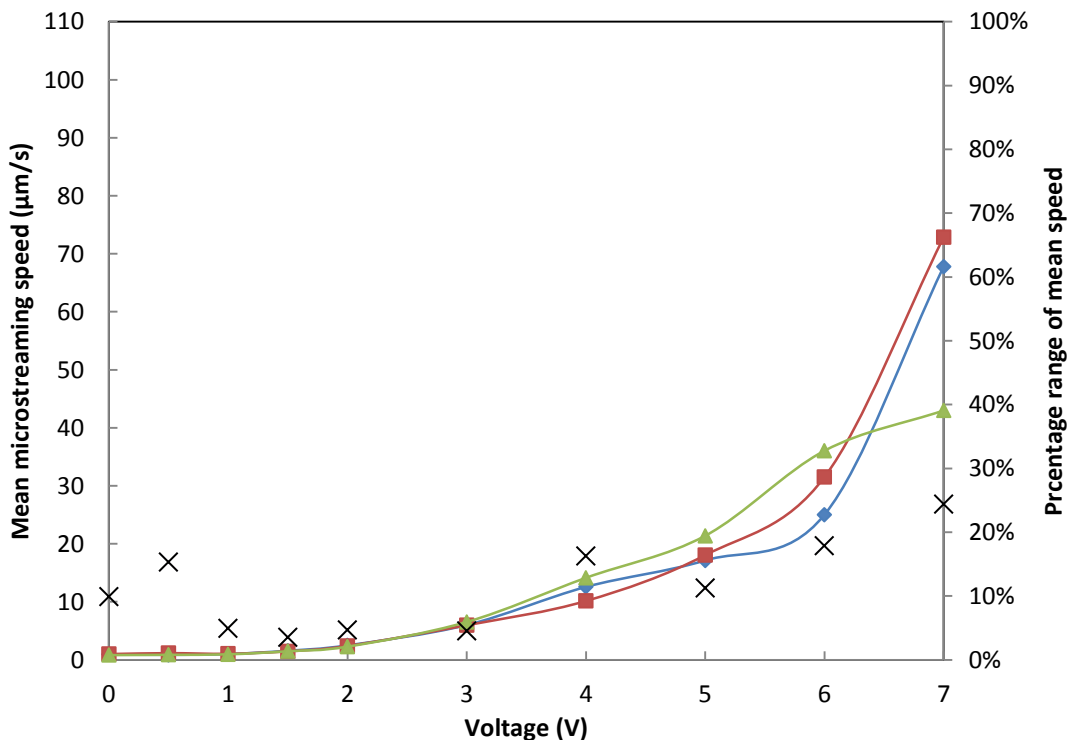


Figure 1.36: Voltage vs. mean microstreaming speed for the 3 repeats of region 8 (blue, red and green respectively) and their percentage range of mean speed (X).

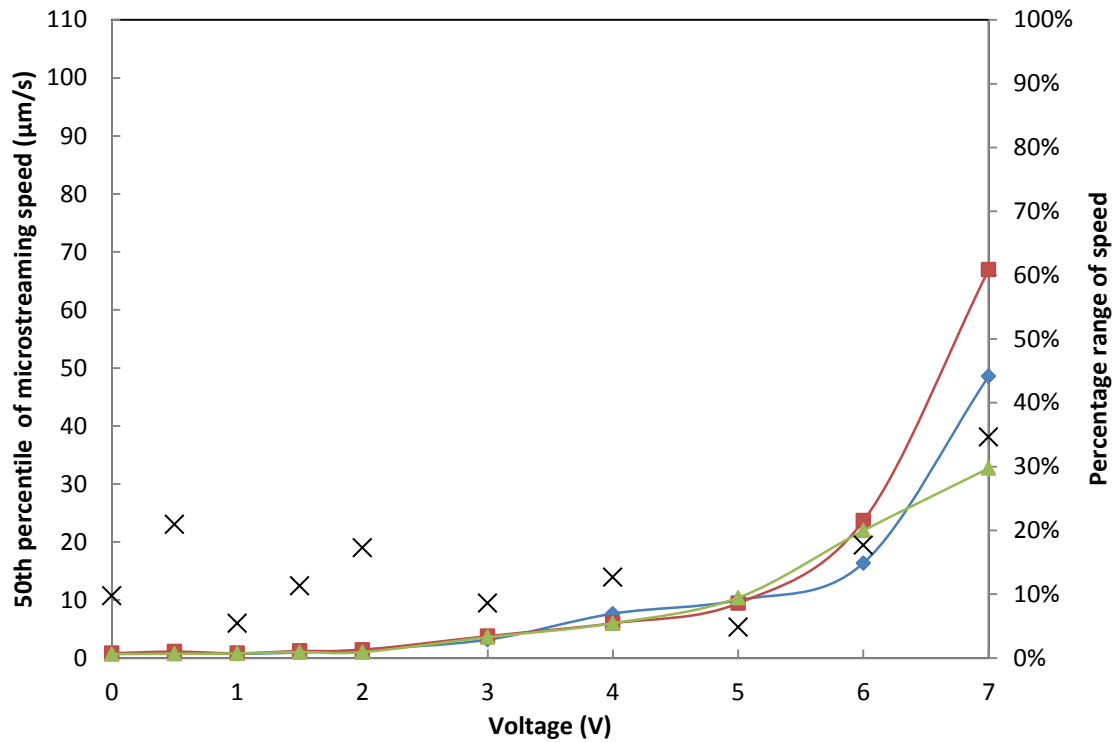


Figure 1.37: Voltage vs. 50<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 8 (blue, red and green respectively) and their percentage range of speed (X).

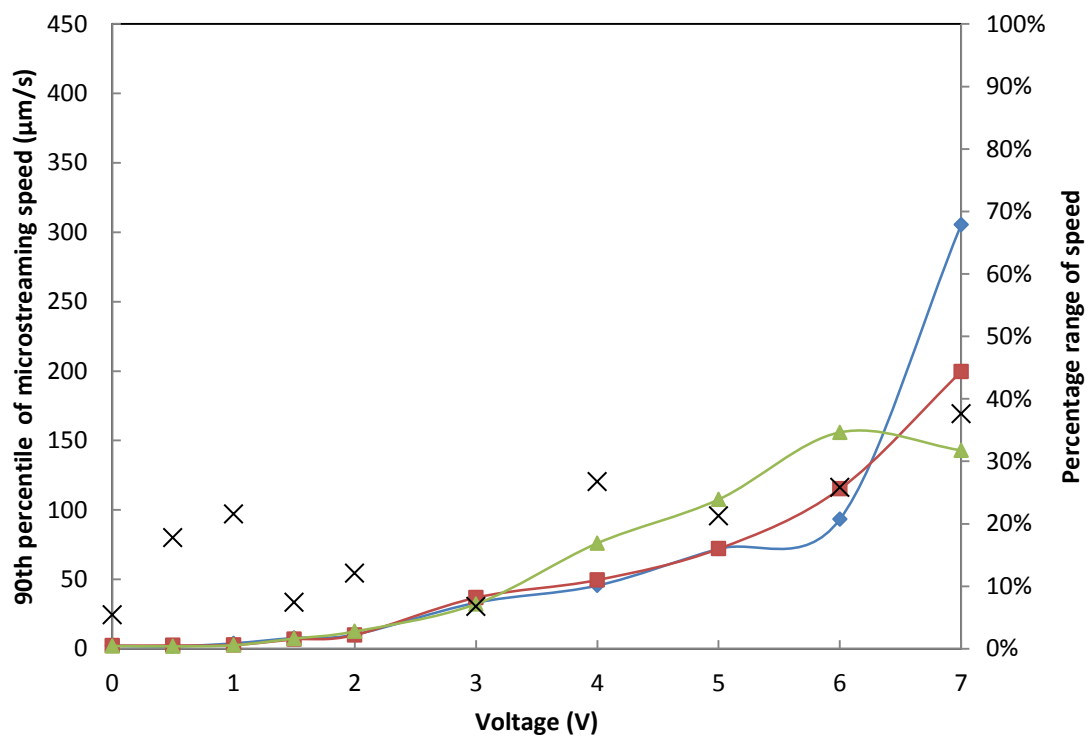


Figure 1.38: Voltage vs. 90<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 8 (blue, red and green respectively) and their percentage range of speed (X).

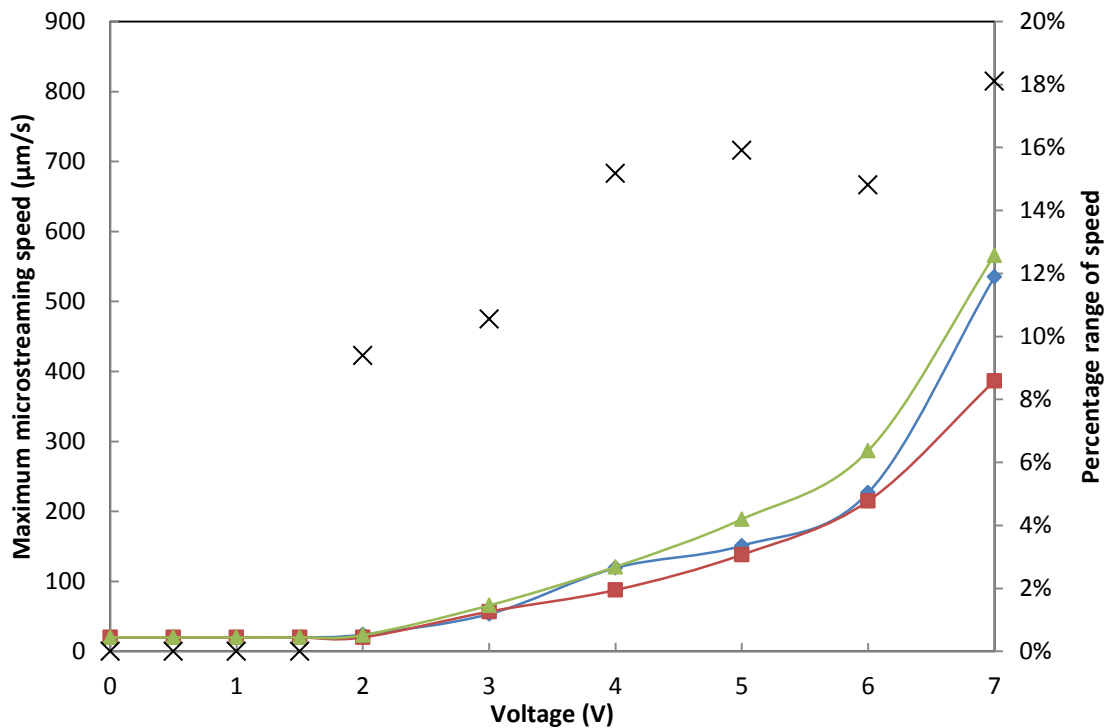


Figure 1.39: Voltage vs. maximum microstreaming speed for the 3 repeats of region 8 (blue, red and green respectively) and their percentage range of speed (X).

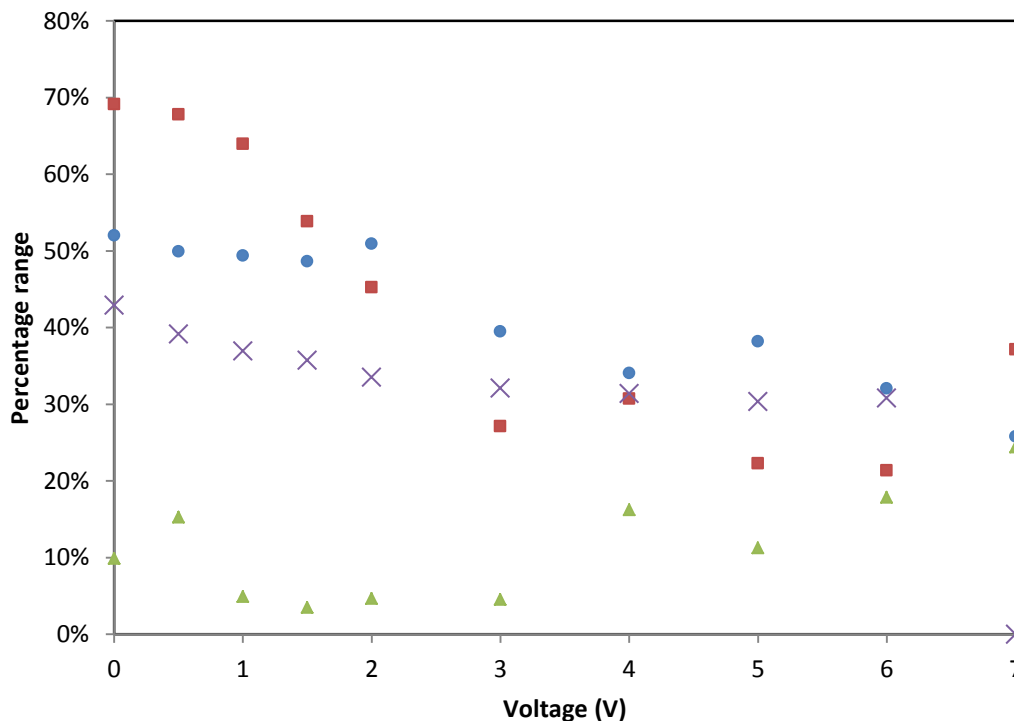


Figure 1.40: The percentage range of mean speed (triangles), pointwise percentage range of speed (circles), pointwise percentage range of direction (squares) and pointwise angular deviation (X) for region 8.

## 1.9. Region 9

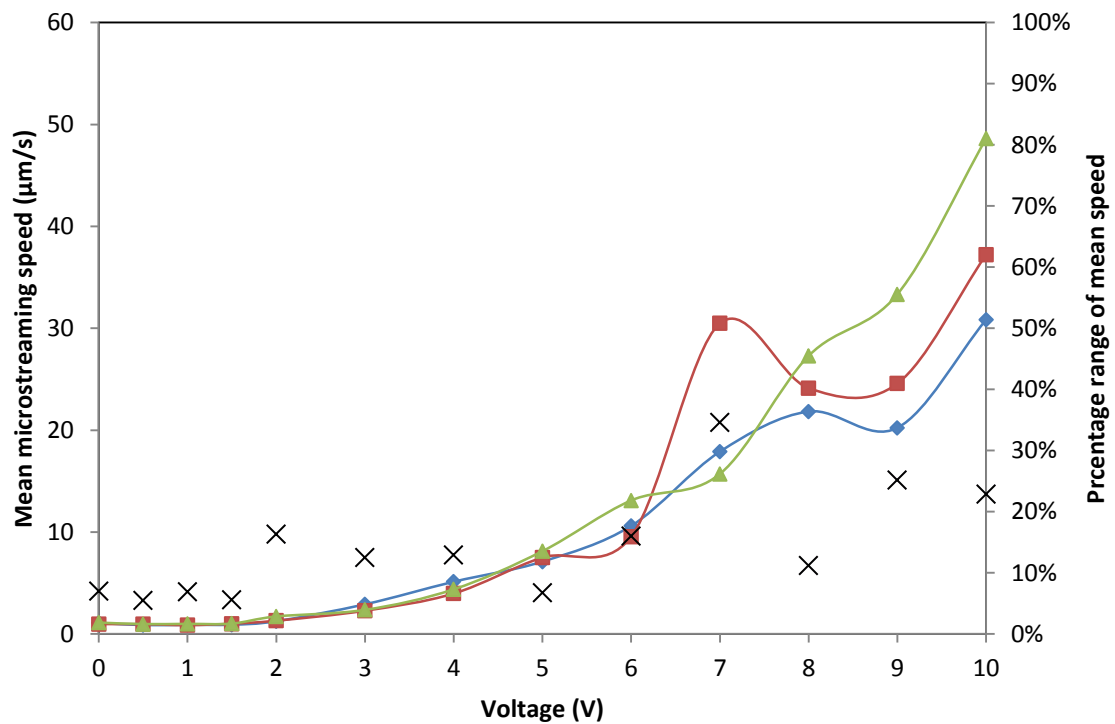


Figure 1.41: Voltage vs. mean microstreaming speed for the 3 repeats of region 9 (blue, red and green respectively) and their percentage range of mean speed (X).

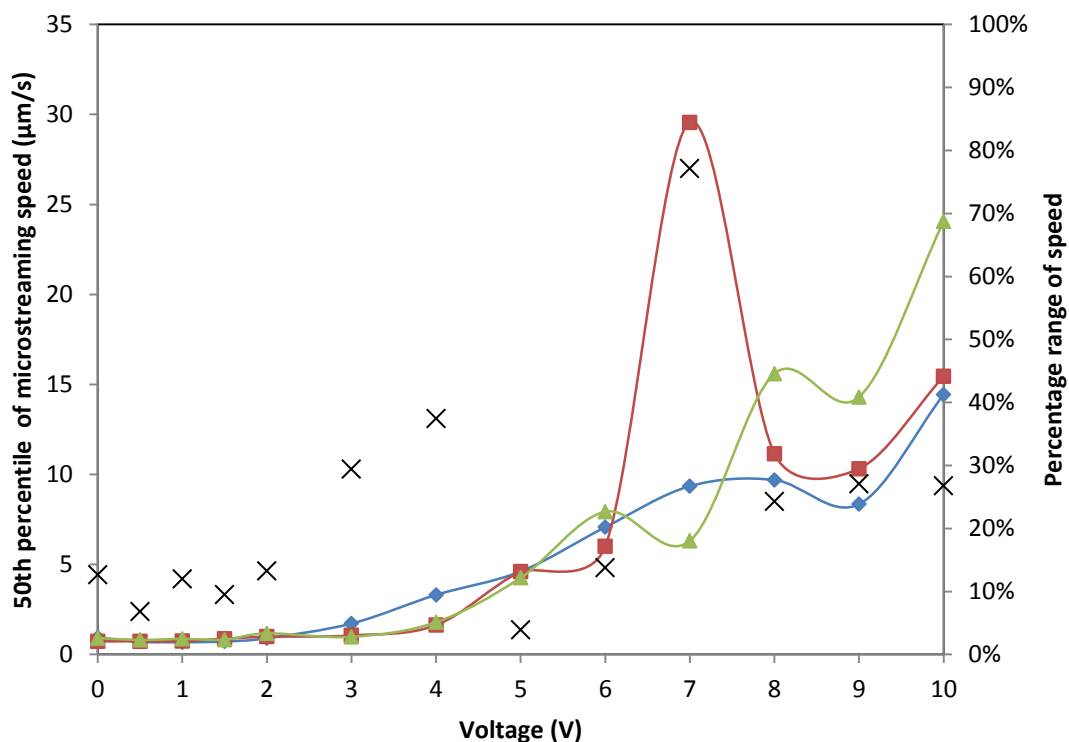


Figure 1.42: Voltage vs. 50<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 9 (blue, red and green respectively) and their percentage range of speed (X).

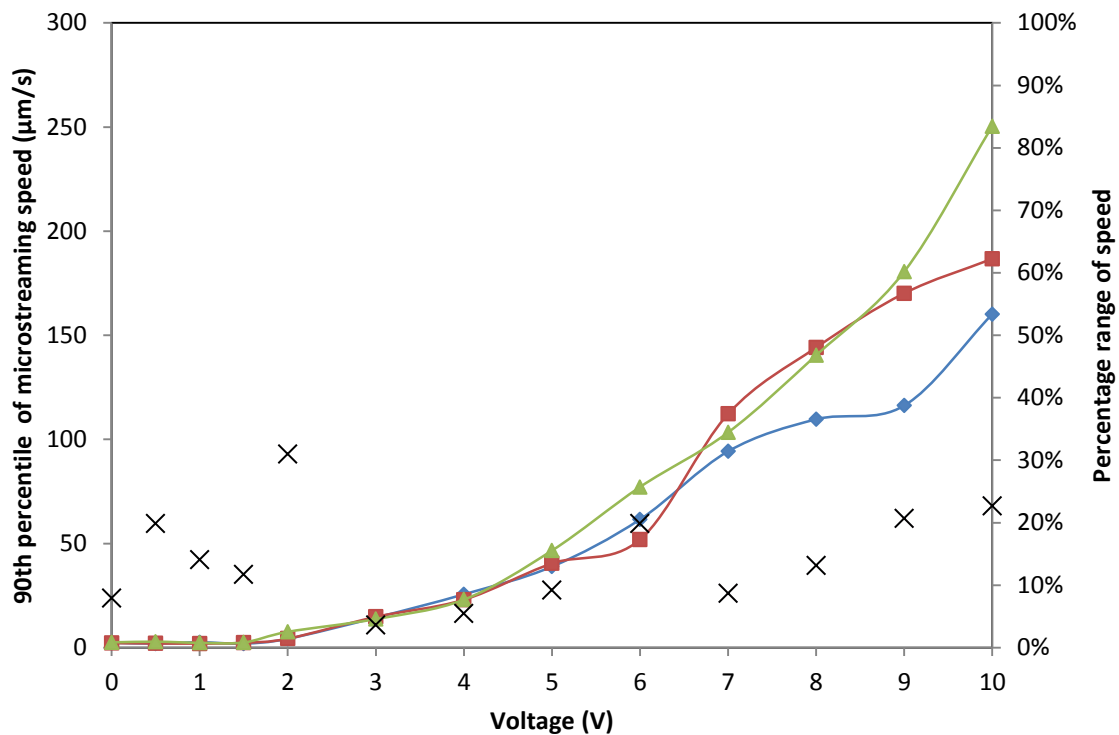


Figure 1.43: Voltage vs. 90<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 9 (blue, red and green respectively) and their percentage range of speed (X).

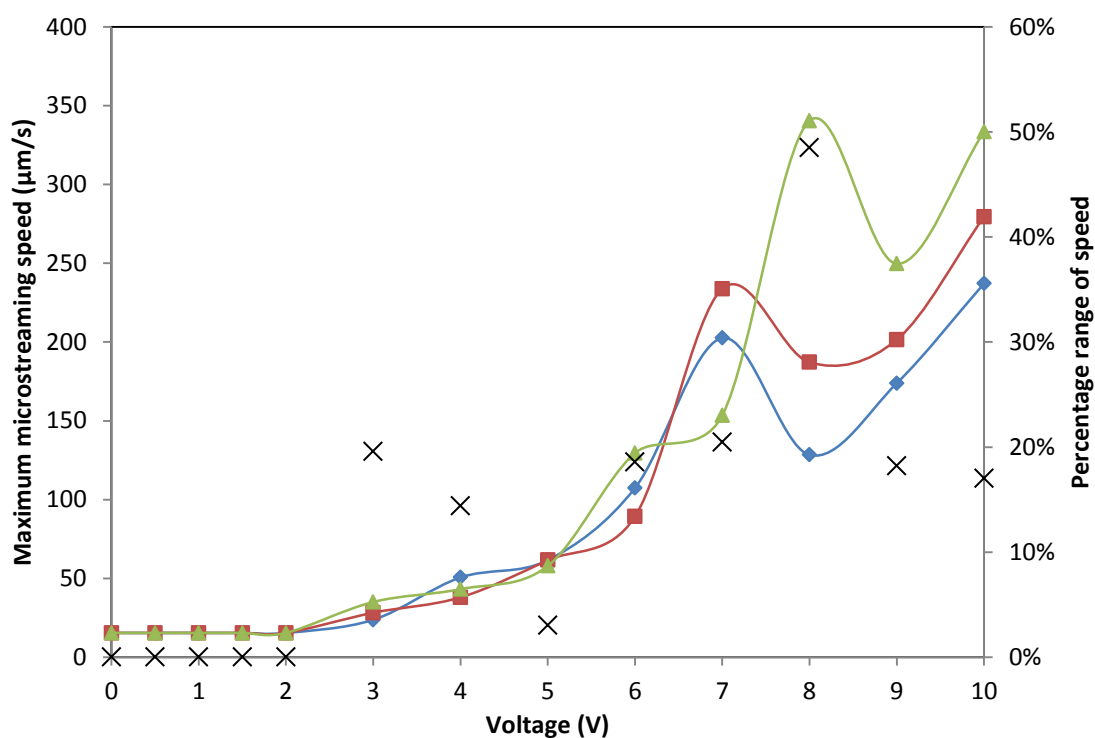


Figure 1.44: Voltage vs. maximum microstreaming speed for the 3 repeats of region 9 (blue, red and green respectively) and their percentage range of speed (X).

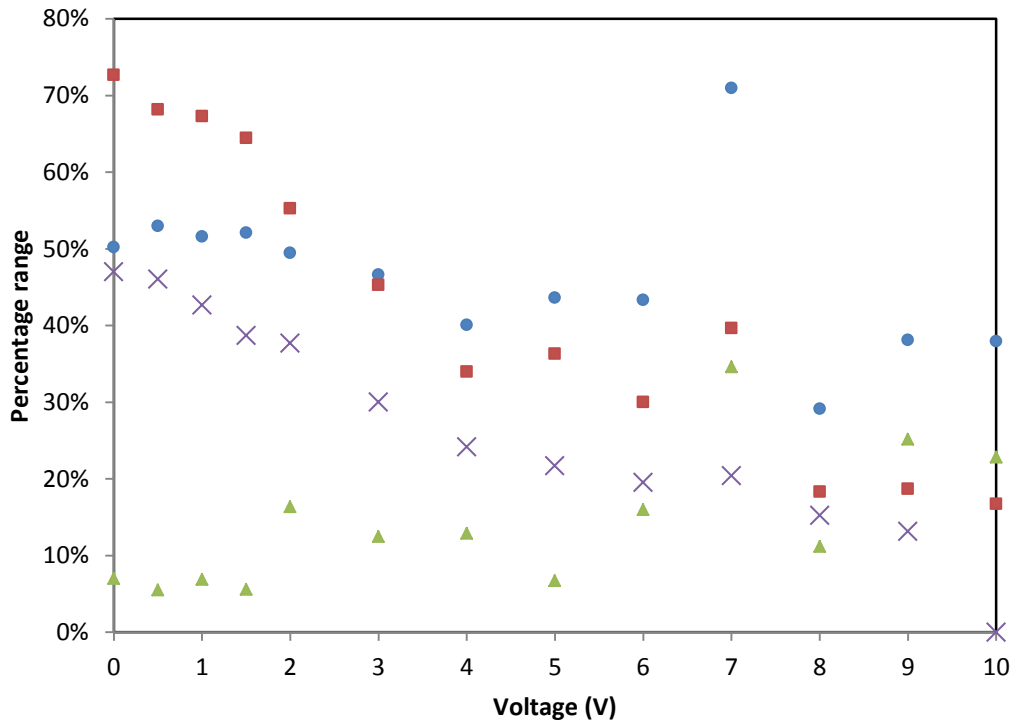


Figure 1.45: The percentage range of mean speed (triangles), pointwise percentage range of speed (circles), pointwise percentage range of direction (squares) and pointwise angular deviation (X) for region 9.

### 1.10. Region 10

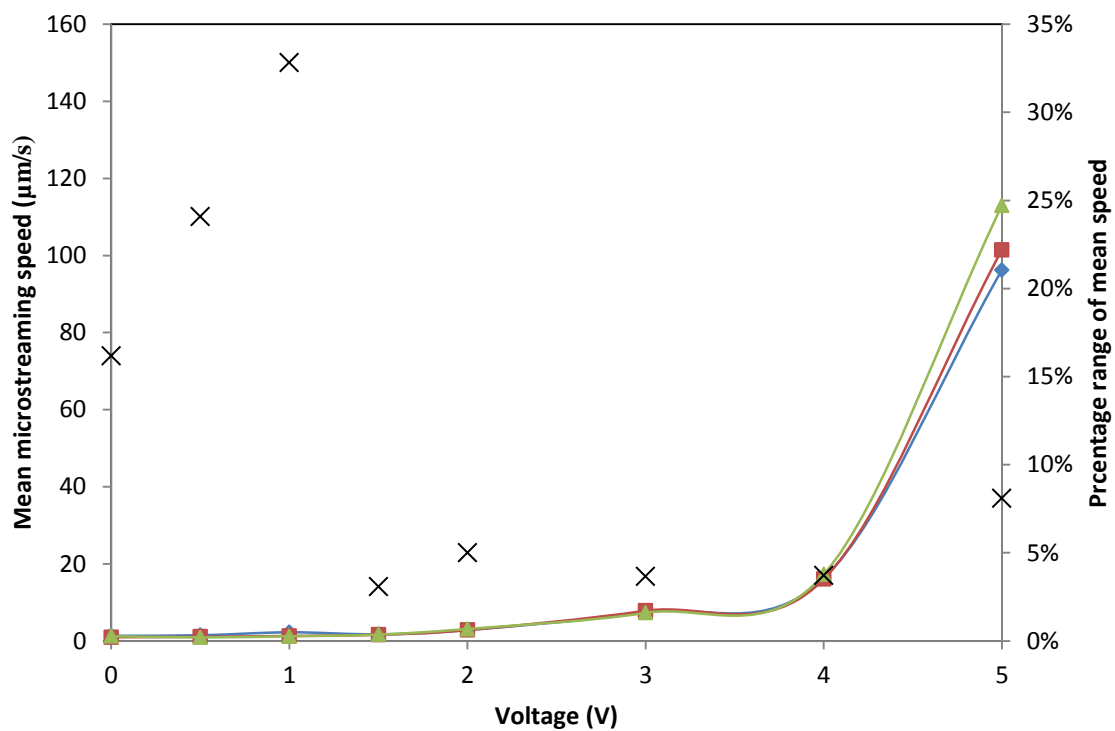


Figure 1.46: Voltage vs. mean microstreaming speed for the 3 repeats of region 10 (blue, red and green respectively) and their percentage range of mean speed (X).

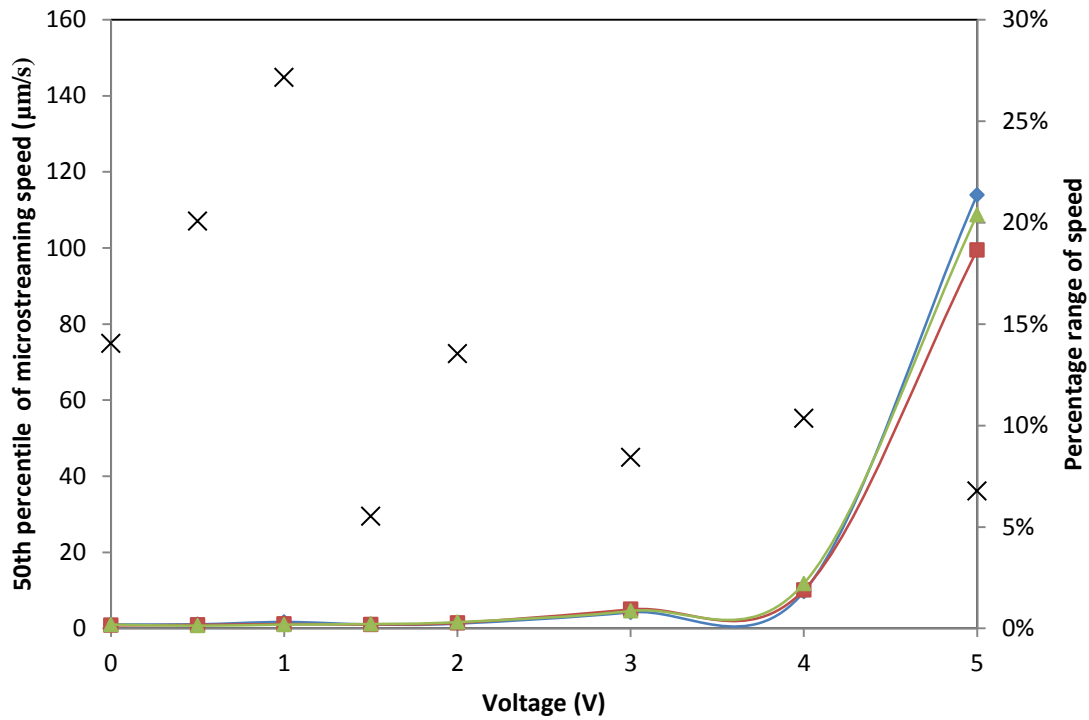


Figure 1.47: Voltage vs. 50<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 10 (blue, red and green respectively) and their percentage range of speed (X).

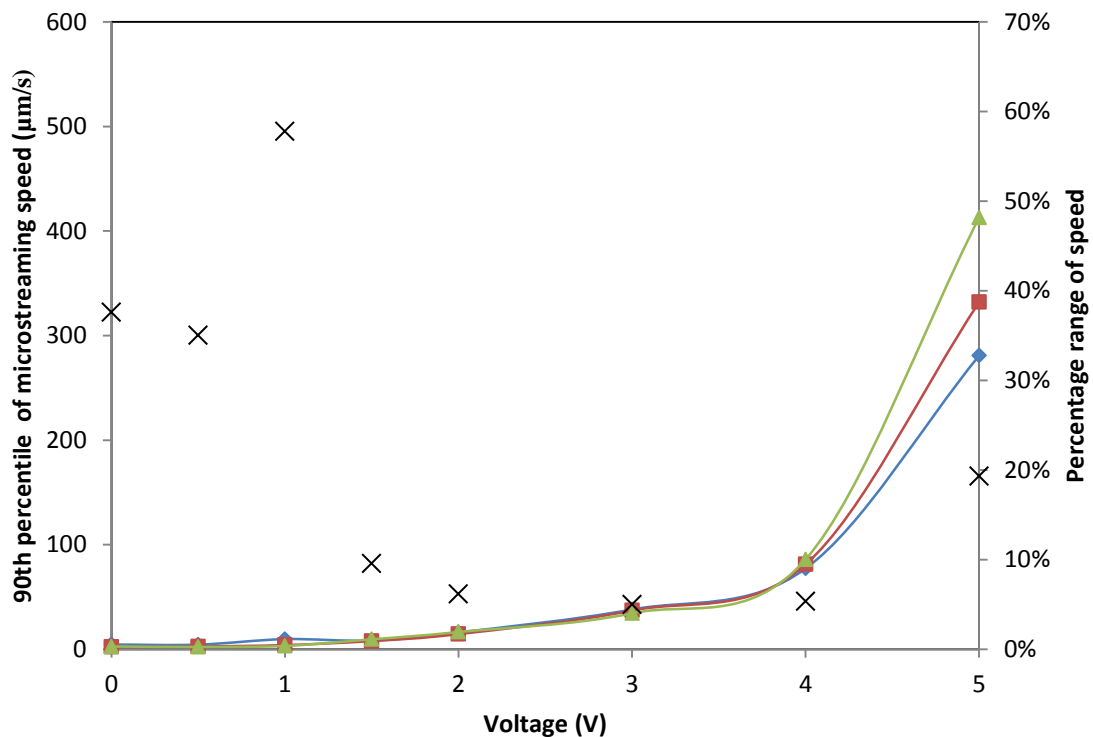


Figure 1.48: Voltage vs. 90<sup>th</sup> percentile of the microstreaming speed for the 3 repeats of region 10 (blue, red and green respectively) and their percentage range of speed (X).

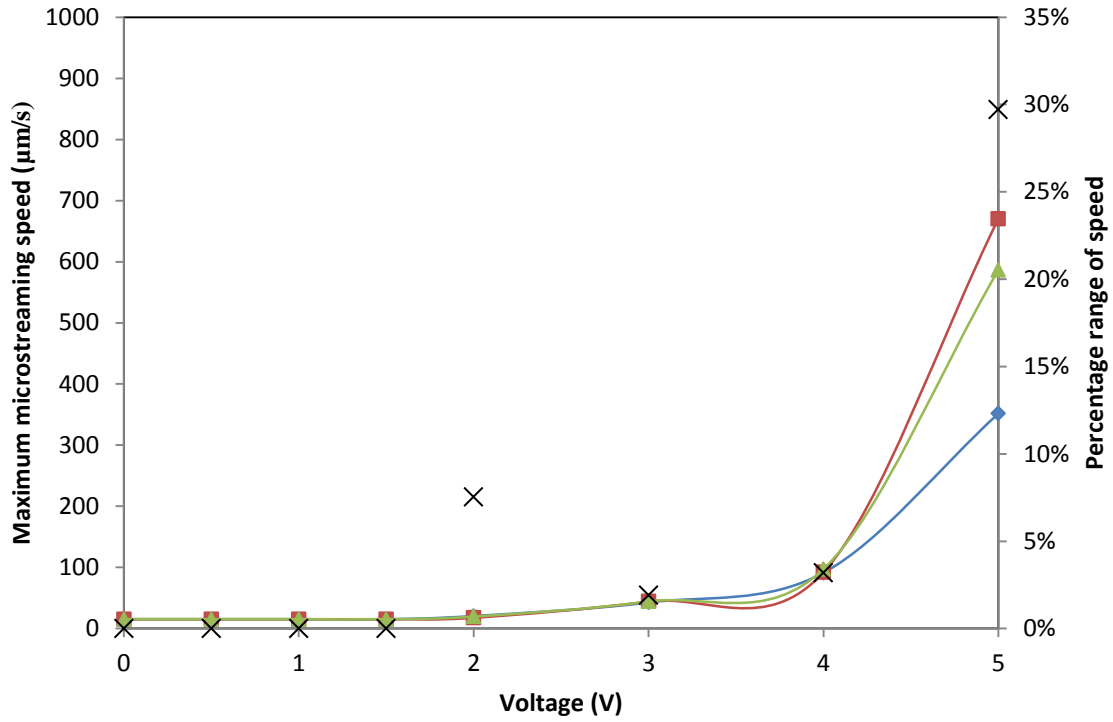


Figure 1.49: Voltage vs. maximum microstreaming speed for the 3 repeats of region 10 (blue, red and green respectively) and their percentage range of speed (X).

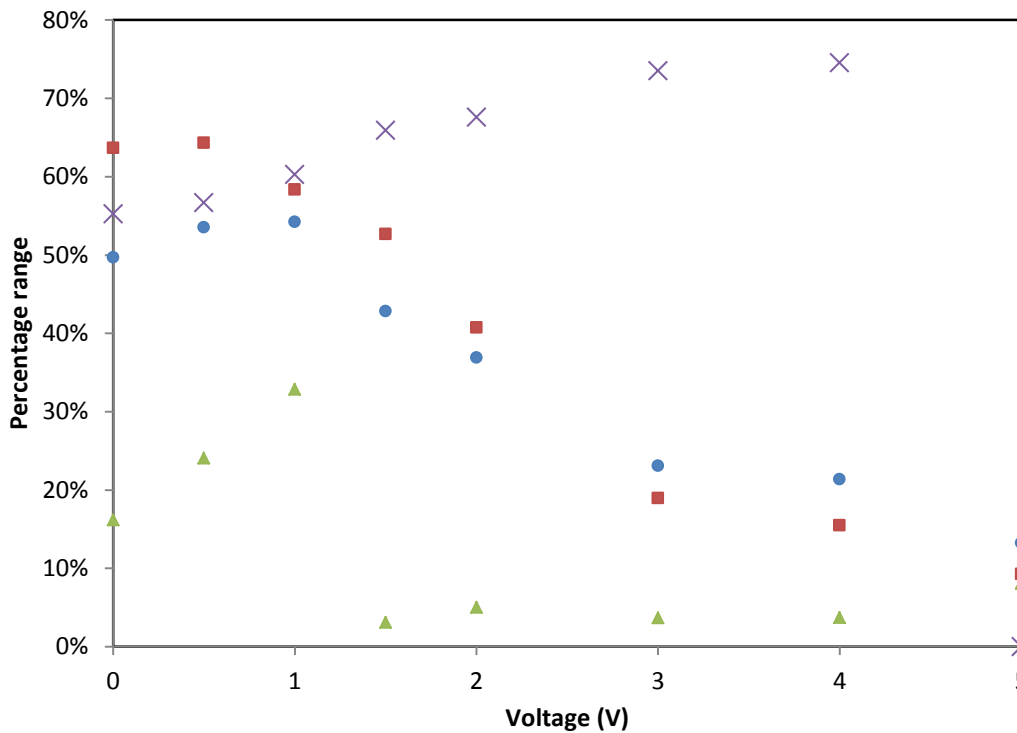


Figure 1.50: The percentage range of mean speed (triangles), pointwise percentage range of speed (circles), pointwise percentage range of direction (squares) and pointwise angular deviation (X) for region 10.



## 2. Curve Fitting to the Mean Speed

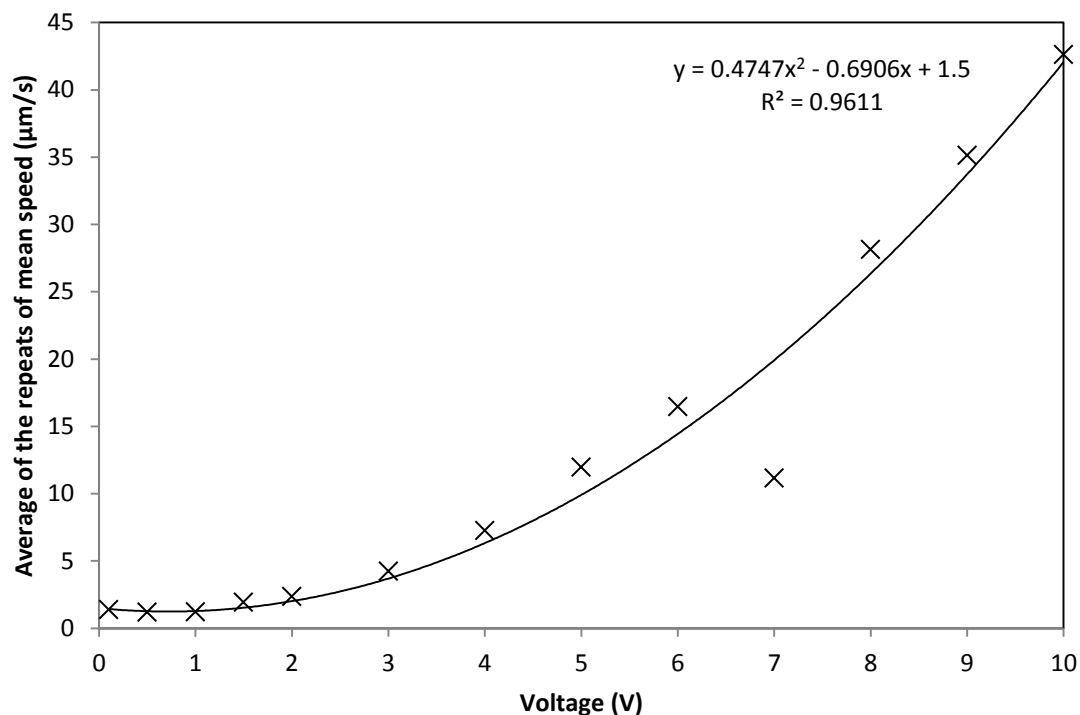


Figure 2.1: Average of the mean speeds from the repeats of region 1, fitted with the polynomial function shown in table 10 of the thesis.

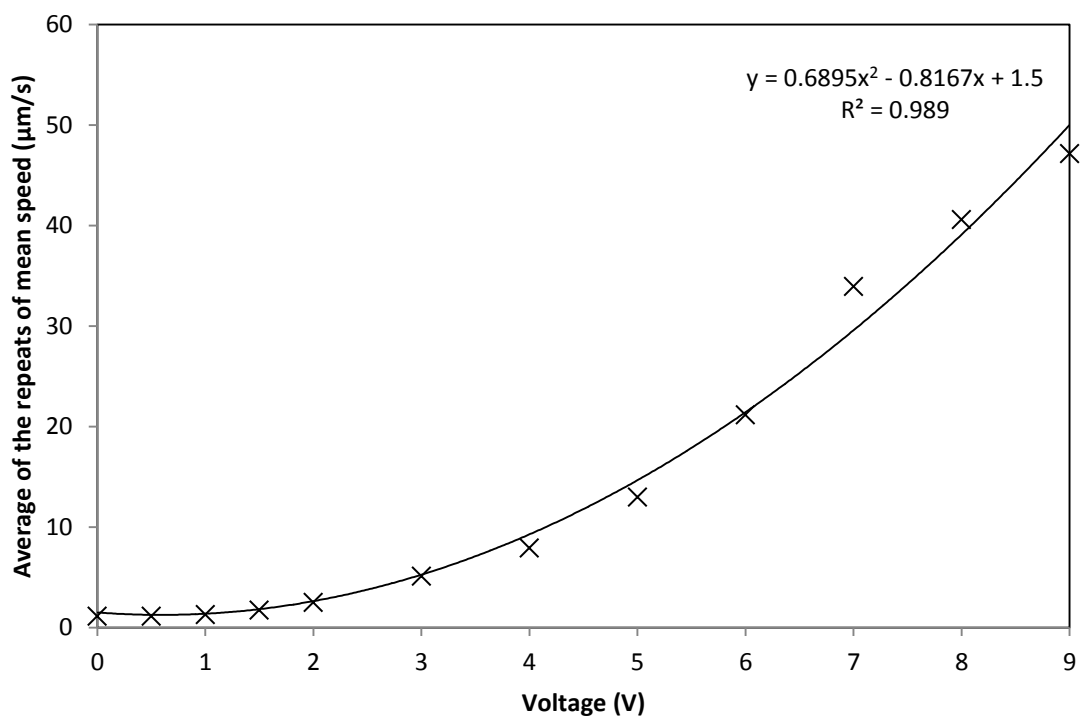


Figure 2.2: Average of the mean speeds from the repeats of region 2, fitted with the polynomial function shown in table 10 of the thesis.

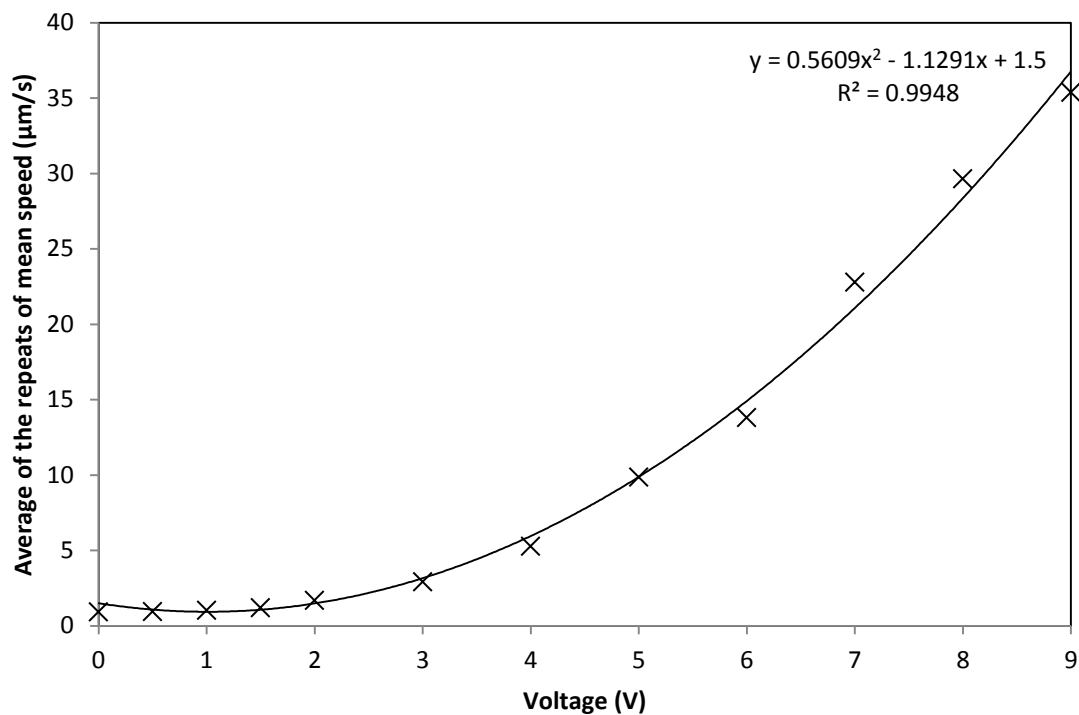


Figure 2.3: Average of the mean speeds from the repeats of region 3, fitted with the polynomial function shown in table 10 of the thesis.

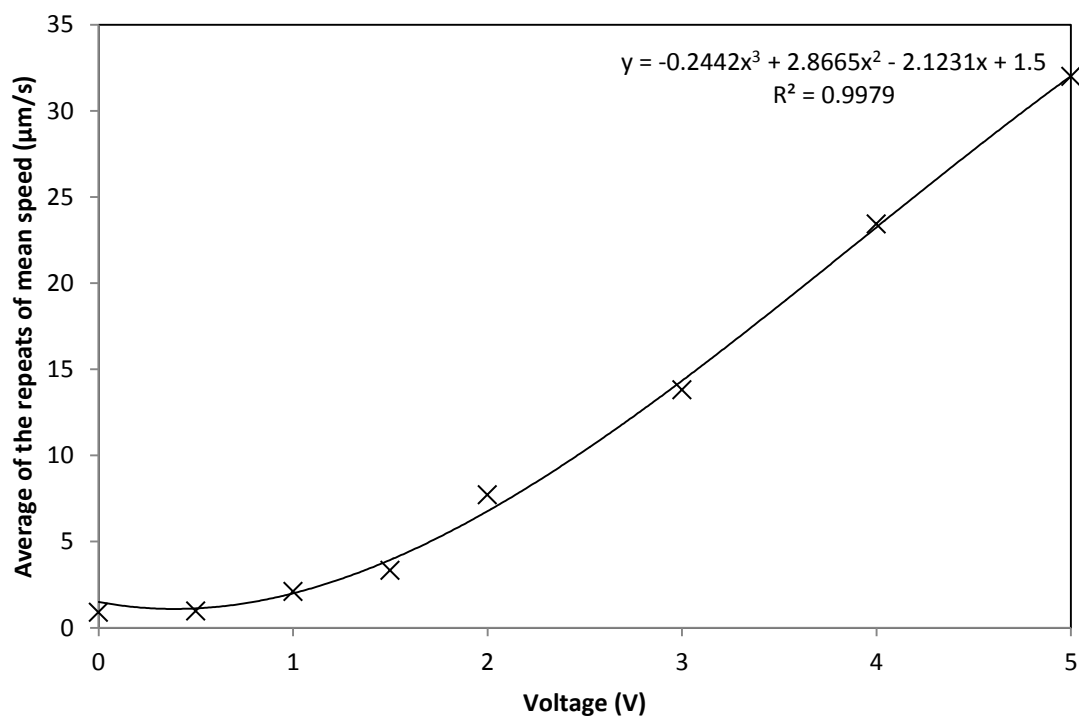


Figure 2.4: Average of the mean speeds from the repeats of region 4, fitted with the polynomial function shown in table 10 of the thesis.

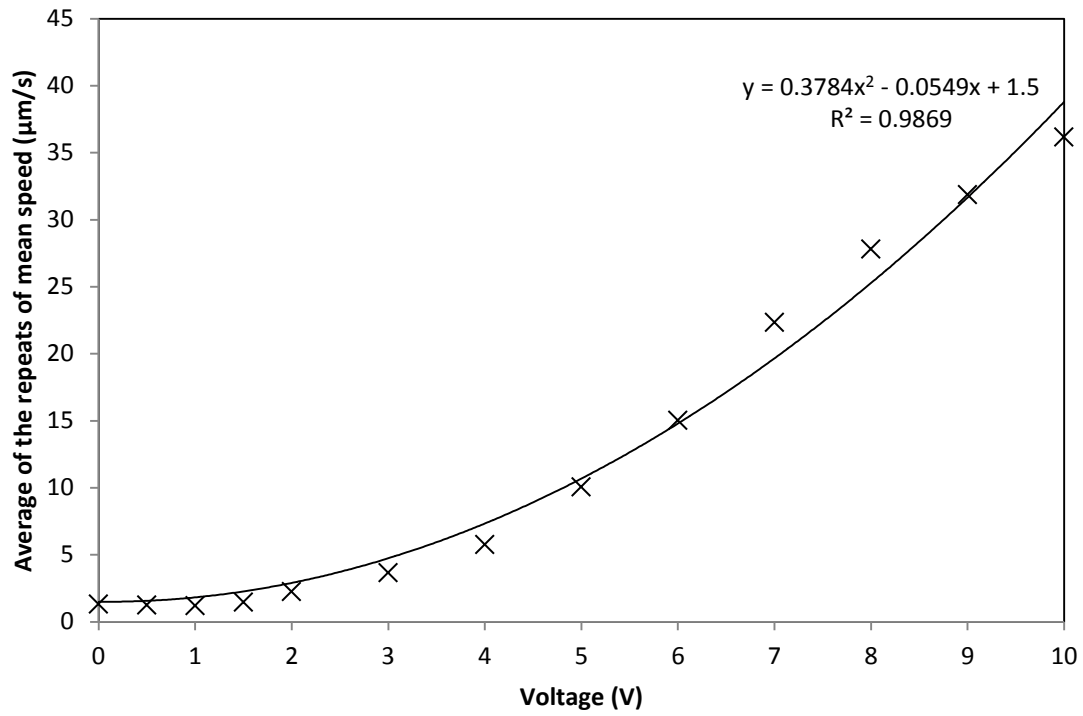


Figure 2.5: Average of the mean speeds from the repeats of region 5, fitted with the polynomial function shown in table 10 of the thesis.

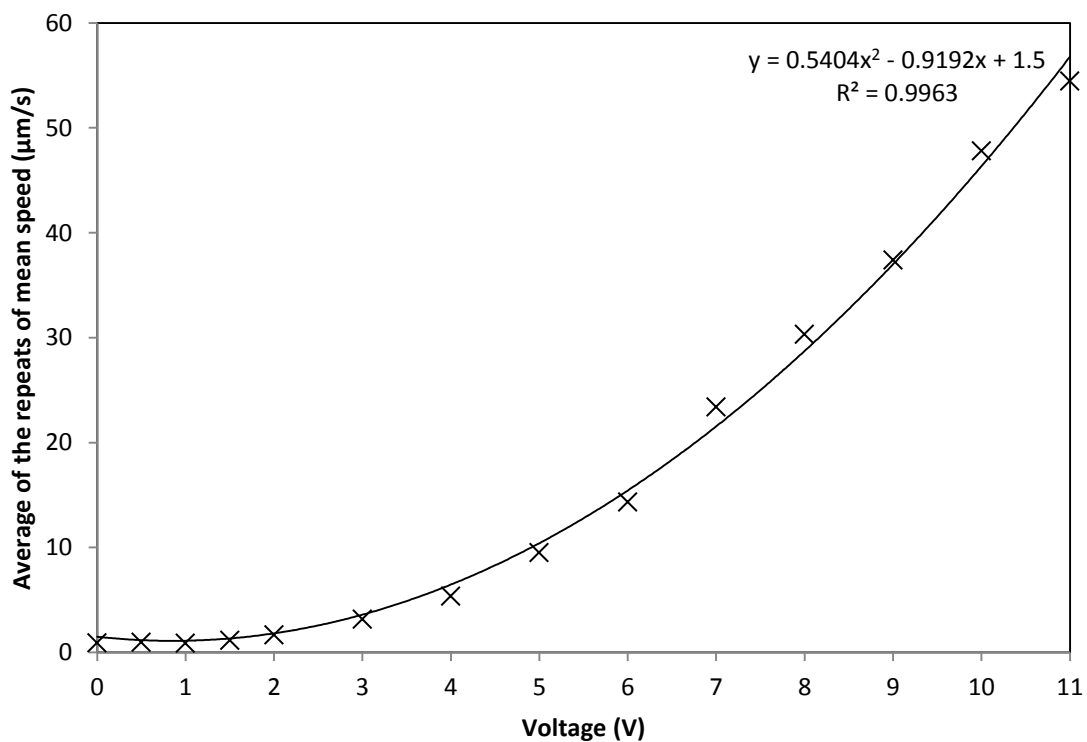


Figure 2.6: Average of the mean speeds from the repeats of region 6, fitted with the polynomial function shown in table 10 of the thesis.

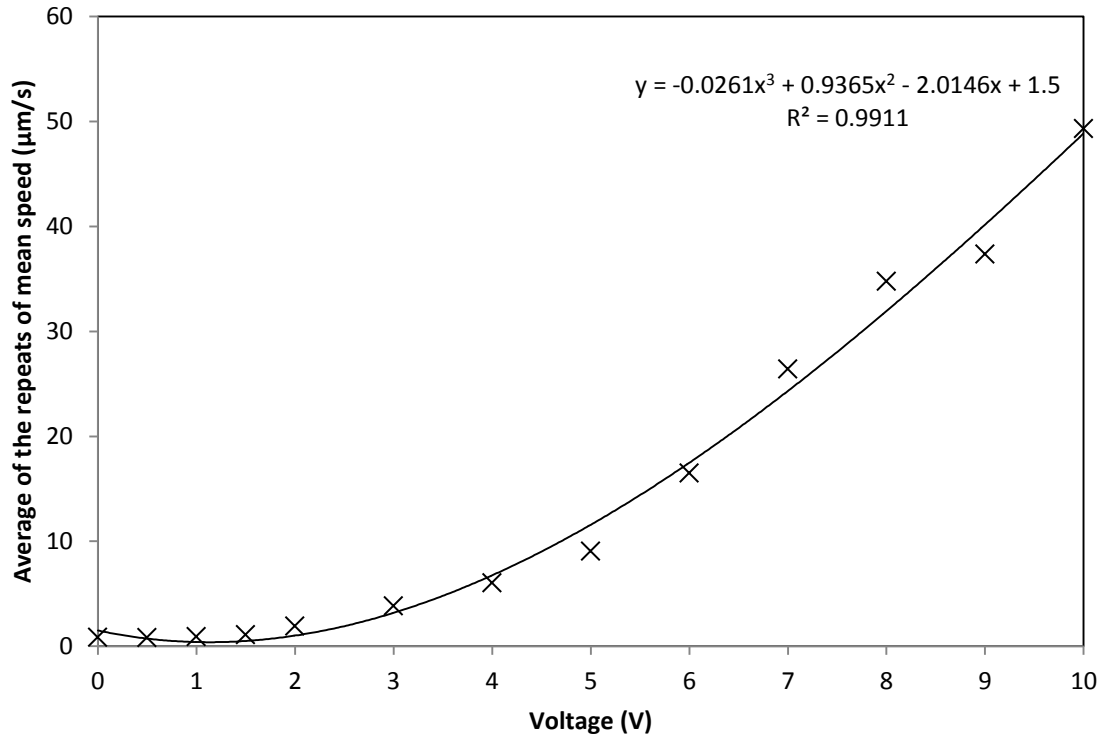


Figure 2.7: Average of the mean speeds from the repeats of region 7, fitted with the polynomial function shown in table 10 of the thesis.

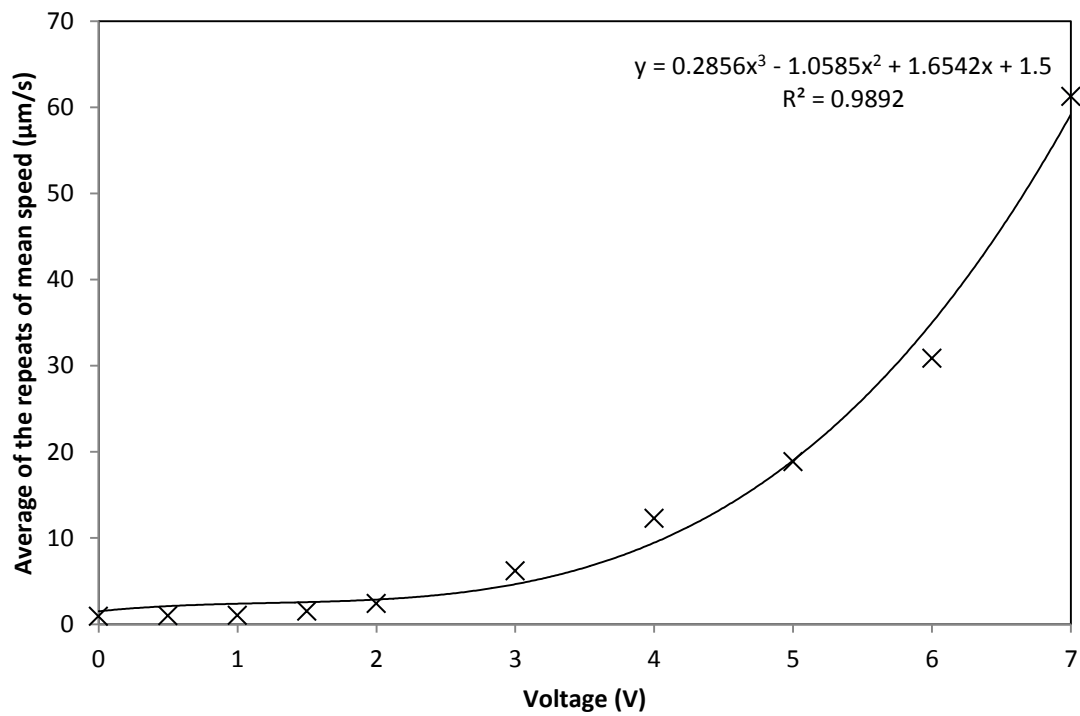


Figure 2.8: Average of the mean speeds from the repeats of region 8, fitted with the polynomial function shown in table 10 of the thesis.

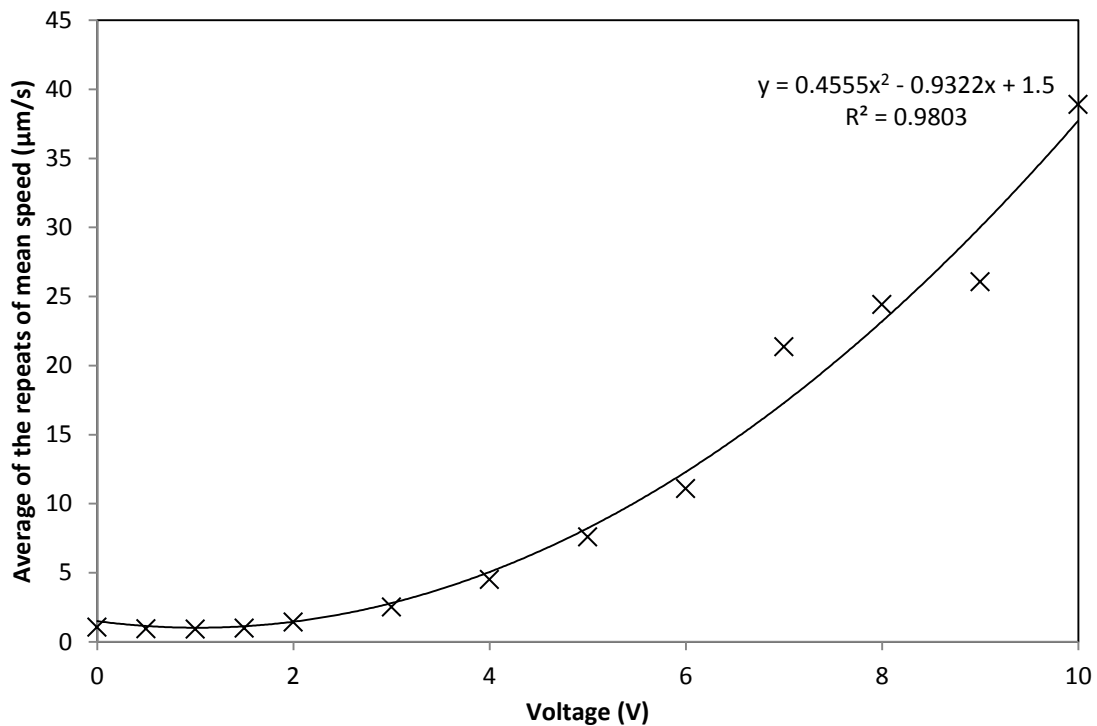


Figure 2.9: Average of the mean speeds from the repeats of region 9, fitted with the polynomial function shown in table 10 of the thesis.

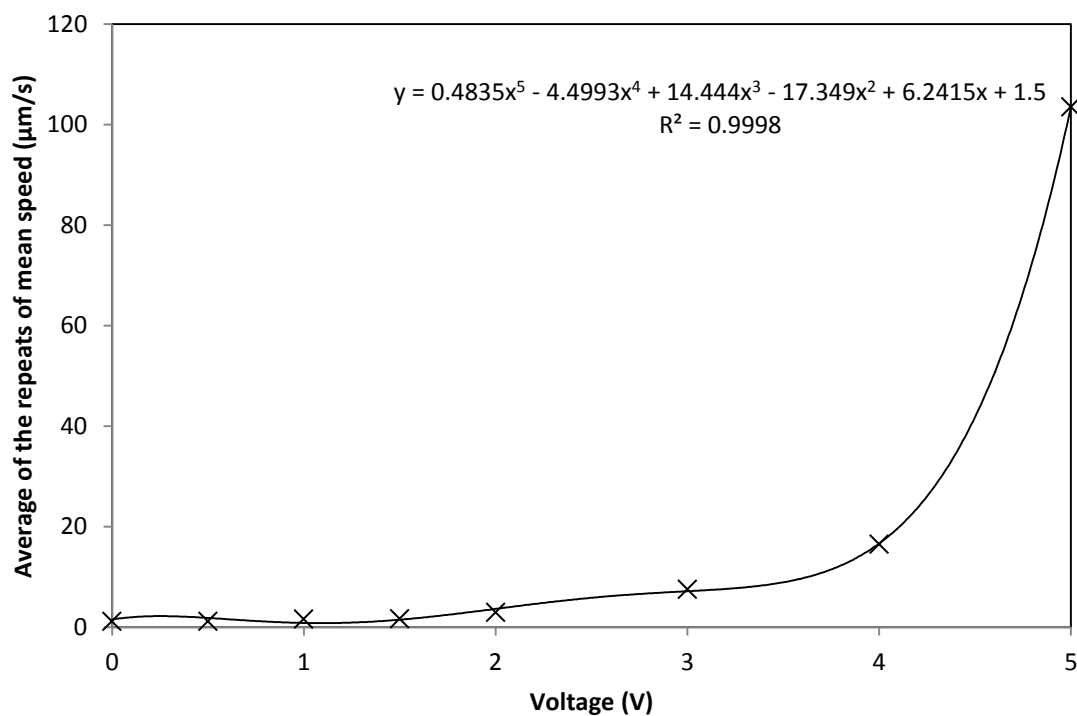


Figure 2.10: Average of the mean speeds from the repeats of region 10, fitted with the polynomial function shown in table 10 of the thesis.