Injection Molding Procedure Report for Beep Band

Introduction

Beep Band is a smart band that helps prevent bullying among students in school. The smart band would have a single button which when pressed three times consecutively would alert all faculty members in the victim's vicinity. The band would also have a built-in microphone that would automatically record any verbal bullying that might be targeted towards the victim as soon as the button is pressed three times. This feature would hopefully allow the school to make the appropriate disciplinary decisions with solid evidence.

Product Design

We hope that this smart band could be incorporated for all ages, which would require it to be extremely durable. Given that this smart band would most likely run on at least one lithium polymer battery, the smart band would need to be rigid to prevent spontaneous combustion upon bending. The band would also need to be at least water-resistant. Given all these requirements, the biggest challenge of this entire project will likely be creating a smart band that is cheap enough to meet the very low budget of most schools.

Once the product is developed and can be produced at a relatively cheap price, there are many options we hope to add which mainly deal with RFID. The main two are attendance systems and payment systems. We believe that utilizing an attendance system to ensure that students are on time to their classes would not only increase teaching time but would also decrease the amount of time that students spend unsupervised by a faculty member. Utilizing a payment system into the smart band would allow the student's guardians to directly deposit money onto the student's watch – like a WISCARD. Students will then not be required to bring money with them to school which would hopefully prevent theft and bullying.

Overall, the product needs to be very durable to prevent electronics from being exposed, rigid to support the product's electronics, cheap to manufacture at lower costs, comfortable so children may wear it for extended periods of time, and water resistant to safely house the system's hardware.

Materials Selection

Given the product design and specifications mentioned above, the two materials that were deemed most suitable for such a product were Thermoplastic Elastomers (TPE) and Thermoplastic Polyurethane (TPU). TPE is a class of copolymers that consist of materials with both thermoplastic and elastomeric properties. The thermoplastic properties are relatively easy to use in manufacturing, especially in processes such as injection molding. TPE also has the ability to stretch and return to its original shape better than most materials can [2]. TPU, on the other hand, is a class of polyurethane plastics with many properties, including hardness, strength, and elasticity [3][9]. Due to its thermoplastic nature, TPU has several benefits over other elastomers, such as its high tensile strength, high elongation at break, and easy processing [4].

This analysis focused on qualities such as mechanical properties, manufacturability, cost, suitability for the part, environmental friendliness, and chemical resistance. Conclusions were based on a combination of the references and the Moldex3D library values shown in Appendix A.

Mechanical Properties

The main mechanical properties of the materials for the bracelet are elasticity, durability, and tensile strength. In order for the bracelet to be comfortably worn on the student's wrist, it's important to have an elastic material. The bracelet also has to be durable as students will be wearing the bracelet during the duration of the school day, making it prone to abrasion. Finally, its tensile strength must be good enough to withstand the students putting on and removing the bracelet each day. Whereas TPE typically has better elasticity, TPU wins out in durability and tensile strength [8].

Manufacturability

TPU and TPE are both ideal substances for injection modeling. As a result, there is not much difference when it comes to injection molding these two materials. Both materials offer colorability, flexibility, and elasticity [7]. They are easily reused and recycled, which allows for better production costs and less manufacturing waste, and they have a wide range of applications in the industrial world [6][8]. As shown in Figures 1 and 2 of the Appendix, TPE's viscosity doesn't vary much with temperature as TPU does and so TPE has a slight edge.

Cost

Cost is an important factor that needs to be taken into account for the smart band, as the main consumer for this product will be schools, some of which do not have as good of funding as others. Although there are many factors that go into cost calculations, TPU is usually considered the more expensive option of the two materials. Due to its higher resistance to force, temperature, and other elements [6], the material is often more costly per unit. However, this does not consider the durability of this material, as it does not need to be replaced as often as TPE. Therefore, the cost over longer periods of time could be lower.

Suitability for the part

Since this product is meant to be worn every school day by a large age range of children, the suitability of the material for this part is one of the bigger considerations. In terms of which material would better suit the need of comfortability, TPE would most likely be the better option. This option beats out TPU in flexibility and softness [6], meaning a band made from TPE would be more comfortable, especially for a user that plans on wearing it as often as it is intended. On the other hand, since TPU is known to last somewhat longer than TPE due to a higher resistance to abrasion [9], a school that plans on trying to keep bands intact for longer periods of time might want to choose this option. In any case, both options are non-toxic and safe for human interaction.

Environmental friendliness

While both materials do offer a considerable level of environmental friendliness, TPE boasts a marginally higher grade than TPU. This is due to its lesser durability and resistance to wear and abrasion, as well as temperature and chemical damage [4]. In the long run, it will take TPE less time to break down than its more resilient counterpart, TPU.

Surface quality

The surface quality must be exceptional for the bracelet, or it will not be comfortable enough to be worn daily by children, who may have more sensitive skin. In this case, TPE is the better choice, due to the softer finish and better flexibility [7], making the surface of this material on a bracelet smoother and less harsh when coming into contact with the skin for long durations of time.

Chemical Resistance

Chemical resistance is not the most relevant factor to consider when choosing a material for our product, but still must be considered, as the band must be as resistant as possible to potential chemical hazards, as well as be water resistant. The chemical resistance of TPU is slightly better than that of TPE. In addition to grease and oils, TPU performs better when exposed to chemical agents or other potentially harmful fluids [6][9]. However, both materials are water resistant, which covers the most significant need for the bracelet [8].

Material Comparison

When comparing the materials Thermoplastic Elastomers, TPE, and Thermoplastic Polyurethane, TPU, there are numerous pros and cons for each. In a general sense, TPE does better when comparing flexibility, elasticity, cost, environmental friendliness, and surface finish/smoothness. In contrast, TPU is better suited when it comes to durability, tensile strength, and chemical or temperature resistance. When these qualities are aligned with those that are paramount for the product, the better option is still not quite clear. A quantitative comparison between the two materials is shown in the decision matrix found in Table 1.

Table 1: Decision matrix for selecting between TPE and TPU

		TPU		TPE	
Weights	Factors	Raw Score (/10)	Weighed Score	Raw Score (/10)	Weighted Score
15	**Manufacturability**	**8**	120	**9**	135
10	**Durability**	8	80	6	60
10	**Tensile Strength**	7	70	6	60
15	**Elasticity**	7	105	9	135
20	**Rigidity**	9	180	8	160
20	**Cost**	7	140	9	180
10	**Surface quality**	6	60	10	100
100			**755**		**830**

The material that ends up coming out on top, however, seems to be the Thermoplastic Elastomers. Although the durability and rigidity is not as good as that of the Thermoplastic Polyurethane, the lower cost and greater comfortability of the material fits the best with the product necessities, being as it is designed for daily use and the budget of school districts.

Gate and Runner System Design

In order for the band to be injected properly, a well-configured gate and runner system was designed. The band has a center thickness of 0.4 cm, and the wrist wrap has a uniform thickness of 0.2 cm. As a result, the gate and runner system had to be installed on the center of the part, so that the material would be uniformly distributed. The filling time was 0.5 seconds for each of the designs due to the relatively small size and low material each band has to be filled up with.

The first design considered is shown on the left model of Figure 1. This design met the specification of having a gate and runner system that injects the material through the part uniformly. Also, the sink mark was placed on the center of the part since it will be covered with other electronic components (not shown in the report). The gate is placed to appropriately allow little to no warpage on the edges of the band, specifically on the far-right hollow region as shown in Figure 2. The only major drawback of this gate and runner system is that the weld line is placed in an area where there is a high-stress concentration, and the cross-sectional area of these 2 connecting paths are the smallest, as shown in Figure 3, hence they are likely to fail under high stresses.

The second gate and runner System design considered is shown in the middle of Figure 1. The following design improved the weld line problem in comparison to the first design as shown in Figure 3. However, warpage was present on the far left and far right of the band. Therefore, some of the parameters must be altered to remove this warpage effect.

The third design was a combination of the first and second design as shown on the far right of Figure 1. The thought process on this design was to remove the warpage introduced on the right side of the band from the second design. However, the 3-gate runner system created more warpage on the right side of the bracelet, increased weld lines on the band, and introduced a new sink mark.

The design chosen for optimization and improvement was the second design, since warpage can be reduced by changing the process values such as the cooling time, packing time and packing pressure. Additionally, it has the most desirable outcome in terms of weld lines.

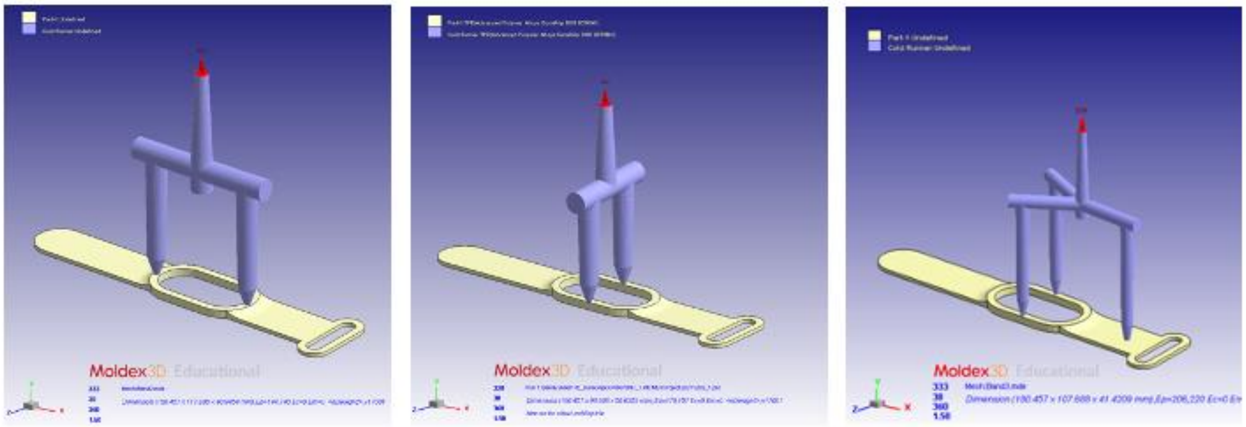

Figure 1: The three different chosen gate configurations

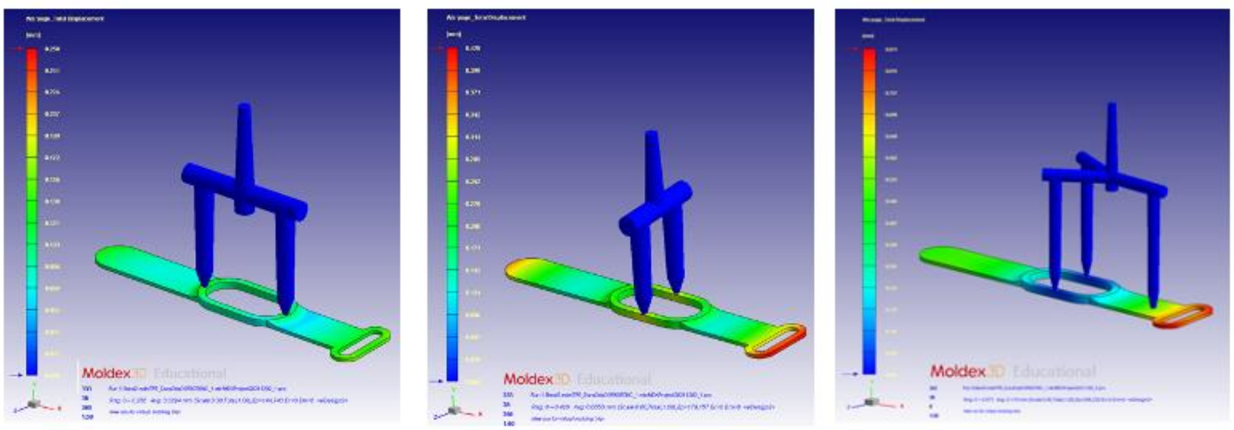

Figure 2: Warpage on the three different chosen gate configurations

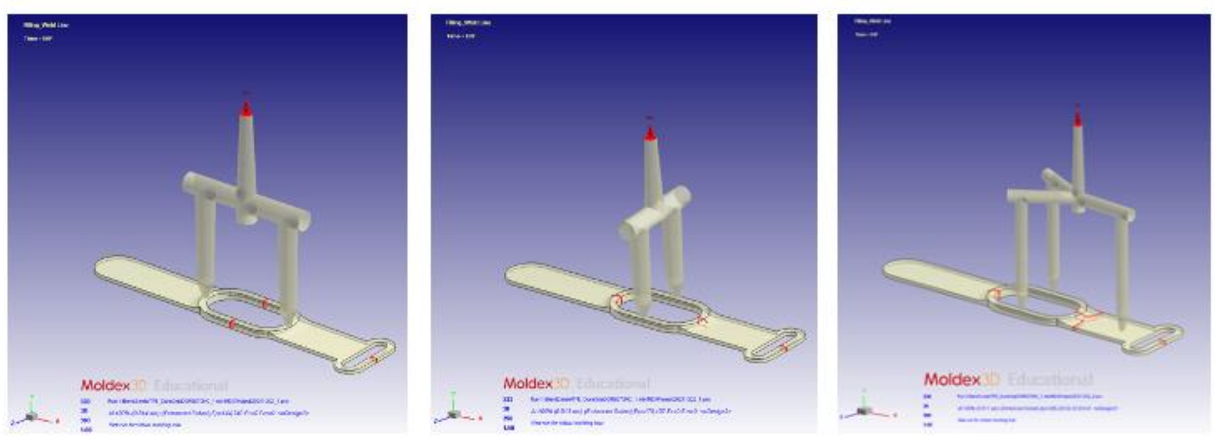

Figure 3: Weld Lines on the three different chosen gate configurations

Modification of Process and Configuration

After analysis of the chosen gate and runner system design, optimization of this design began. Due to the warpage on the far left and right side of the band, variables such as cooling time, packing time, and packing pressure were altered in order to achieve more desirable results. In comparison to the initial design specifications, the packing time was increased from 5 seconds to 7 seconds, and the packing pressure was increased from 250 MPa to 300 MPa. This was in hopes of creating an environment where the warpage on the outer parts of the band was less likely. The results of this configuration seemed to alleviate the warpage on one side of the band -- the side without the loop. However, the loop side of the band still contained a considerable and unacceptable amount of warpage. Next, the cooling time was increased from 11 seconds to 20 seconds. Again, this improved on the previous characteristics, however, did not fully solve the problem of warpage in the full width of the band loop.

Change of Runner Size

The runner size was changed from 10.8 mm to 6.8 mm to increase the pressure drop on the gate. This improved the warpage from the previous designs, as shown in Figure 4.

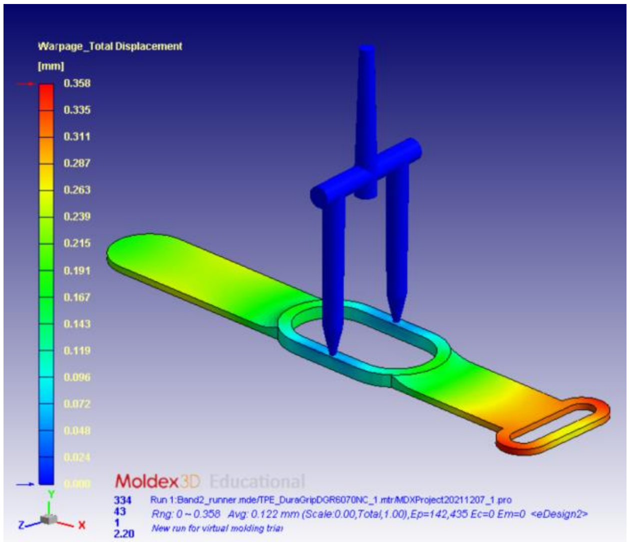

Figure 4: Warpage of the optimized design

Although this change decreased the flow rate for the runner system, it provided positive results for our design goals and obstacles. The negative change of increased time due to decreased flow rate was worth the improvement in other areas, such as the pressure drop.

Optimized Design

The final design was a combination of changing the gate size and increasing the cooling time and packing pressure. Packing pressure was applied to force more molten material into the thicker areas, minimizing the effects of differential shrinkage [9]. Thus, with an increased amount of cooling time, the warpage was significantly reduced in comparison with the base design. The characteristics of the optimized design are shown in Table 5 of the appendix.

Analytical Calculation

The analytic pressure drop of the optimized runner system can be calculated by combining the pressure drops individually from each pipe. These geometries are tapered pipes and straight pipes. The equations for calculating the pressure drop in the tapered pipe and straight pipe are shown in equations 1 and 2, respectively.

$$\Delta P_x = \frac{8\mu L_x Q}{\pi (R_x)^4} \tag{1}$$

Where μ is the viscosity of TPE calculated; L_x is the length of the straight pipe; Q is the volumetric flow rate of the filling process, and $R_x$is the radius of the pipe.

As for a tapered pipe,

$$\Delta P_x = \frac{8\mu L_x Q}{3\pi} \cdot \frac{{R_O}^2 + R_O R_L + {R_L}^2}{{R_O}^3 {R_L}^3} \tag{2}$$

R_0 is the entrance radius and R_L is the radius at the exit of the tapered pipe.

Since the system has a single sprue that divides into two gates, the pressure drop for each gate will be calculated separately and then summed together as shown in equation 3 and Figure 5.

$$\Delta P_{total} = \Delta P_1 + \Delta P_2 + \Delta P_3 + \Delta P_4 + \Delta P_5 + \Delta P_6 \tag{3}$$

The calculation steps for each variable are shown in Appendix B. A summary comparing the analytical pressure drop, and the simulated pressure drop is shown in Table 2.

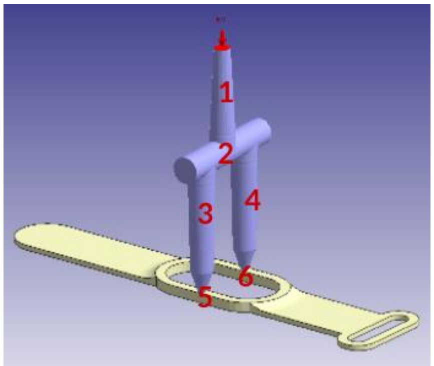

Figure 5: Individual geometries location

Table 2: Analytic and simulated pressure drop for the gate and runner system

	Pressure Drop (MPa)
Analytic	4.722
Simulated	3.00638

The theoretical pressure drop found from calculations was found to be 4.722 MPa. This is only slightly larger than the pressure drop found in Moldex3D. This discrepancy could be due to the viscosities used for calculations being somewhat inaccurate. The viscosity was found from the plot in Figure 8, so the exact value could not be determined accurately. Also, the points picked for the experimental values were subject to human error, which could have accounted for the discrepancy.

Summary

The settings of our optimized design focused on decreasing warpage as much as possible and eliminating any weld lines in vulnerable areas. This design consisted of a two-gate runner system, with a decreased runner size. The manufacturing processes that were chosen for this design include increasing the cooling time, increasing the residence time, and increasing the packing pressure, due to their ability to decrease warpage. Overall, our proposed design will fit the product specifications by minimizing the weld lines along where the bands will most likely bend, thereby increasing the tensile strength of the band and its durability. The cooling and packing times were minimized to increase the rate of production and decrease the cost of manufacturing. In addition to decreasing production time and weld lines along the band's rotation, the design reduced warpage, so that the shape of the band would stay intact. In a real manufacturing operation, the processes would need to be optimized in efforts to decrease the final production time for each band. Realistically, even if the final design ended with perfect quality results, the time is a lot for a production of this magnitude and would need to be decreased before manufacturing.

References

[1] https://en.wikipedia.org/wiki/Thermoplastic_elastomer
[2] https://en.wikipedia.org/wiki/Thermoplastic_polyurethane
[3] https://omnexus.specialchem.com/selection-guide/thermoplastic-polyurethanes-tpu
[4] http://www.cavosmart.com/which-kind-of-material-is-smart-bracelet-silicone-tpe-tpu/
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[9] https://www.sciencedirect.com/topics/engineering/packing-pressure

Appendix

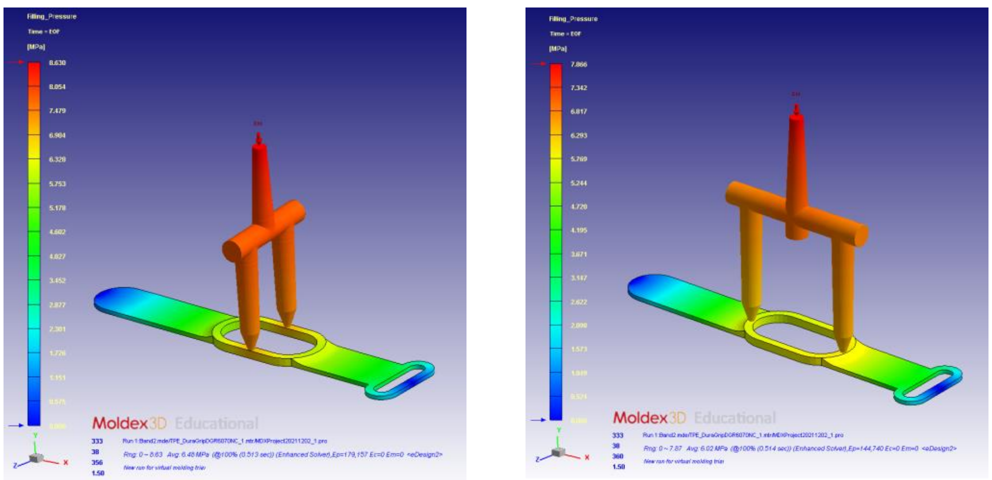

Figure 6: Filling pressure for the different gate configurations

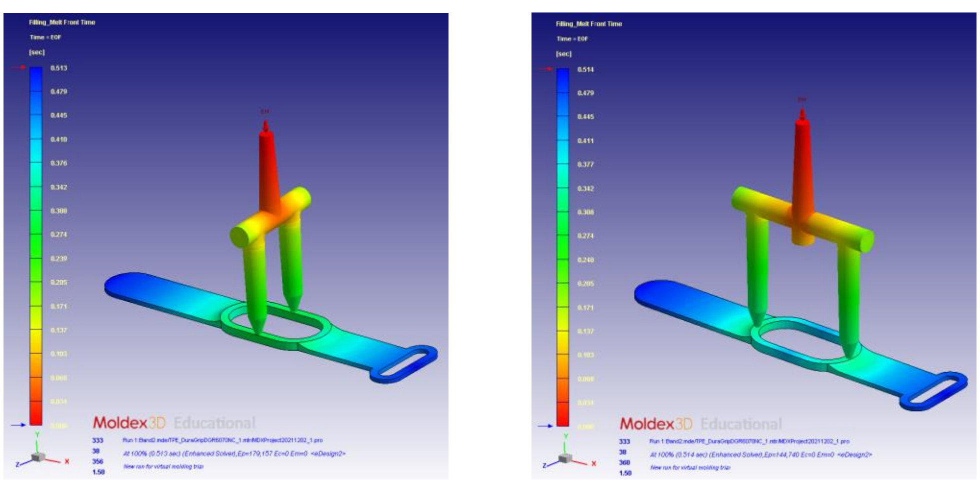

Figure 7: Filling time for the different gate configurations

Table 3: Characteristics of the first simulation

Filling time (sec)	0.5
Melt Temperature (oC)	200
Mold Temperature (oC)	50
Maximum injection pressure (MP...	250
Injection volume (cm^3)	21.704
[Packing]	
Packing time (sec)	5
Maximum packing pressure (MPa)	250
[Cooling]	
Cooling Time (sec)	11
Mold-Open Time (sec)	5
Eject Temperature (oC)	80
Air Temperature (oC)	25
[Miscellaneous]	
Cycle time (sec)	21.5
Mesh file	Band2.mde
Material file	TPE_DuraGripDGR6070NC...

Table 4: Characteristics of the second simulation

Filling time (sec)	0.5
Melt Temperature (oC)	200
Mold Temperature (oC)	50
Maximum injection pressure (MP...	250
Injection volume (cm^3)	21.704
[Packing]	
Packing time (sec)	7
Maximum packing pressure (MPa)	300
[Cooling]	
Cooling Time (sec)	11
Mold-Open Time (sec)	5
Eject Temperature (oC)	80
Air Temperature (oC)	25
[Miscellaneous]	
Cycle time (sec)	23.5
Mesh file	Band2.mde
Material file	TPE_DuraGripDGR6070NC...

Table 5: Characteristics of the third and optimized simulation

Filling time (sec)	0.5
Melt Temperature (oC)	200
Mold Temperature (oC)	50
Maximum injection pressure (MP...	250
Injection volume (cm^3)	13.9902
[Packing]	
Packing time (sec)	7
Maximum packing pressure (MPa)	300
[Cooling]	
Cooling Time (sec)	20
Mold-Open Time (sec)	5
Eject Temperature (oC)	80
Air Temperature (oC)	25
[Miscellaneous]	
Cycle time (sec)	32.5
Mesh file	Band2_runner.mde
Material file	TPE_DuraGripDGR6070NC...

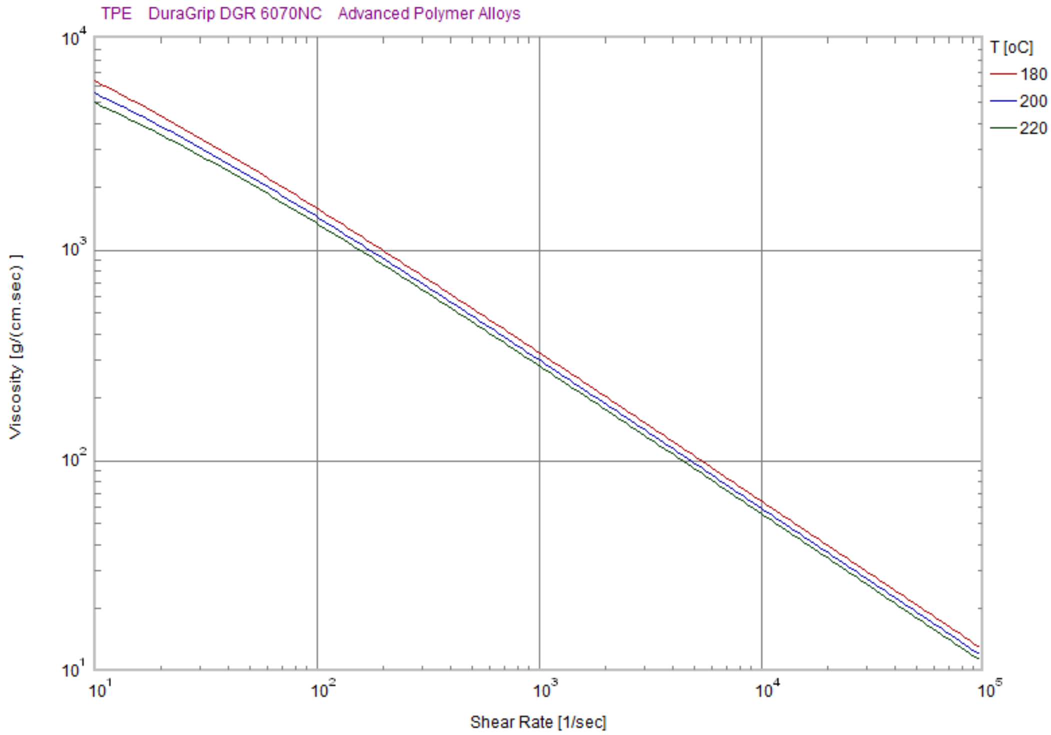

Figure 8: Viscosity as a function of shear rate plot from Moldex3D