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Extrusion Line Start-up and Operation

by Shawn Cole

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Weapons and Materials Research Directorate, CCDC Army Research Laboratory

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1. Purpose

The purpose of this report is to detail the start-up procedure for both single- and twin-screw extruders with various dies and attachments. Additional notes and tips are provided throughout the procedures.

2. Experimental Procedures

2.1 Thermo Fisher Scientific HAAKE Rheomex 19/33 OS Single-Screw Extruder with 90° Die

2.1.1 Start-up

- 1) Turn the Thermo Fisher Scientific (Waltham, Massachusetts) HAAKE PolyLab RheoDrive OS 16 power switch to the “on” position.
- 2) Log in to the extruder computer and open PolySoft software. Opening the software prior to starting the drive unit can sometimes cause the software to crash, or make the software unable to communicate with the drive unit. In the event that the software crashes, exit the software and restart the program. If the problem persists, reboot the computer and turn the drive unit off and then back on again while the computer reboots.
- 3) Ensure that all pressure and temperature sensors are affixed correctly to the die. The software should automatically recognize the die (or any other attachment that is connected), but in the event that it does not, follow these steps:
 - a. Go to “Device” and click “Setup”.
 - b. Click the “Die” tab.
 - c. Under “Die type” select the die that is being used; in this case, it is a rod capillary die with $D = 2.0$ mm and an $L/D = 20$.
 - d. Select the heating mechanism “Die ring heater” and select the heater that the die is connected to on the extruder.
 - e. Select “OK”.
 - f. A dialog box will pop up to confirm a reset of the changes that are made. Select “Yes”.
- 4) Change the temperatures at each of the five zones (four on the extruder, one on the die) to match the desired temperature profile for your extrusion run.

- 5) Go to the extruder and select the green button to turn on the heaters. Allow the heaters approximately 0.5–1 h to ensure that the entirety of the extruder is at the desired temperature.
- 6) After the extruder is at the correct temperature, calibrate the instrument by zeroing the torque and pressure as follows:
 - a. Select “Device” and then “Calibrate”.
 - b. Click “Select all” and then click “Do calibration”.
 - c. Each of the sensors selected should now read 0.00.
- 7) A chiller is attached to the feed throat of the extruder to prevent bridging from occurring during feeding. The temperature should be kept significantly lower (e.g., 20 °C) than the melting point of the polymer.
- 8) There are several different feeding mechanisms available for extrusion in L1130 including gravimetric, volumetric, and standard hopper feeders (Figs. 1 and 2).
 - a. Gravimetric feeder: The user must be trained to use the gravimetric feeder. The sensitivity of the feeder allows the most consistent feeding out of the three feeders, but can also be damaged easily. A mass balance is used to determine the amount of polymer the feeder is dispensing while tracking the remaining mass in the hopper. The user can set the feed rate in kg/h from 0.75 kg/h up to approximately 30 kg/h, depending on the polymer.
 - b. Volumetric feeder: The polymer feed rate can be controlled using software in PolySoft OS when using volumetric feeders. The feeder uses Controller Area Network connections and the software will automatically load it once it is connected to the extruder. The hopper can be filled with polymer pellets and then the user must set a screw speed to control the rate that the polymer is fed into the extruder. The feed rate can be determined using a tared container and a stopwatch to measure the amount of material being fed per unit of time. The accuracy of this method is dependent on the timed measurement or measurements and assumes that the feed rate remains constant at a specific screw speed.
 - c. Gravity feeder/hopper: When using the standard hopper, fill the hopper with polymer and start the screw speed at 10 revolutions per minute (RPM) until the torque begins to build in the barrel. This type of feeder is useful during single-screw extrusion when the operation is completed in a flood state.



Fig. 1 A) gravimetric and B) volumetric feeders



Fig. 2 Gravity feeder attached to a single-screw extruder

- 9) Click the boxes for “n [rpm]”, “M [Nm]”, and “p50 [bar]”. Three dialogue boxes should appear. Click the “Graph” tab at the bottom of the software. It is helpful to arrange the dialogue boxes around the plot.
- 10) The axes should be setup to show the torque and pressure at the die. To set up the axes, click “View”, then click “Graphic”, and then click “Axes”. Adjust the axes by clicking on “Scaling” and change the minimum and maximum values for the plot.

2.1.2 Operation

- 1) The extruder can now begin operation. Go to the drive unit and press the green “Drive enable” button. The extruder screws will not turn without the drive being engaged.
- 2) Start the extruder at a low RPM (10–20 RPM) and gradually increase the screw speed.
 - a. The extruder must begin at low RPMs when processing high viscosity polymers, such as high-density polyethylene (HDPE), to avoid overpressurizing the die. If the pressure limit is reached, the extruder will stop running, the alarm will trip, and the screws will stop rotating.

Reset the alarm and begin extruding at a slower screw speed. If the pressure remains too high at the die, increase the die temperature or unscrew the die and clean out any polymer blockage. Begin extruding at a slower screw speed.

- 3) If using a gravimetric or volumetric feeder, the feed rate can be increased incrementally as the screw speed is increased. The extruder will reach a steady state once a balance between feed rate and screw speed is achieved. The torque and die pressure curves will have very little fluctuation. An example of pressure and torque curves of extruding HDPE is shown in Fig. 3.

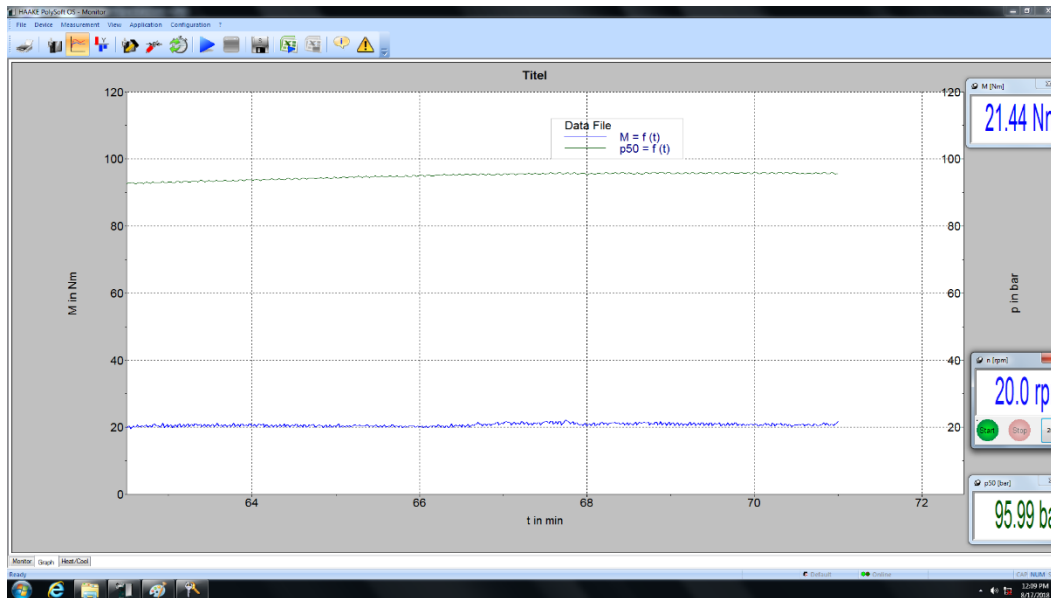


Fig. 3 Pressure and torque curves for HDPE filament once equilibration is reached

- 4) A conveying belt or water or oil bath can be used to cool/quench the filament before spooling. The filament thickness may also be drawn down by the spooling unit if a thinner diameter is desired.
- 5) After the extrusion run is complete, run a purge with a similar melt temperature through the system with varying pressures. Run the extruder until it is empty of the purge material.
- 6) Turn off the heaters, chiller, and drive unit after closing out of the software.

2.2 Thermo Fisher Scientific HAAKE Rheomex 19/33 OS Single-Screw Extruder with 150-mm Slit Die and a Melt Pump

2.2.1 Start-up

- 1) The start-up for the 150-mm slit die and the melt pump setup is the same as the 90° filament die except for the following:
 - a. Prior to turning on the heaters, the user may have to add the die and melt pump in the “Device” setup page. The user must add the correct heating sources to the die and melt pump by using the drop-down menus provided.
 - b. After the temperature profile is set, the heater on the extruder can be turned on. Turning this on also turns on the heaters in the melt pump. However, if you turn off the heaters on the extruder, the melt pump heaters do not automatically turn off. The user must press the red button on the melt pump to turn the heaters off. The melt pump will also be effectively turned off when powering down the drive unit.
 - c. During the heat-up phase, the user must monitor the pressures in p50, p51, and p52. The pressure sensors are shown in Fig. 4. Sensor p50 is in the die, p51 is the pressure between the die and the exit of the melt pump, and p52 is the pressure between the inlet of the melt pump and the bypass valve. The steel connections between these pressure sensors take longer to get to temperature than the die and melt pump themselves because they are not heated directly. Heated tape or extruder barrel heaters are used to ensure a uniform temperature profile throughout the entire process. **WARNING: The entire line must be at temperature prior to starting the extruder or overpressures will occur.**

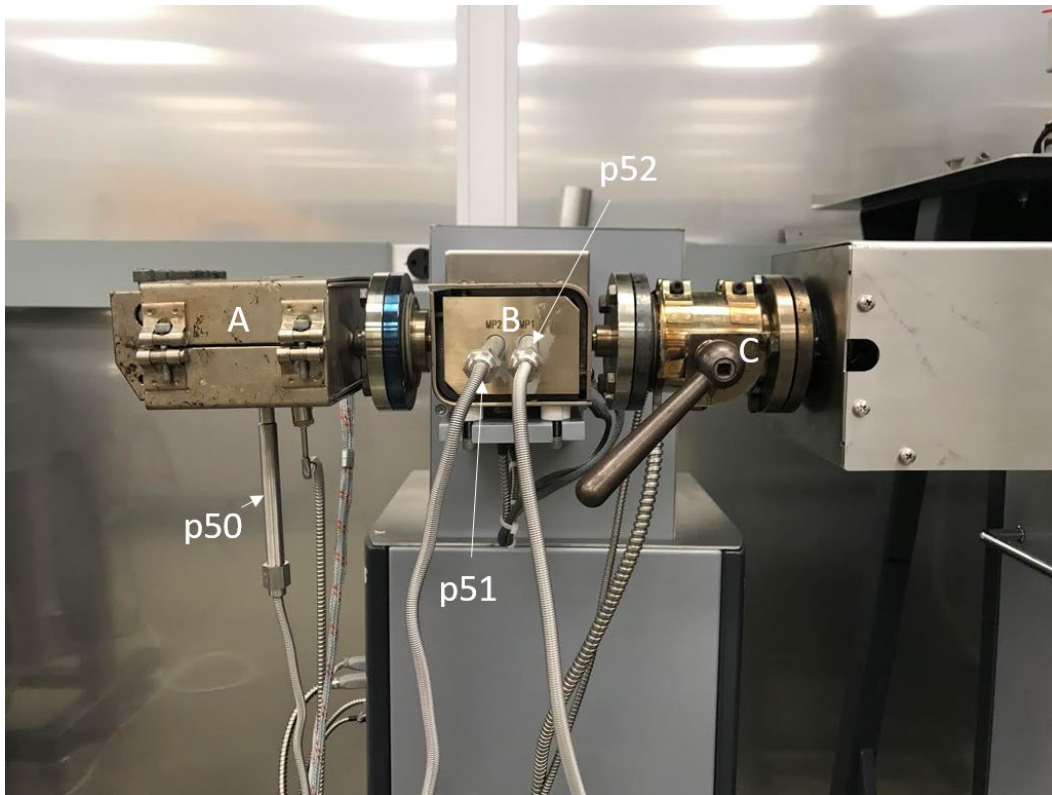


Fig. 4 A) die, B) melt pump, and C) bypass valve; pressure sensors p50, p51, and p52

2.2.2 Operation

- 1) The extruder can be started at a slow screw speed (10–20 RPM) until polymer begins flowing out of the bypass valve and onto the floor. The bypass valve should be completely open during start-up. The user can then adjust the screw speed and feed rate until a steady state is reached.
- 2) Start the melt pump at a slow screw speed via the dialogue box on the PolySoft software. There may be a slight rise in pressure at the die from residual polymer being pushed out. Check to see that the die gap is at its widest thickness. The thickness can be adjusted by rotating the screws found at the front of the die lip (Fig. 5).

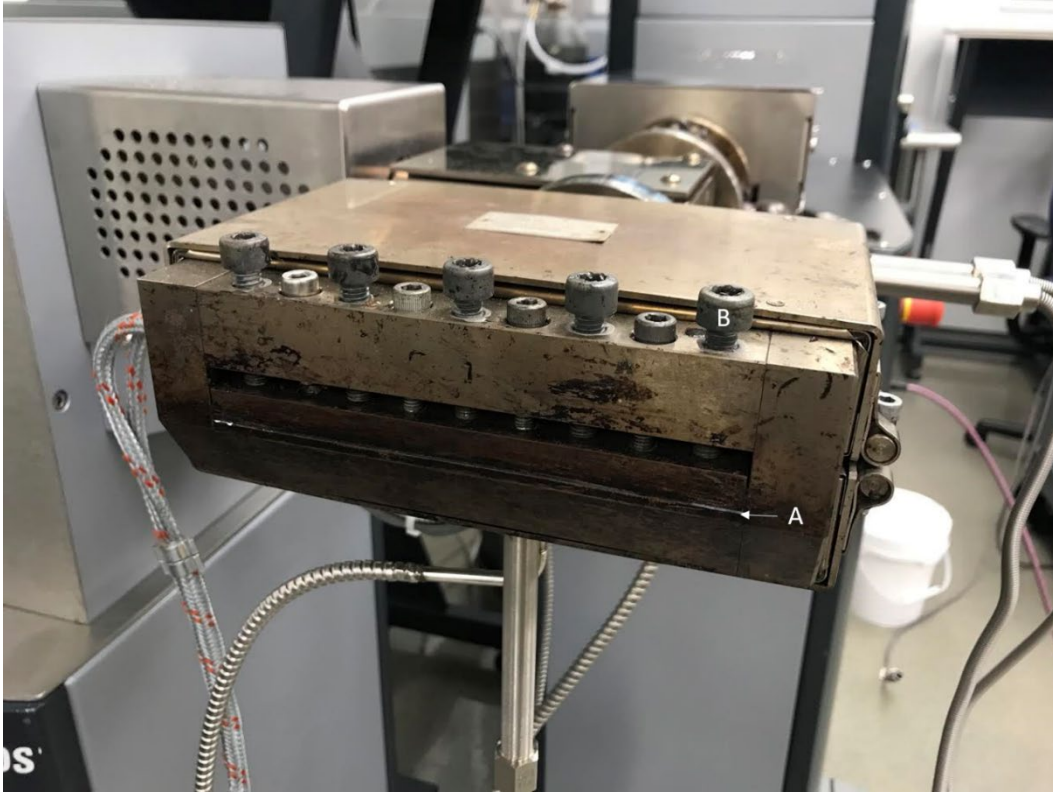


Fig. 5 A) die gap and B) tension screws to control the gap width

- 3) Begin gradually closing the bypass valve while monitoring the rise in pressure at p52. As the pressure rises at p52, increase the melt pump's screw speed until there is a pressure rise at p50. The melt pump is now moving polymer from the bypass valve region to the die, and p52 will drop while keeping p50 constant. The user can continue closing the bypass valve by adjusting the melt pump's screw speed to equalize the pressure in the system. Once the bypass valve is fully closed, there will be no waste generated and the pressure at p52 will be controlled by the feed rate. Uniform films will only be produced when the sensors p50 and p52 are at a steady state of constant pressure. Inconsistencies in the pressure would most likely be attributed to a variation in feed rate but may also arise from the feedstock itself (i.e., escaping water during melt due to ineffective drying).
- 4) The film commonly contains residual polymer from a previous run flowing out with it when the extruder is first running. To reduce the amount of residual polymer, run purge through the extruder for 15–30 min to remove as many impurities from the polymer melt as possible. It should be noted that it is very difficult to remove all of the impurities without simply running the desired material through the extruder until no more impurities are observed.

- 5) When the film is impurity free, move the take-up unit as close to the lip of the die as possible without touching it. Turn the take-up unit on and begin winding the film over the first two rollers. The take-up unit controls the tension in the film with a gripping roller after the film passes over the first two rollers. The user can set the tension by adjusting the dial on the take-up unit.
- 6) To adjust the film thickness, first tighten the screws along the lip of the die in equal iterations. Allow the film to extrude for a few minutes and then measure the thickness across the length and width of the film. Changes to the system should be evaluated after a few minutes pass so that the system can equilibrate. Overtightening the screws on the die can cause the polymer melt to split while in the die, resulting in a broken film. If the film is still too thick and the gap cannot be closed anymore, adjust the tension of the wind-up unit to draw the film down. Note: Drawing the thickness down will also result in a decreased film width. Decreasing the gap width at the die lip will increase the pressure at the die, increasing the likelihood of overpressure.
- 7) If die lines appear in the film, remove the wind-up unit from in front of the die lip and use a brass shim with a thickness less than the die gap to remove any material that is stuck in the back of the die. Only use tools that are present in L1130 as they have been carefully selected for use on the extruders. Non-brass tools can permanently damage the extruder and eliminate the ability to produce high-quality films without refurbishment.
- 8) When the run is finished, feed a suitable purge through the extruder to clean out residual polymer. Vary the pressure in the system by changing the loading of the purge that is being fed. Stop the purge feed and allow the entire system to run until the purge has exited the extruder.
- 9) Turn off the heaters on the melt pump and extruder as well as the chiller used to cool the feed throat. Turn off the drive and exit the software.
- 10) **IMPORTANT:** Turn the bypass valve to the fully open position before the residual polymer in the system solidifies.
- 11) Die cleaning (only for trained personnel):
 - a. Initial cleaning should be done at the temperature of the previous run so that the polymer can be easily removed and the die taken apart while the polymer is still molten.
 - b. All cleaning should be done with cloth, brass, or wood. Using anything harder runs the risk of damaging the polished surface of the die.
 - c. Unscrew the four bolts that hold the heating band to the die (Fig. 6).

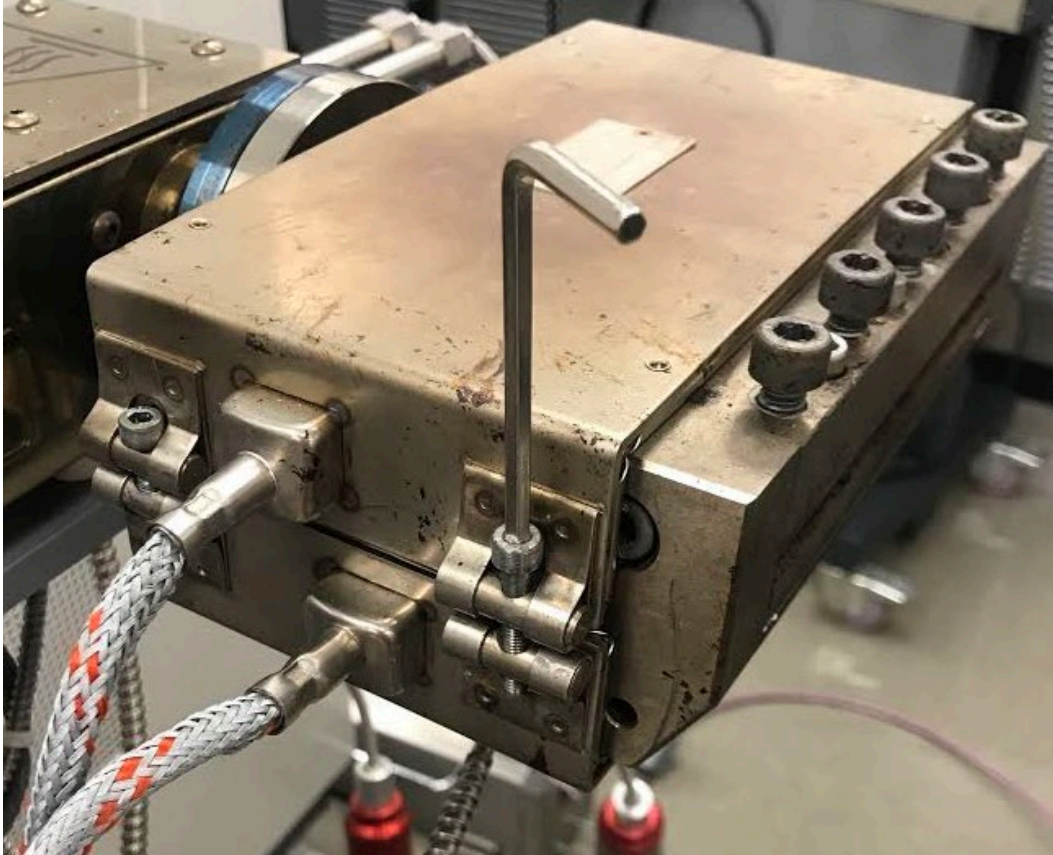


Fig. 6 Heater band on the die prior to removal

- d. Turn off the melt pump heaters and then remove the die pressure and melt temperature sensors. The heater band can now be completely removed from the die.
- e. Remove the die from the melt pump by loosening the screws and rotating the lock at the rear of the die.
- f. Place the die on a clean surface, making sure that the die lip is not face down.
- g. The die consists of five components: two side walls, a top and bottom, and then a port that connects the die to the extruder (Fig. 7).

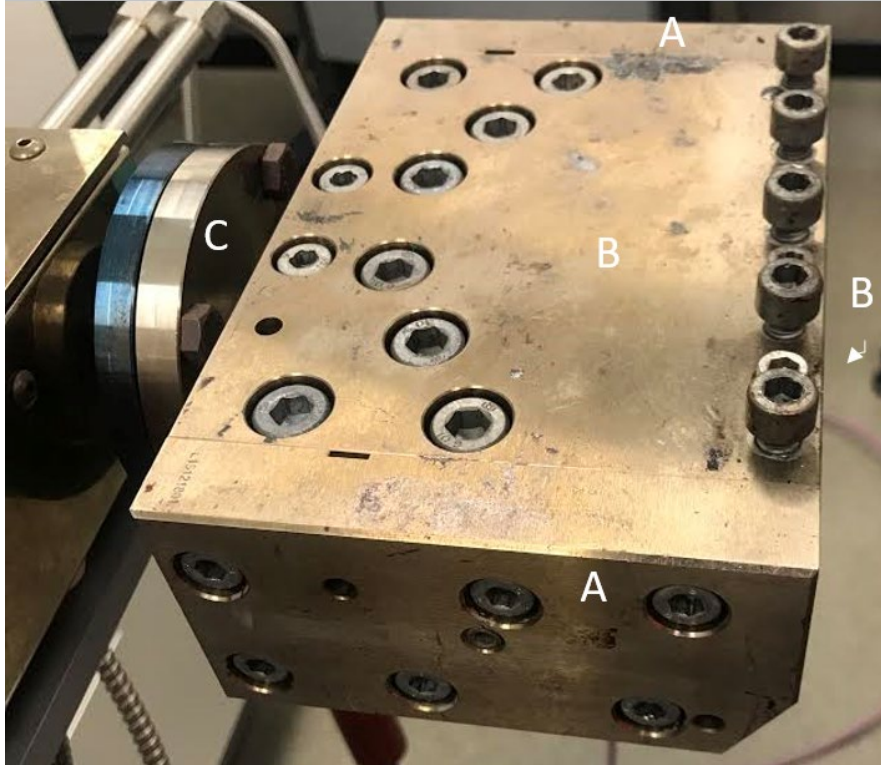


Fig. 7 150-mm slit die with the heating band removed; A) side walls, B) top and bottom sections, and C) connection port exposed

- h. Begin disassembling the die with a torque wrench. Start with the side walls first. Do not place any of the components with the polished surface face down or place anything on top of the polished surfaces to avoid damage.
- i. Use a brass brush to remove residual anti-seize lubricant from the threads of the bolts and then reapply a small amount to the threads for reassembly.
- j. Once the die is fully apart, use brass and wood tooling to remove any polymer that remains on the die faces. WD-40 is recommended by Thermo Fisher as a useful solvent to break down polymer and to lubricate the die's surface. Heating the individual components in an oven may be required if the die components cool before the polymer can be removed.
- k. Once the majority of the polymer is removed from the surface and the die cools to room temperature, the die faces should be cleaned with a die polish. Figures 8–10 show examples of what the die will look like upon disassembly (Fig. 8), after polymer removal (Fig. 9), and after applying die polish (Fig. 10).



Fig. 8 Die deconstructed to its individual components, A) side walls and B) top and bottom sections, with residual polymer prior to cleaning



Fig. 9 A) side walls, B) top and bottom sections, C) feed port into the die, and D) rotating locking mechanism with polymer removed and surface cleaned

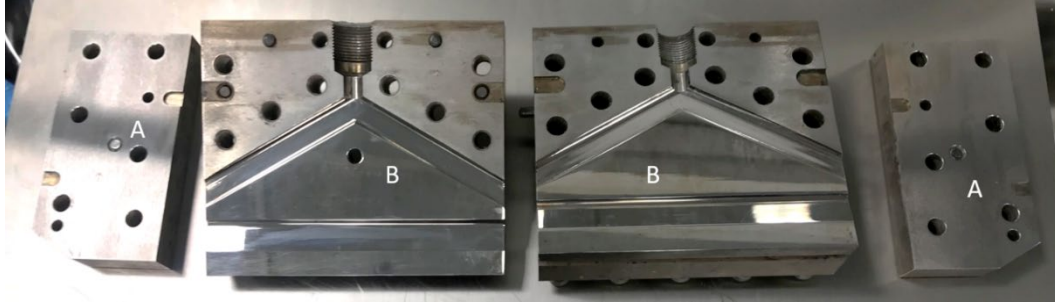


Fig. 10 A) side walls and B) top and bottom sections of the die after polishing

- l. Assemble the die back together. Hand-tighten the bolts in an alternating pattern to ensure an even distribution of pressure throughout the die. It is easiest to complete this step after the die components have cooled to ambient temperature.
- m. Use a torque wrench to tighten down the bolts on each interface according to the guidelines in Table 1.

Table 1 Guidelines for torquing down the bolts used to clamp the die components together

	8.8 (Metric grade)	10.9 (Metric grade)
M8	17 Nm	...
M10	...	50 Nm

- n. Reattach the lip die to the melt pump by rotating the lock and securing the screws.

2.3 Thermo Fisher Scientific HAAKE PTW16 Twin-Screw Extruder with 45° Die

2.3.1 Start-up

- 1) The start-up for the twin-screw extruder is the same as the single-screw extruder with the 90° die except for the following:
 - a. The twin-screw extruder uses 10 heating zones so the temperature profile can be customized more than on the single-screw extruder.
 - b. Twin-screw extruders are run in starve mode where the feed rate is less than the conveyance of the polymer along the screw. This means that the overall throughput of twin-screw extrusion is controlled by the feed rate, not by the screw speed.
 - c. The user may feed multiple components into the twin-screw extruders by opening up additional ports down the barrel and positioning the feeders accordingly, or have the components feed into the same port.
 - i. Screw design plays a significant role in the processing of multicomponent systems. The user must be trained on screw assembly and design prior to changing the screw's design.
 - ii. Gravimetric and volumetric feeders are typically used with twin-screw extruders because they can meter the components at set rates, which allows the user to operate the extruder in starve mode.

2.3.2 Operation

- 1) The operation of the twin-screw extruder follows the same guidelines as detailed in previous sections.

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