Diagnosis and Analysis of Screw and Barrel Wear in Twin-Screw Compounding Extruders
Presentation Outline

How and why extruders wear
  – Wear mechanisms
Where extruders wear
  – Process implications
Minimizing extruder wear
  – Solutions for abrasive and adhesive wear
Extruder Wear Mechanisms

Abrasive Wear

Corrosive Wear

Adhesive Wear
Analyzing extruder wear

**Abrasive Wear**

Erosion of metal surfaces due to harder materials (i.e. TiO$_2$) rubbing against softer materials.
Analyzing extruder wear

**Abrasive Wear**

Localized to regions experiencing high mechanical stresses

- Melting and mixing sections where abrasive materials are present
- Conveying sections developing pressure
- Formulation-specific problem

Smooth, rounded edges; polished surfaces
Analyzing Wear

Identifying abrasive wear

Abrasive wear is localized – identify where is the wear

Feeding
Melting
Mixing
Venting
Pressurization
Where is the wear?

Feeding abrasive fillers into the main feed port – TiO2, CaCO3, talc, etc… provides great dispersion at the expense of component lifetime.
Where is the wear?

As the flights of conveying elements are worn, conveying efficiency is reduced. As wear progresses, feed-limitation can be observed (i.e. backup into main feed port).
Where is the wear?

Feed Zone

Screw speed can be increased to compensate for reduced conveying efficiency – for a while. Note that rate of wear of conveying elements is accelerated with higher screw speed.
Where is the wear?
Where is the wear?

As the tips of kneading elements are worn, melting and mixing efficiency are reduced. As wear progresses, melting of resin(s) and mixing of additive(s) moves to downstream kneading elements.
Where is the wear?

As wear progresses, deterioration of physical properties results from decreased melting and mixing. Unmelted resin appears at side feeder, downstream mixing of fillers is affected (venting problem at side feeder).
Where is the wear?

Screw speed can be increased to compensate for reduced efficiency of kneading elements – for a while. Note that rate of wear of kneading elements is accelerated with higher screw speed.
As first kneading elements wear, melting is delayed – note mixing cannot start until melting is completed!
Wear in melting section can result in unmelted resin at side feeder – this is usually mis-diagnosed as wear in downstream mixing section!
Note that mixing does not begin until melting is completed – mixing time decreases with wear.
Where is the wear?

Similar to wear of conveying elements prior to the melting section – conveying efficiency also deteriorates as the downstream conveying elements wear and is observed as a feeding limit at the side feeder (backup).
Where is the wear?

Screw speed can be increased to compensate for reduced conveying and/or mixing efficiency – for a while. Note that rate of wear of conveying and kneading elements is accelerated with higher screw speed.
Where is the wear?

Feeding abrasive fillers downstream minimizes wear (compared to feeding in main feed port); first kneading element(s) exposed to filler experiences highest mechanical stress.
Where is the wear?

Similar to wear of kneading elements in the melting section – mixing deteriorates as the kneading elements wear and is observed as decreased physical properties. Filler appears in vacuum vent or on screens.
Where is the wear?

If clearances are enlarged (from abrasive wear) within the restriction element used to create a melt seal for vacuum, sustainable vacuum level is reduced.
Diagnosing a worn melt seal is easy – polymer is pulled from the vacuum port only under vacuum; at atmospheric pressure, polymer remains within the extruder screws.
Where is the wear?

Screw speed can be decreased to compensate for worn restriction elements to increase pressure drop – for a while. Note that melting and mixing are decreased at reduced screw speed.
Where is the wear?

As the flights of conveying elements are worn in the pumping section, conveying efficiency is reduced and the backup length required to develop pressure increases to upstream (i.e. unworn) conveying elements.
Where is the wear?

Screw speed can be increased to compensate for reduced pumping efficiency – for a while. Note that rate of wear of conveying elements is accelerated with higher screw speed.
Where is the wear?

With enlarged clearances in pumping section, melt backs-up further into last barrel.
Local Fill Factor

As wear progresses in pumping section, melt eventually backs-up into vacuum vent.
Where is the wear?

With enlarged clearances in pumping section, melt temperature increases from increased leakage flow.
Where is the wear?

With increased leakage flow, melt residence time increases (increased backup length).
Extruder Wear Mechanisms

Abrasive Wear

Corrosive Wear

Adhesive Wear
Analyzing extruder wear

**Corrosive Wear**

Erosion of metal surfaces due to chemical attack
Analyzing extruder wear

Corrosive Wear

Localized to regions experiencing chemical interaction between raw materials and metal surface(s)

- Addition of corrosive materials prior to mixing
- Reaction by-product(s) evolving from interaction between materials
- Formulation-specific problem

Rough, pitted surfaces
Corrosive Wear
Corrosive Wear
Corrosive Wear
Extruder Wear Mechanisms

Abrasive Wear

Corrosive Wear

Adhesive Wear
Analyzing extruder wear

Adhesive Wear

Rubbing of metal surfaces against each other
Analyzing extruder wear

**Adhesive Wear**

Localized to regions experiencing abnormal mechanical stresses

- *Inadequate screw support/centering*
- *Shaft deflection*
- *Incorrect screw assembly*

Can also be seen across the entire length of the extruder where chronic mechanical problems exist (i.e. gearbox timing, incorrect screw assembly, etc.)
Causes of Adhesive Wear

Adhesive wear WILL result when ALL of the following are not provided:

• Centering and support of shafts
• Proper timing and assembly of elements
• Proper coupling of shafts to gearbox
• Proper barrel alignment
• Lubricating film between screws/barrel
Diagnosing Adhesive Wear

**Extent of Adhesive Wear**

Some causes of adhesive wear produce symptoms that are **localized** to specific regions of the extruder.

Other causes of adhesive wear produce symptoms that can be seen across the **entire length** of the extruder.
Diagnosing Adhesive Wear

Evidence of Adhesive Wear

Some causes of adhesive wear produce forces resulting in screws contacting the barrel surface.
Diagnosing Adhesive Wear

Evidence of Adhesive Wear

Other causes of adhesive wear produce forces that result in screw-screw contact.
Causes of Adhesive Wear

Adhesive wear WILL result when ALL of the following are not provided:

- Centering and support of shafts
- Proper timing and assembly of elements
- Proper coupling of shafts to gearbox
- Proper barrel alignment
- Lubricating film between screws/barrel
Diagnosing Adhesive Wear

The viscous material within intermeshing, co-rotating twin-screw extruders acts as a dynamic bearing, providing support and centering of the screw shafts within the barrel – these "bearings" are located where the screws are filled.
The filled sections of the extruder are created by the screw design – so the screw design provides support and centering of the screws within the barrel.
Screw designs that do not provide filled sections within the extruder allow screws to “move around” within and “rub” against the barrel surface.
Screw designs that do provide filled sections, but not enough to support or center the shafts also contribute to adhesive wear (usually on large diameter and/or long L/D machines).
Adhesive wear from lack of support gets worse with low viscosity and/or high screw speed and/or high discharge pressure
Without adequate centering of the screw shafts, high discharge pressure can cause deflection (bowing) of the screw shafts – this condition produces adhesive wear on the outer screw flights over an extended L/D.
Normal Screw Profile

A

Smoothing surface on pushing side of flight

B

Abrasie Wear

“Mushroom” or “anvil” shape of flights that rub on barrel wall – on both pushing and trailing edges – very sharp edges

C

Adhesive Wear
Causes of Adhesive Wear

Adhesive wear WILL result when ALL of the following are not provided:

- Centering and support of shafts
- Proper timing and assembly of elements
- Proper coupling of shafts to gearbox
- Proper barrel alignment
- Lubricating film between screws/barrel
Diagnosing Adhesive Wear

Correct installation of screw elements on shafts and proper timing are required to maintain constant clearances – problems occur when spacers are omitted (e.g. ZME elements, offset kneading blocks, etc.)
Diagnosing Adhesive Wear

Evidence of improper timing – when the leading edge of one screw contacts the trailing edge of the adjacent screw, sometimes referred to as “chatter marks”
Diagnosing Adhesive Wear

If elements are not seated properly (gap between elements, e.g. from contamination) – then elements can move axially on shaft. Signs of adhesive wear are evident as improper timing, damage on leading/trailing edges of conveying screw flights.

Twisted screw shaft(s) produce the same effect as improper timing – evidence of adhesive wear begins where the shaft is twisted and continues to the end of the screws.
Diagnosing Adhesive Wear

While a rare occurrence, adhesive wear can also result from incorrect timing/orientation from the gearbox output shafts (shafts off by one spline) – in this case, the “chatter marks” are visible along the entire screw length (this machine would most likely also produce excessive vibration while operating).
Causes of Adhesive Wear

Adhesive wear WILL result when ALL of the following are not provided:

- Centering and support of shafts
- Proper timing and assembly of elements
- **Proper coupling of shafts to gearbox**
- Proper barrel alignment
- Lubricating film between screws/barrel
If one shaft does not seat completely into couplings – the other shaft will also not seat properly.

This condition allows axial displacement of the shafts relative to each other.

Adhesive wear (“chatter marks”) are observed throughout the entire machine, appears as improper timing.
Diagnosing Adhesive Wear

When inserting assembled screws into barrel, material within the barrel (polymer residue, pellets, etc.) can be pushed back behind the feed opening and prevent shafts from seating properly into the couplings.

Incorrect assembly of split rings in coupling assembly also creates a condition where one shaft can move axially.
Diagnosing Adhesive Wear

Shaft Components
Causes of Adhesive Wear

Adhesive wear WILL result when ALL of the following are not provided:

- Centering and support of shafts
- Proper timing and assembly of elements
- Proper coupling of shafts to gearbox
- Proper barrel alignment
- Lubricating film between screws/barrel
No adhesive wear observed here (barrel alignment OK)

Distinct separation where barrels meet

Adhesive wear from improper barrel alignment
Causes of Adhesive Wear

Adhesive wear WILL result when ALL of the following are not provided:

- Centering and support of shafts
- Proper timing and assembly of elements
- Proper coupling of shafts to gearbox
- Proper barrel alignment
- Lubricating film between screws/barrel
Analyzing Wear

*Identify your wear type*

Note that chronic adhesive wear requires a change in screw design to correct – and is NOT normal

Corrosive wear requires a metallurgical solution specific to the chemistry involved

Abrasive wear is the most common type of wear in compounding applications
How much wear is OK?

The answer is not straightforward – depends on product sensitivity with respect to dispersion; some materials cannot be produced when even small amounts of wear are observed, while other materials can be produced with severe wear on screws and barrels...

You need to wear down the machine until you produce ‘bad’ material – at this point, you can measure dimensions and understand your own threshold value for replacement of components.
Minimizing Abrasive Wear

Identify an appropriate metallurgical solution

Presentation describes wear of screw components – barrel wear *always* accompanies screw wear, usually at a slower rate

Reducing wear rate implies identifying suitable chemistry for materials of construction and fabrication method

- *Hot Isostatic Pressing (HIP)*
- *Powder Metallurgy (PM)*
- *Barrel liner, element crest welding, etc...*
Minimizing Abrasive Wear

Wear and Corrosion Comparison

- Blue bars represent Wear Rating.
- Green bars represent Corrosion Rating.

Materials compared:
- Nitralloy (Nitrided)
- CPM 9V
- CPM 10V
- 10V-12
- CPM 15V
- Cast Iron
- D2
- 420V
- 440C
- CS 460
- Inconel 625+
- Wexco 555
- Wexco 777
- 17-4 PH
Eliminating Adhesive Wear

Chronic adhesive wear

If screw design does not provide adequate support, changing metallurgy is not a solution – the screw design must be changed!

Gearbox timing, barrel misalignment, bent/twisted screw shafts all produce chronic adhesive wear and are caused by mechanical deficiencies – that must be corrected!
Eliminating Adhesive Wear

**Chronic adhesive wear**

If material does not provide adequate lubrication between screws/barrel (e.g. in feed zone) – there are metallurgical solutions to improve compatibility and reduce ‘galling’

Selection of compatible metallurgy between screws and barrels is critical to avoid adhesive wear in situations where it would not normally exist (i.e. where materials are incompatible – adhesive wear can develop during clean-out, for example)
Eliminating Adhesive Wear

One-time events

Adhesive wear observed after improper screw or coupling assembly – is caused by “human error” and requires proper training to avoid the same problem from occurring again.
Eliminating Adhesive Wear

Adhesive wear is NOT a normal condition

You should expect to replace extruder components from abrasive or corrosive wear, this is the cost to produce your material – like replacement of brakes, tires, etc. on your car.

If there are metal particles in the engine oil in your car – it is a sign that you have a serious (usually expensive) problem – but you need to check the oil to know that you have a problem. If you don’t bother to look – you will find out when your engine fails…
Questions?

Thank You!