



National Technical University of Athens
School of Chemical Engineering
Polymer Technology Lab.

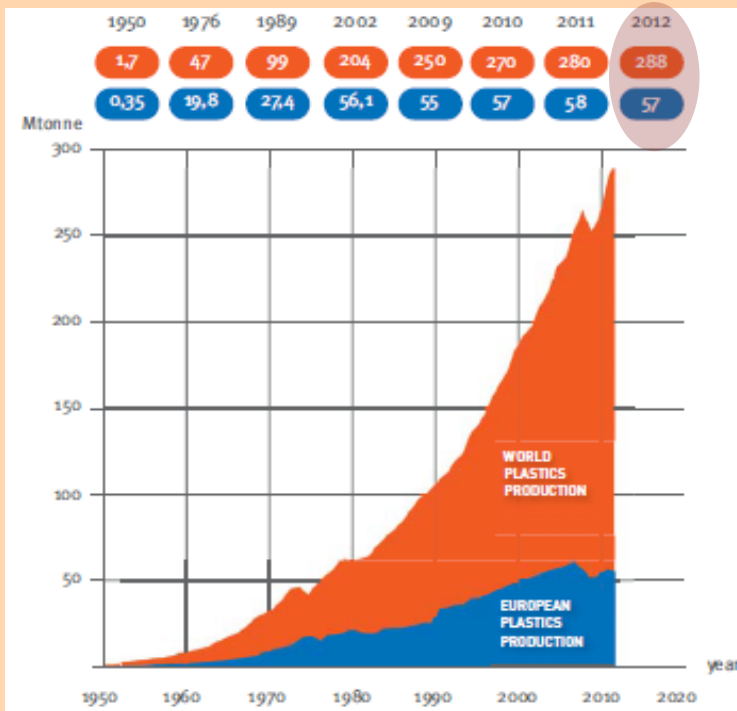


RECYCLING AND REUSE OF PLASTICS CONTAINED IN WASTE FROM ELECTRICAL AND ELECTRONIC EQUIPMENT

M.I.Triantou, P.A.Tarantili, A.G. Andreopoulos



Plastics production and demand



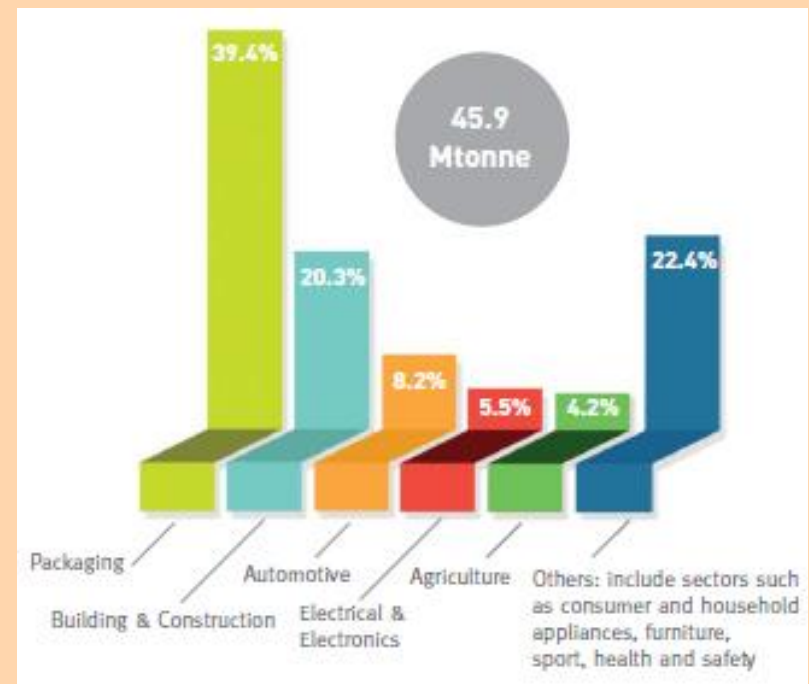
World plastics production 1950-2012

Source: Plastics Europe-Plastics – The Facts 2013: An analysis of European latest plastics production, demand and waste data

In 2012:

- ❖ demand in Europe decreased by 2.5% and reached 45.9 million tones,
- ❖ the electrical and electronic equipment sector covered the 5.5% of the european plastics demand.

- ❖ Global production of plastics in 2012 rose to 288 million tones – a 2.8% increase compared to 2011.
- ❖ In Europe, in line with the general economic situation, plastics production decreased by 3% from 2011 to 2012 reaching 57 million tones.



European plastics demand by segment 2012

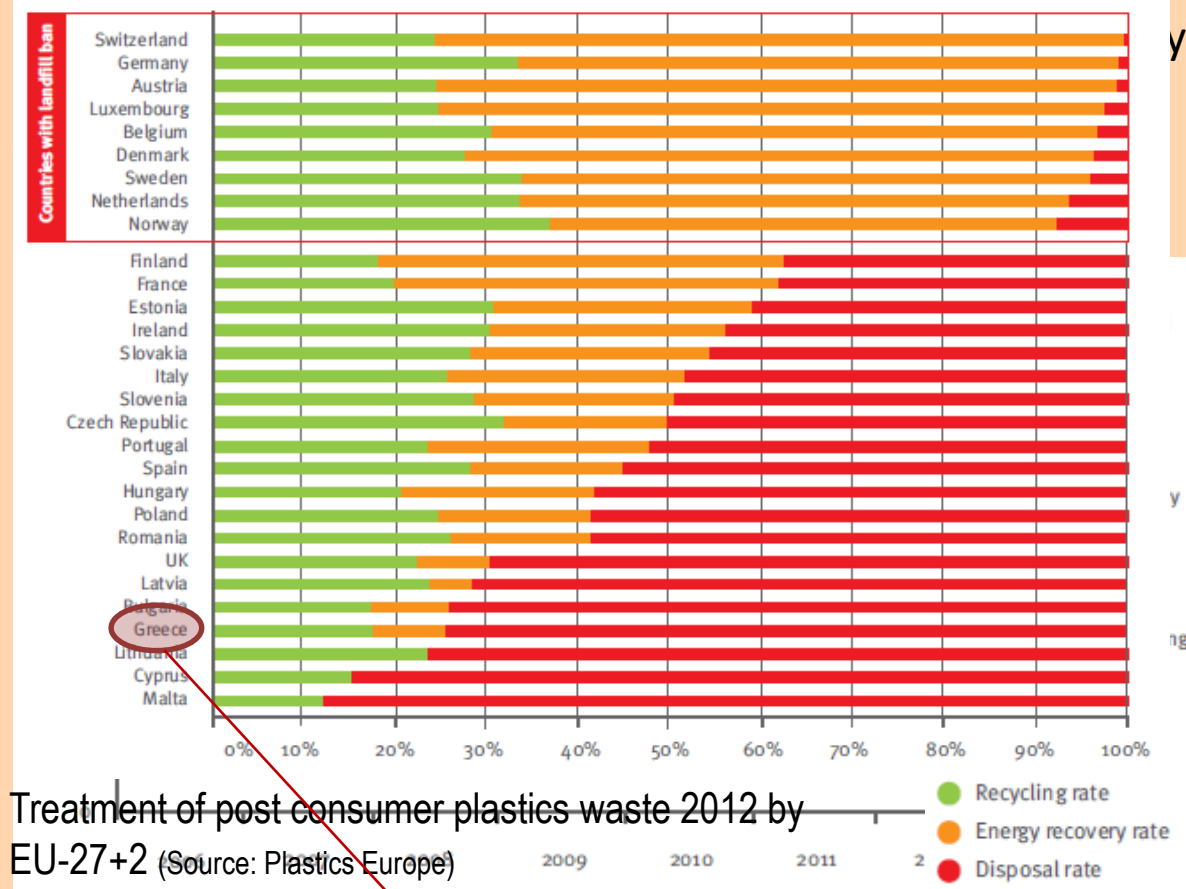
Source: Plastics Europe

Waste management of plastics



Disposal, recycling and energy recovery of plastics in 2012 in Europe
(Source: Plastics Europe)

❖ The total recovery of plastics increased by 4% in 2012



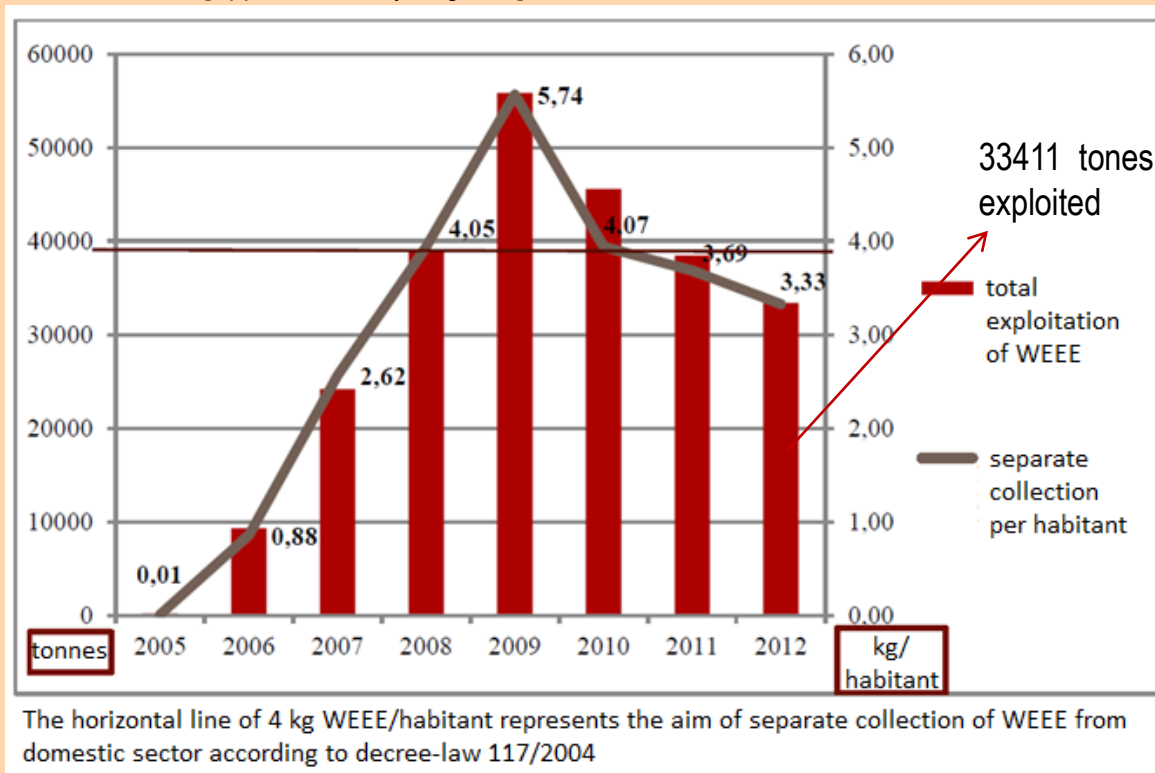
Treatment of post consumer plastics waste 2012 by EU-27+2 (Source: Plastics Europe)

Total plastics waste recycling and recovery 2006-2012 in Europe
(Source: Plastics Europe)

In Greece, recycling and energy recovery rates are still at low values.

Waste management of EEE

- ❖ The waste coming from EEE represents an about 8% of the total municipal waste internationally.
- ❖ In European Union, 12-20 kg WEEE/habitant is produced each year and their overall, annual production varies between 6.5-7.5 million tones [Hellenic Solid Waste Management Association].
- ❖ In Greece, 170.000 tones WEEE are produced per year [Hellenic Solid Waste Management Association].
- ❖ During 2005-2013 (1st semester), the 87.73% of EEE was treated, whereas the 12.27% was led to landfill in Greece [Appliances Recycling S.A.].

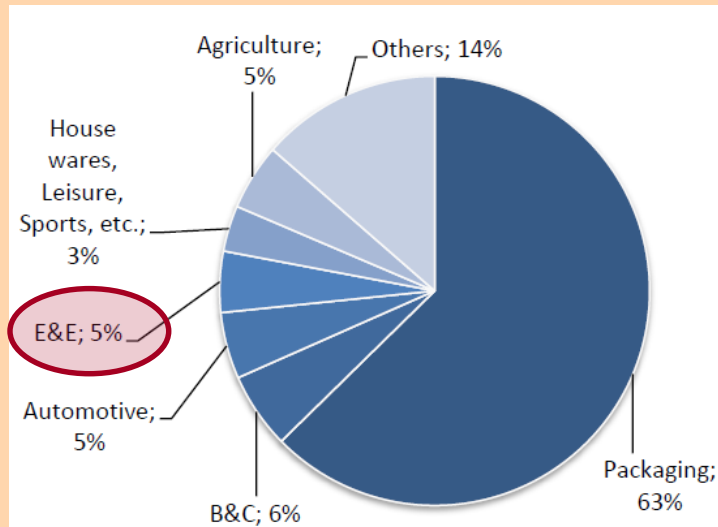


Total exploitation of WEEE (tones) and separate collection WEEE from domestic sector (kg/habitant) during 2005-2012 in Greece

(Source: eoan -Report of recycling in Greece, September 2013, Athens, 18-22)

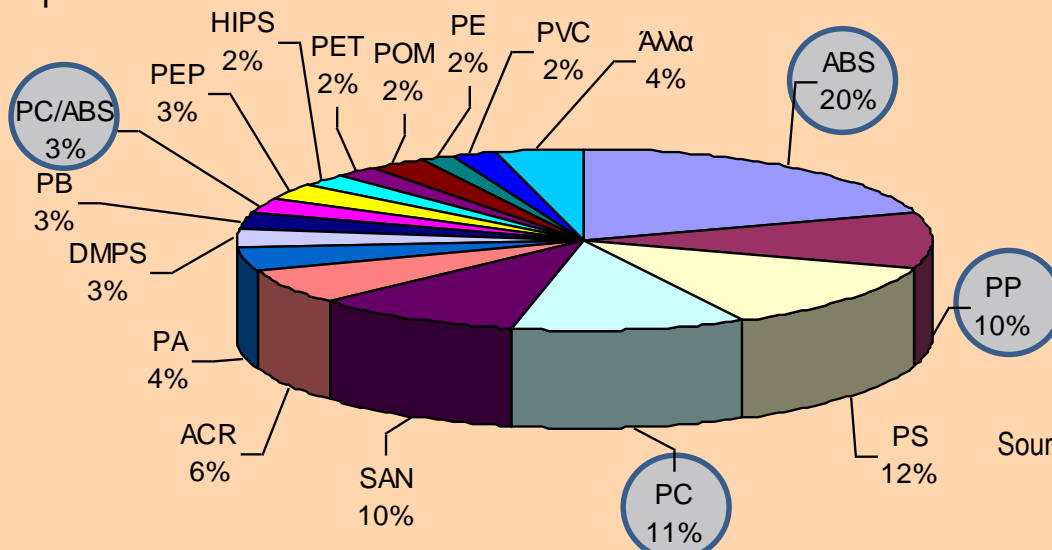
Composition of WEEE

- ❖ Packaging dominates the waste generated from plastics, covering 62.2% of the total. Other applications like building and construction, electrical and electronic products and agriculture count for 5 till 6% each [Plastics Europe] .

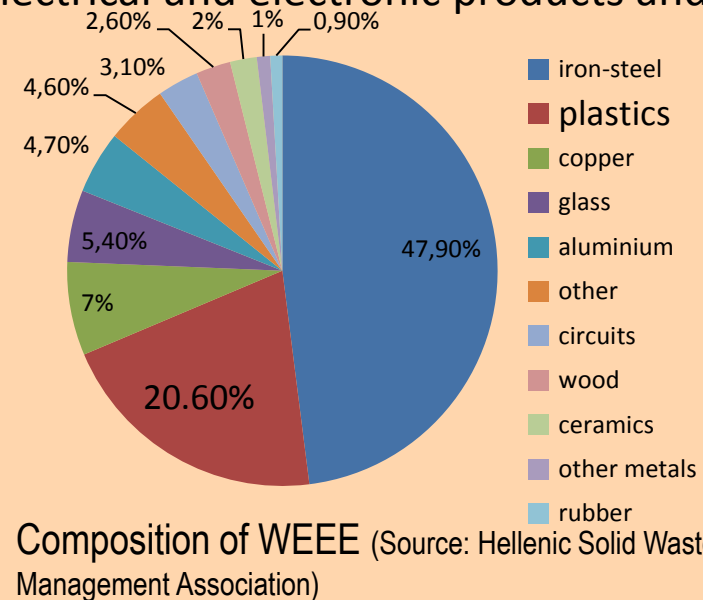


Generation of post-consumer plastics waste by application

(Source: Plastics Recyclers Europe)

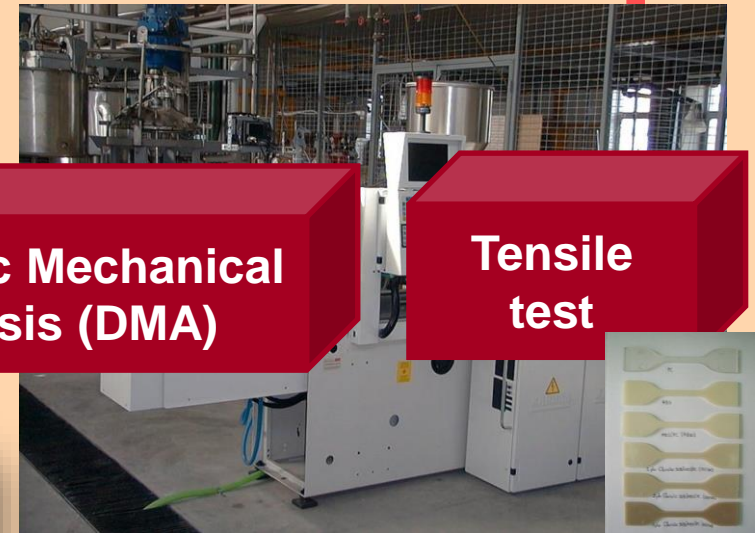
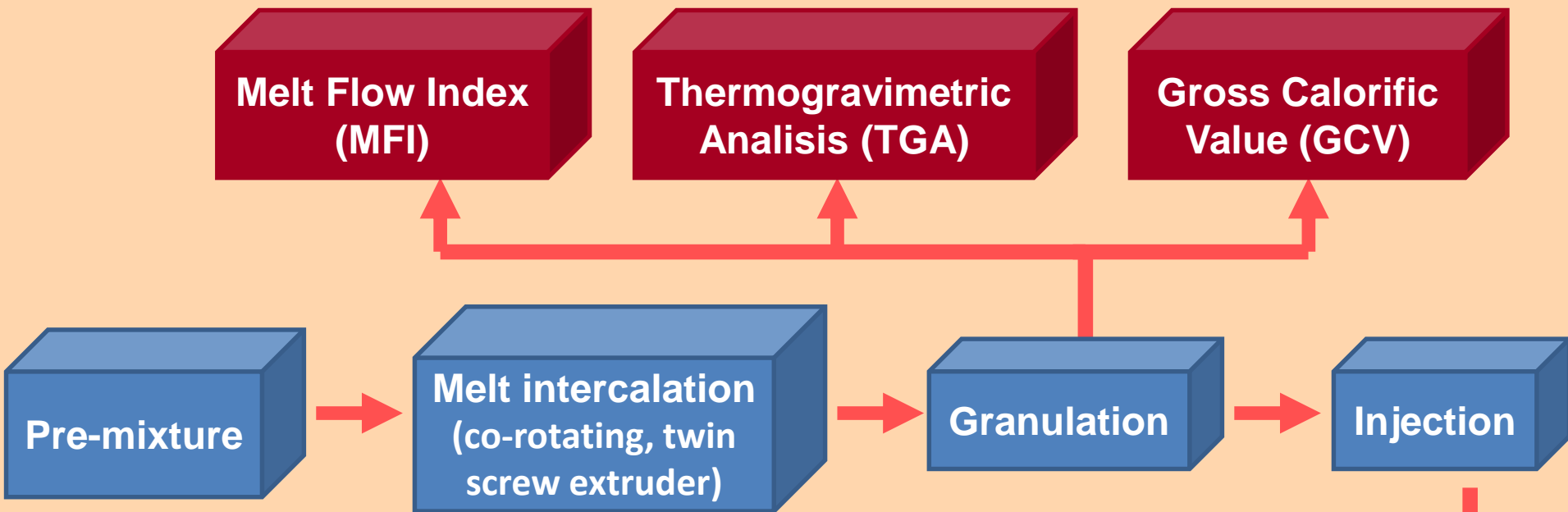


Source: WRAP, 2009



Composition of WEEE (Source: Hellenic Solid Waste Management Association)

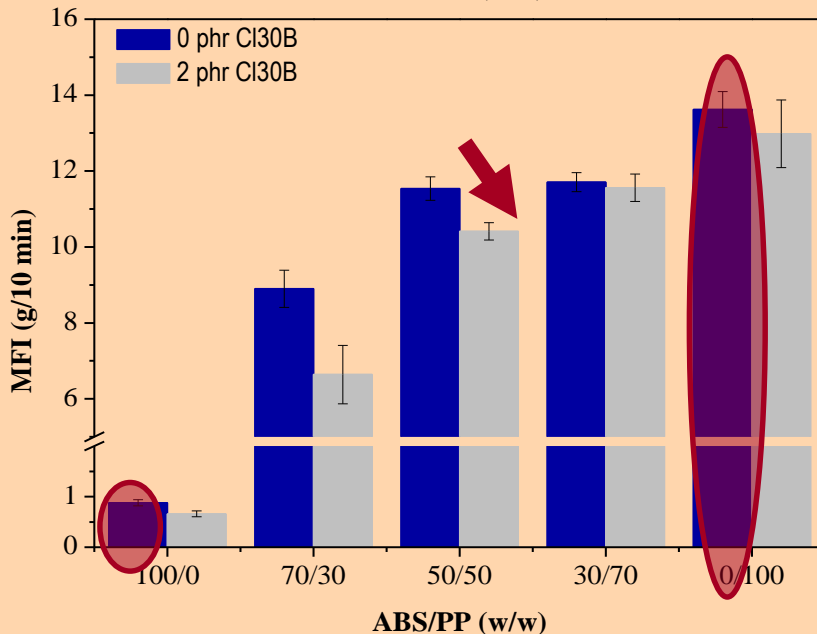
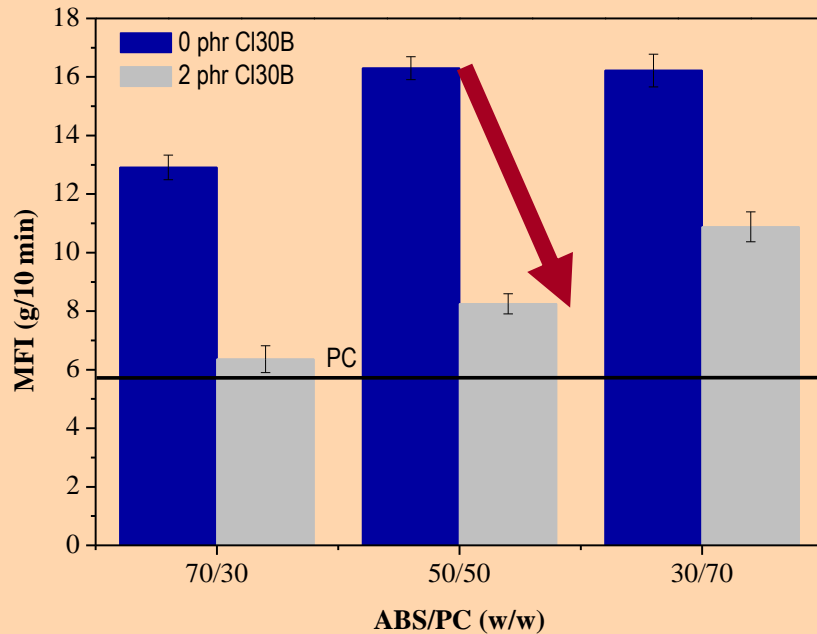
Experimental procedure



Dynamic Mechanical Analysis (DMA)

Tensile test

Melt Flow Index (MFI)



❖ The ABS/PC blends exhibit higher MFI than that of PC.

❖ ABS exhibits lower MFI than PP and ABS/PP blends presents melt behavior closer to that of PP.

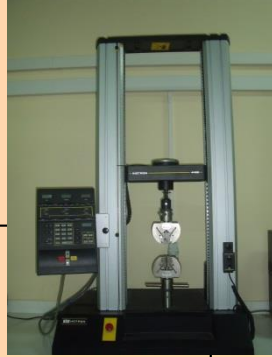
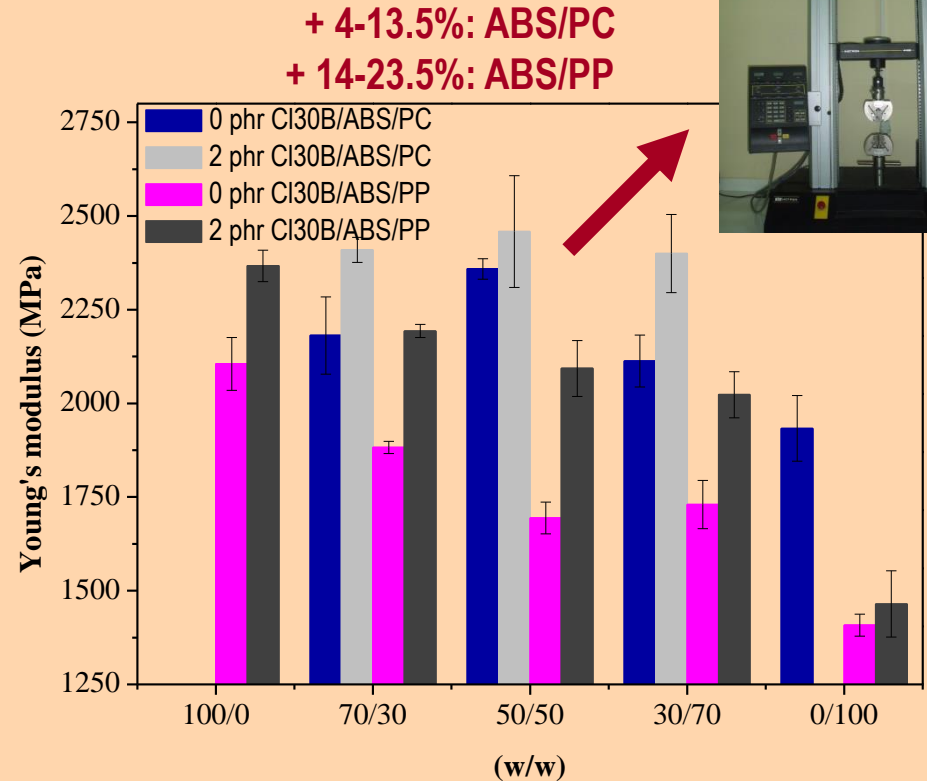
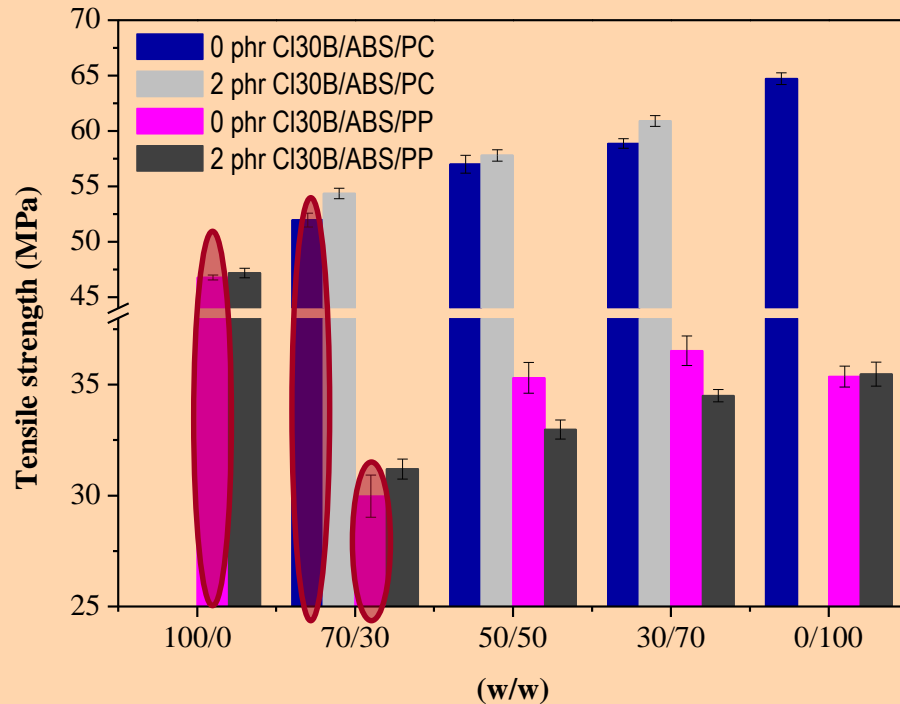
Blending of polymers is the key for the improvement of their processability.

❖ The incorporation of organoclay into the ABS/PC blends results in a decrease of the MFI, maybe due to the confinement of polymer chains motion, caused by organoclay platelets and tactoids, and the interactions between the polar groups of ABS and oxygen containing groups of Cloisite 30B.

❖ The MFI of ABS/PP blend tends to be decreased by incorporating OMMT.



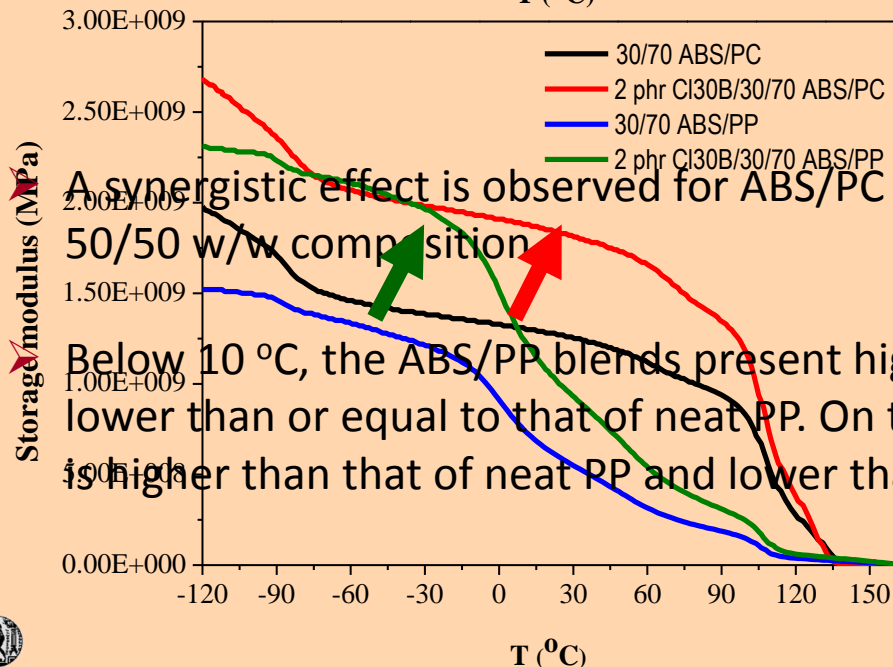
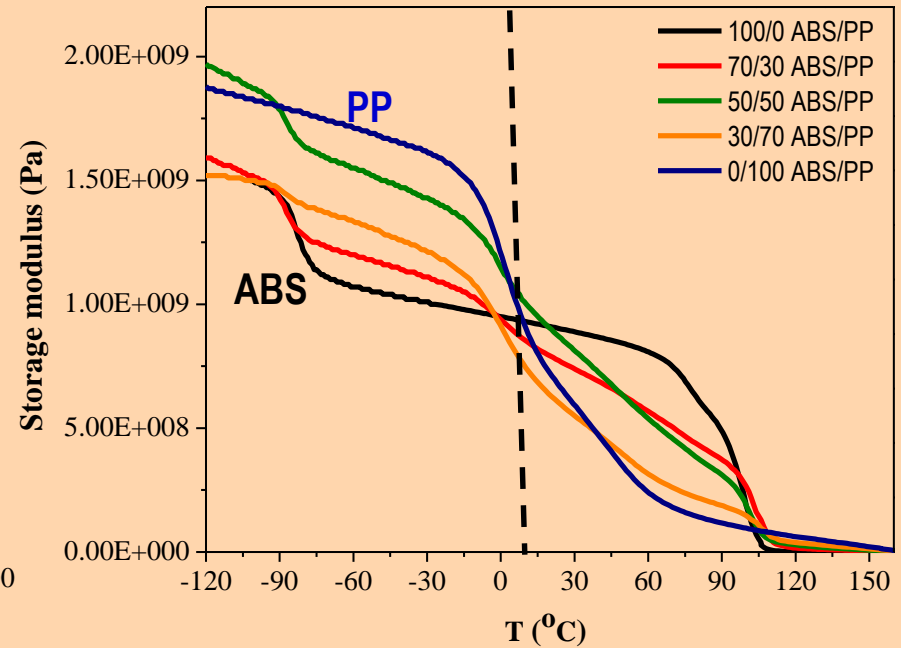
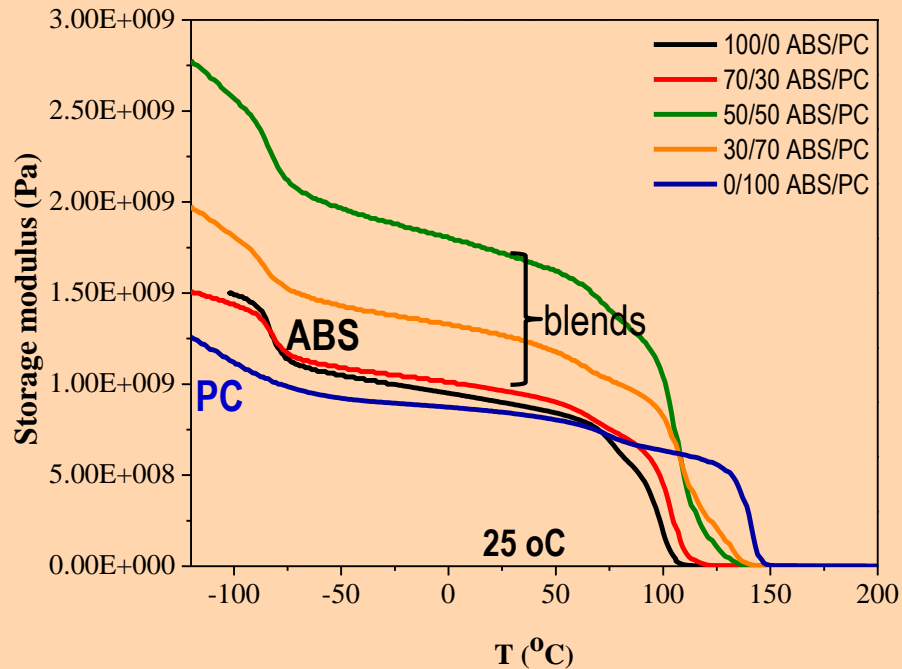
Tensile test



- In ABS/PC blends, a synergic action between the two polymers is observed for Young's modulus.
- The tensile strength of ABS is increased by the addition of PC, whereas it is decreased significantly by the addition of PP.
- In ABS/PP blends, the Young's modulus is decreased as the PP concentration is increased.
- The ABS/PC blend containing the clay significantly improves the Young's modulus of the examined blends.
- In ABS/PP blends, the tensile strength is closer to that of pure PP.
- The incorporation of organoclay in ABS/PC blends begins to reduce the modulus of the clay and to bring the low deformability of polymeric chains penetrating the silicate galleries.



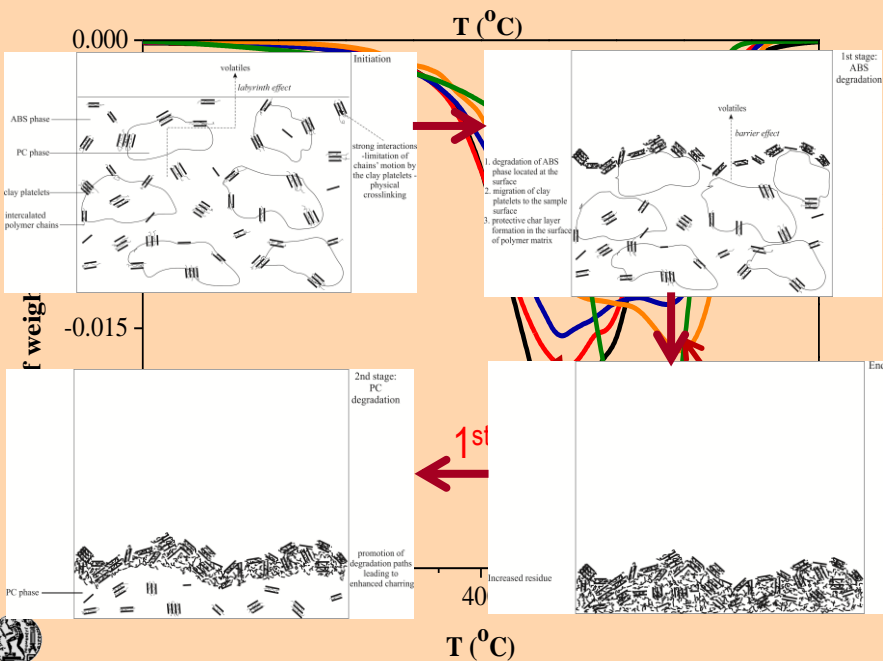
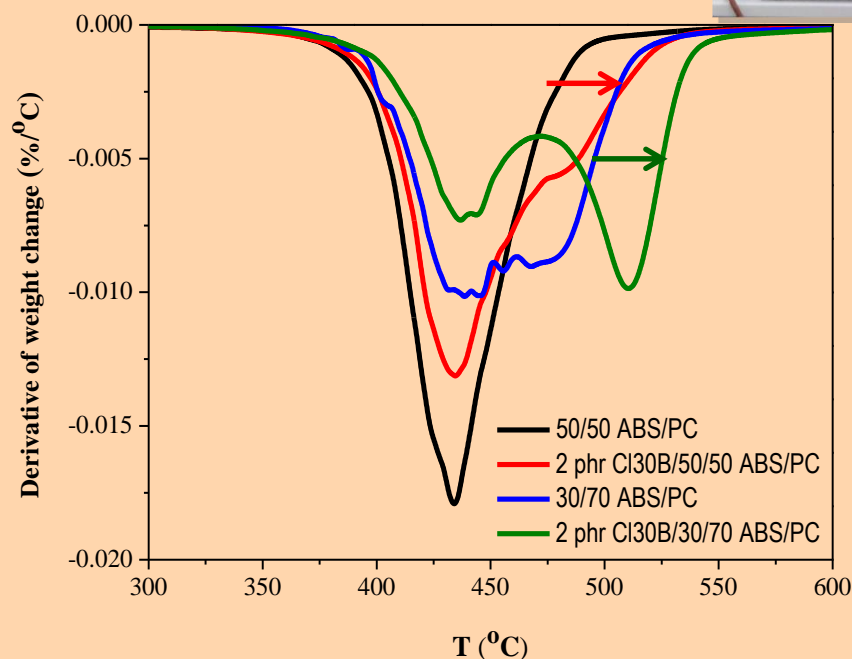
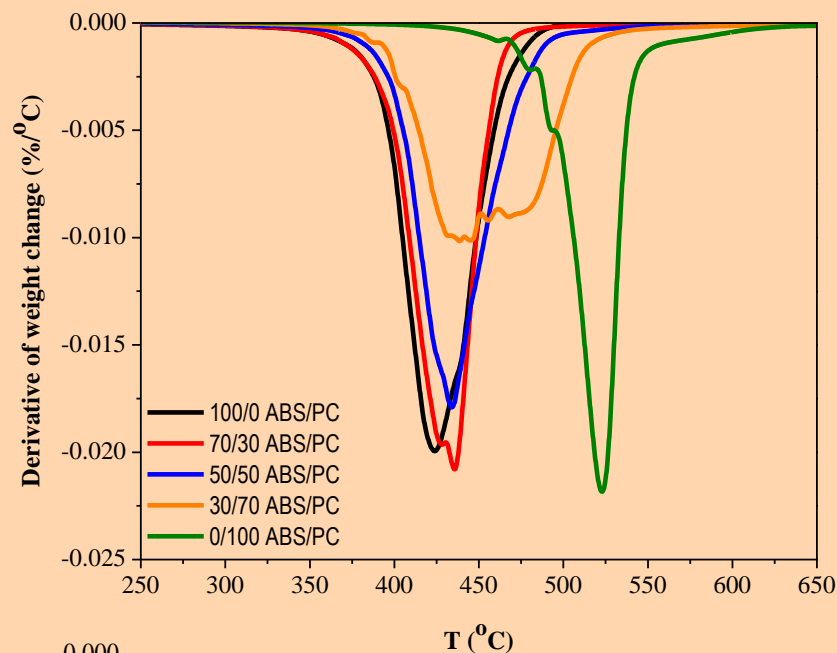
Dynamic Mechanical Analysis (DMA)



❖ The ABS/PC blends present higher storage modulus and the greatest value is recorded for modulus than that of ABS/PP blends.

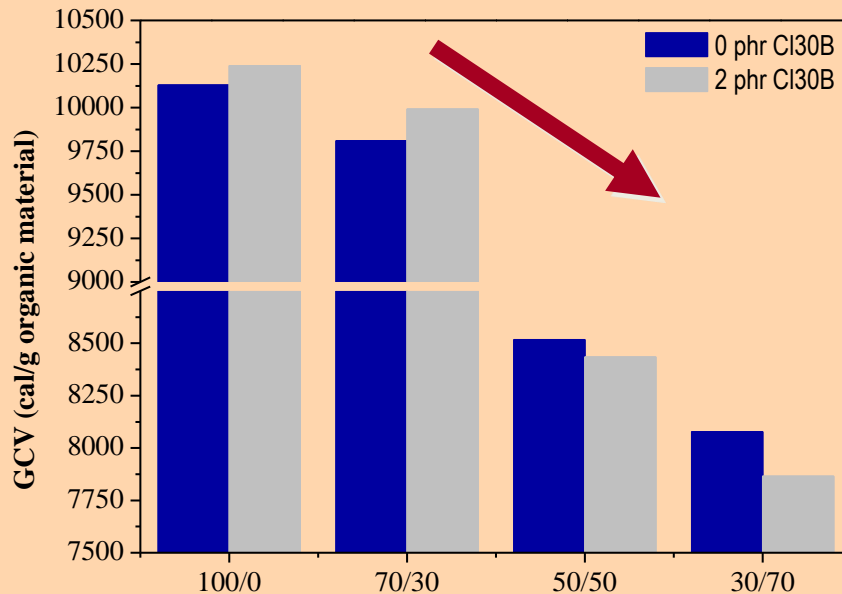
❖ The incorporation of organoclay leads to an impressive increase of storage modulus, in comparison with this corresponding to unreinforced blends.

Thermogravimetric Analysis (TGA)



The thermal stability increases with the following order: $ABS < PP < PC$. The OMMT seems to inhibit thermal degradation of the PC phase, which might be due to the creation of new paths of the degradation reaction and to the formation of a protective layer of nanoclay at the ABS/PC interface. The incorporation of clay platelets in PC-rich ABS/PC blends turns the thermal degradation mechanism to a two stages process and leads to higher values of char residue.

Gross Calorific Value (GCV)

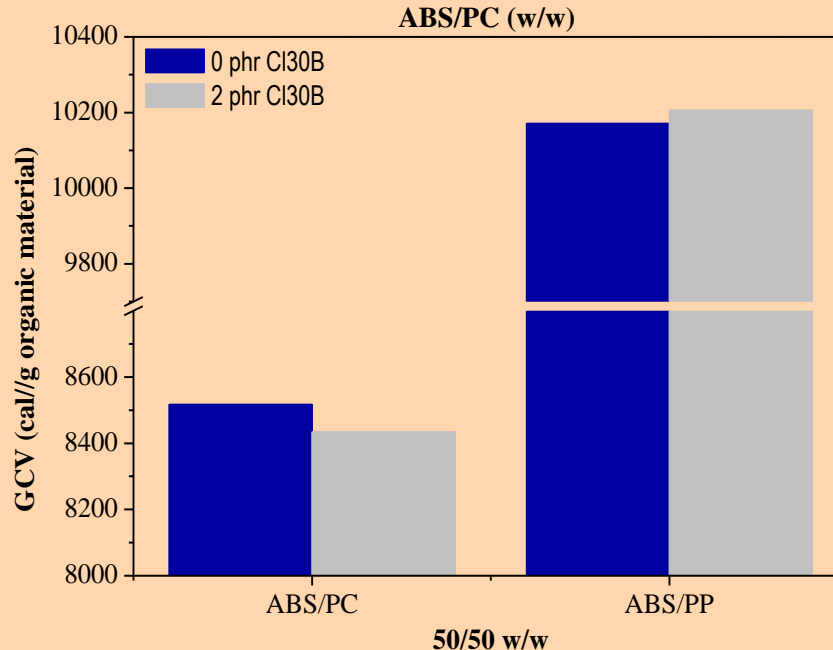


➤ The GCV increases with the following order:
PC < ABS < PP.

➤ As the PC content in ABS/PC blends increases, a reduction of GCV is observed, due to the poor burning characteristics of PC as compared with ABS.

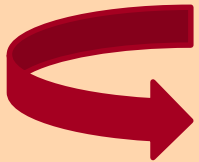
➤ The incorporation of OMMT to ABS/PC or ABS/PP blends does not have a significant effect.

➤ Emissions from hazardous substances in WEEE (heavy metals, halogens, organic components like brominated and chlorinated flame retardants) complicates the technical aspects of energy recovery.



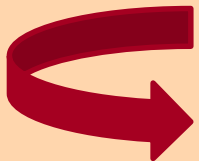
Conclusions

- ❖ The addition of PC in ABS matrix improves its thermomechanical properties, whereas the addition of ABS in PC matrix makes feasible its processing at lower temperatures.
- ❖ The addition of PP in ABS matrix increases its thermal stability, whereas the addition of ABS in PP matrix improves its mechanical behavior.



The blending of polymers used in WEEE is an appropriate procedure for their common management, which eliminates the time consuming and costly phase of sorting.

- ❖ The incorporation of OMMT to ABS/PC or ABS/PP blends leads to an increase of their melt viscosity, improves significantly the Young's modulus and the storage modulus and protects the PC phase during the thermal decomposition of PC-rich, ABS/PC blends.



The incorporation of organoclay to polymer blends is a low-cost and environmentally friendly alternative technique for the upgrading of their performance during their mechanical recycling.



Future Research

- ✓ Thorough investigation capability of Cloisite 30B to improved compatibility and performance of ABS/PC and ABS/PP blends.
- ✓ Extension of the study to other polymeric blends with various components (e.g. PC/SAN).
- ✓ Upgrading of the examined plastic blends by the incorporation of the appropriate amount of additives (e.g. carbon nanotubes, graphene) as advanced technology reinforcing fillers.





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*Thank you very much
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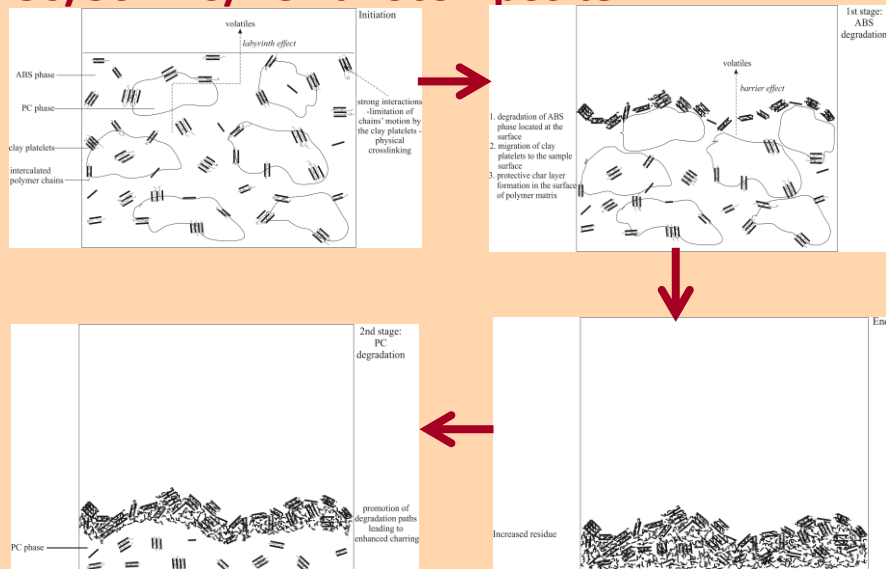
Screw speed:200 rpm

	Temperature at six zones of extruder (°C)					
	1 st	2 nd	3 rd	4 th	5 th	Die
(100/0 w/w) ABS/PC	210	200	200	195	195	190
(100/0 w/w) ABS/PC*	190	195	195	200	200	205
(70/30 w/w) ABS/PC	230	215	215	210	210	205
(50/50 w/w) ABS/PC	240	235	235	230	230	225
(30/70 w/w) ABS/PC	260	255	255	250	250	245
PC	290	280	275	270	265	260

	Temperature at six zones of extruder (°C)					
	1 ⁿ	2 ⁿ	3 ⁿ	4 ⁿ	5 ⁿ	Die
0/100 ABS/PP	180	180	185	185	190	190
30/70 ABS/PP	190	190	195	195	200	200
50/50 ABS/PP	190	190	195	195	200	200
70/30 ABS/PP	190	190	195	195	200	200
100/0 ABS/PP	190	195	195	200	200	205

ABS is composed of :
 44% acrylonitrile
 42% styrene
 14% butadiene

50/50 ABS/PC nanocomposite



- According to SEM this nanocomposite consists of a continuous ABS phase and a dispersed PC phase.
- Clay tactoids are arranged mainly on the ABS/PC interphase and in the ABS phase

- It is possible the formation of a physical crosslinking network structure composed of clay particles and polymeric chains which limitates the chains' motion and protects them during the thermal degradation.
- The dispersion of organoclay layers leads to the formation of a tortuous path which inhibits the passage of volatile degradation products during the initiation of thermal degradation (labyrinth effect).
- The heat barrier effect could also provide superheated conditions inside the polymer melt leading to extensive random scission of polymer chain and evolution of numerous chemical species which, trapped between clay layers, have more opportunity to undergo secondary reactions. As a result, some degradation pathways could be promoted leading to enhanced charring.
- The clay may permit radical recombination reactions, exerting thus a stabilization effect in the ABS/PC/layered silicate nanocomposite.