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Mechanical behavior and statistic study of Acrylonitrile Butadiene Styrene (ABS) test pieces.

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A B S T R A C T

Amorphous polymers require a great interest thanks to their important industrial applications. This importance is reflected in many studies about their mechanical responses.

Among these polymers, Acrylonitrile butadiene styrene (ABS) which has seen significant industrial development as a result of its proprieties. The combination of the three monomers that constitute it from different chemical and physical proprieties provides a material of interest with higher performance.

This study is based on the control of the mechanical behavior of the "ABS" polymer, in order to optimize and enhance the mechanical properties of this polymer, another aspect of the characterization that was taken into account is the statistic study. Through this work, we're going to mainly look at the statistic tests of STUDENT distribution and WEIBULL distribution.

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Introduction:

Amorphous thermoplastic polymers require a great interest thanks to their important industrial applications. This importance is reflected in many studies about their mechanical responses [2].

Acrylonitrile butadiene styrene (ABS) has seen significant industrial development as a result of its proprieties: good heat resistance, high impact resistance, rigidity, and its dimensional stability [1]. The combination of the three monomers that constitute it from different chemical and physical proprieties, provides a material of interest with higher performance [8].

Statistics in the popular sense treat populations, their purpose is to characterize a population based on an unclear image, established using a sample from this population. We may then try to extrapolate information obtained from a number of samples. We can find statistics applications in all fields: Industry, environment, medicine, marketing, etc.….

This study is based on the control of the mechanical behavior of the "ABS" polymer, in order to optimize and enhance the mechanical properties of this polymer, another aspect of the characterization that was taken into account is the statistic study. Through this work, we're going to mainly look at the statistic tests of STUDENT distribution and WEIBULL distribution.

Mechanical behavior of pierced and simply notched specimens

Mechanical characterization:

Polymers take a prominent role in the industrial field, and evolve over time. Therefore, understanding its behavior is important.

For this matter, a statistic study was conducted on 17 specimens of Acrylonitrile butadiene styrene "ABS", the main extracted mechanical characteristics of which are gathered in table (1).

Table: 1. Mechanical characterization of ABS specimens

	E(GPa)	σ_e (MPa)	σ_{ur} (MPa)
Average	2,7464	35,3011	36,3164
Standard deviation	0,26960	0,23640	0,3672

Statistic study

Application of Student distribution:

Student distribution has been highlighted by the probabilistic William E. Gosset, It is used to identify the confidence interval "IC", when the number of samples is reduced, and the standard deviation of the population is unknown. Student law "t", determines a confidence interval in which limit values of the maximum stress has a percentage of 90% chance, to contain the average value of the distribution. In this case, it's used to regulate the average distribution of the tensile tests [3].

We have:

$$P\left[-t(\alpha; n-1); \alpha \leq \frac{X-\mu}{S/\sqrt{n}} \leq +t(\alpha; n-1); \alpha\right] = 1-\alpha \quad (1)$$

This defines limits in probability of the true average "μ":

$$P\left[X - t(\alpha; \mu); \alpha * \frac{S}{\sqrt{n}} \leq \mu \leq X + t(\alpha; \mu); \alpha * \frac{S}{\sqrt{n}}\right] = 1-\alpha \quad (2)$$

With:

X: The average.

S: The standard deviation.

n :The number of samples.

t(α ;μ) : The value given by Student table.

α :The risk threshold.

In order to determine the confidence interval by calculating upper and lower limits of the rupture stress's true average, we apply the relation (2) to the results from static tensile tests. We obtain confidence intervals of the blank specimens.

a) The yield strength:

X= 35,30Mpa

S= 0,236

n= 17 specimens

α= 0,1 ; α/2= 0,05

t(α/2 ; n-1)= 1,746

Then:

$$\mu = 35{,}30 \pm 1{,}746 \times \frac{0{,}236}{\sqrt{17}}$$

Therefore

μ= [35,20 ; 35,40]

Table: 2. All the yield points within the confidence interval

N° of the test	Yield strength (MPa)
1	35,34
2	35,22
8	35,20
11	35,3
17	35,33

b) The maximum limit

X=36,31Mpa
S= 0,367
n= 17 specimens
α= 0,1 ; α/2= 0,05
t(α/2 ; n-1)= 1,746

Then

$$\mu = 36{,}31 \pm 1{,}746 \times \frac{0{,}367}{\sqrt{17}}$$

There for

μ= [36,15 ; 36,46]

Table: 3. All the maximum limits within the confidence interval

N° of the test	Maximum limits (MPa)
6	36,18
7	36,25
8	36,29
9	36,32
10	36,38
11	36,41

The confidence interval is the set of values reasonably compatible with the obtained result, IC provides a visual indication of the uncertainty in the estimation. It's a range of values that has 90% chances to contain the true value of the estimated yield strength hand the maximum limit, these values are gathered in the tables above 2 and 3.

Application of Weibull distribution

The aim of this section is to carry out a statistic study based on the experimental results obtained from tensile tests of ABS specimens, to deduce there from the yield strength and the maximum limit so that the probability of rupture is lower than 1%.

The probability of survival of the specimens subjected to tensile stress, under mechanical stress, could be modeled according to the following Weibull distribution [6]:

$$P_s = e^{-\left(\frac{\sigma}{\sigma_0}\right)^m} \quad (3)$$

With:
Ps: Probability of Survival.
σ: The applied constraint.
σ_0: The scale parameter.
m: The Weibull modulus (dimensionless).

In order to verify whether the data obtained from the results of the experimental tests on the specimens follow the Weibull law, we draw the points having as their coordinates (lnσ; ln(ln(1/Ps))).

The Weibull curve whose data follow a Weibull distribution [5], such as:

$$\ln\left(\ln\left(\frac{1}{P_S}\right)\right) = m(\ln\sigma - \ln\sigma_0) \qquad (4)$$

Thus, if we plot the curve ln (σ) as a function of lnln(1/Ps), and if the curve is straight, we can subsequently obtain the parameters of the Weibull distribution namely:

- ✓ The parameter "m": The slope of the adjusted line.
- ✓ σ_0: The exponent of the intersection of the adjusted line.

a) The yield strength:

The shape of the curve ln(ln (1/Ps)) as a function of ln(σ) is given by Figure 1.

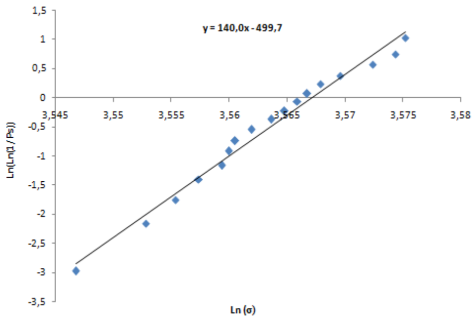

Fig: 1. The evolution of Ln (Ln (1/Ps)) as a function of Ln(σ) for the yield strength.

It is observed that the cloud of points is rectilinear (Figure. 1), and the appearance of the curve obtained is more or less a straight line, which shows that the statistical behavior of our ABS test pieces under tensile stress follows the law of Weibull. This curve has for equation:

$$y_{elastic} = 140x - 499{,}7 \qquad (5)$$

Therefore:

$$m_{elastic} = 140 \quad ; \quad \sigma_{0\ elastic} = 35{,}49$$

Modeling the probability of survival Ps

Using the equation Eq3, the probability of survival "Ps" as a function of the elastic stress indicated on the function (6). It is therefore possible to add the representation of its inverse: the probability of failure Pf such that [4]:

$$Pf + Ps = 1 \qquad (6)$$

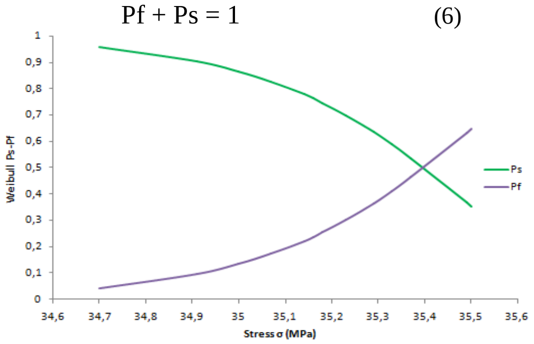

Fig: 2. The probability of survival and failure as a function of elastic stress

b) The maximum stress

The trend of the curve Ln (Ln (1/Ps)) as a function of Ln (σ) is represented in Figure. 3 [7]:

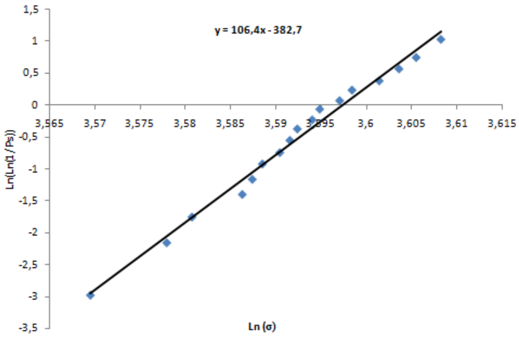

Fig: 3. Trend of Ln(Ln(1/Ps)) as a function of Ln(σ) for the maximum stress

Similar to the results obtained for the yield strength, the results of the maximum stress follows the Weibull law described by equation (4):

$$y_{maximum} = 106{,}4\,x - 382{,}7$$

There for:

$$m_{max} = 106{,}4 \quad ; \quad \sigma_{0max} = 36{,}48$$

As for the yield strength, the probabilities of survival and failure are given in Figure 4.

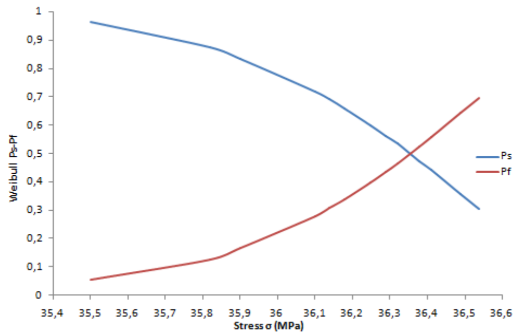

Fig: 4. Probability of survival and failure as a function of maximum stress

In order to deduce the maximum stress to be applied to this material so that the probability of fracture is less than 1% is obtained as follows:

$$Pf > 0{,}99 \qquad (7)$$

$$e^{-\left(\frac{\sigma}{\sigma_0}\right)^m} = 0{,}01 \qquad (8)$$

We obtain:

$$\sigma = 36{,}89 \text{ MPa}$$

Superposition of the curves: probability of survival - probability of failure

The superimposition of the set of curves obtained from the tensile tests carried out on ABS test pieces for the elastic stress and the maximum stress is represented in Figure. 5.

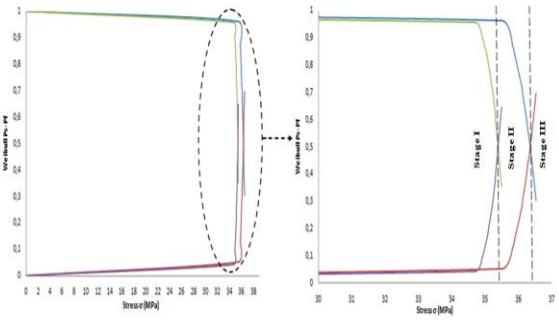

Fig: 5. Superposition of the curves: probability of survival and probability of failure of the yield strength and the maximum stress

From Figure 5, it can be concluded that Acrylonitrile Butadiene Styrene 'ABS' is somehow homogeneous with a uniform distribution of defects. This superposition of curves allowed us to distinguish three zones namely:

- Zone I [0 ; 35,87]: This zone is characterized by a reversible behavior that represents the elastic zone: it is the safe zone.
- Zone II [35,87 ; 36,89]: This is the plastic zone where the material undergoes irreversible but controllable damage requiring maintenance.
- Zone III [36,89 ; 37]: It is the unstable plastic zone where the damage is uncontrollable, this is the area of sudden rupture.

Conclusion:

Statistics in the popular sense treat populations, their purpose is to characterize a population based on an unclear image, established using a sample from this population. We may then try to extrapolate information obtained from a number of samples.

The Student distribution allowed us to determine the confidence intervals for the blank specimens.

On the other hand, the Weibull distribution allows us to define the probability of survival and the probability of failure, for blank specimens and thus distinguish the elastic zone, the stable plastic zone and the unstable plastic zone for a predictive maintenance, in order to ensure the effectiveness of the specimens and the ABS polymer in general.

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