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ORIGINAL PAPER

Investigation of a constitutive law for the prediction of the mechanical behavior of WEEE recycled polymer blends

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Abstract

This research focuses on a mechanical study of an acrylonitrile–butadiene–styrene (ABS)/ polycarbonate (PC) blend totally derived from Waste Electrical and Electronic Equipment (WEEE) recycling. First, an experimental work was developed in laboratory for the preparation of different mixtures of ABS/PC blend. Then, mechanical tensile tests were performed on the injected specimens and the stress/strain experimental data were gathered to be used in the modelling part. In order to enable the prediction of the mechanical response of the blend, G'Sell and Jonas constitutive law was considered for this purpose. An optimization method based on the Generalized Reduced Gradient (GRG) nonlinear algorithm was developed to identify the input parameters governing the mechanical model. In addition, an uncertainty parametric study was assessed to qualitatively and quantitatively evaluate the constitutive law sensitivity versus the parameter uncertainty. Monte Carlo simulations were performed and the convergence of the numerical model was proved in terms of means and standard deviation statistical data. The results showed an excellent agreement between the numerical approach and the experiments. Besides, it was highlighted the crucial role of coupling uncertainty parametric study with modelling for accurately describing the mechanical behavior of the blend.

Keywords WEEE · Polymer recycling · ABS/PC blends · Constitutive law · Uncertainty · Monte Carlo simulations

Introduction

Over the past years, recycling plastics from Waste Electrical and Electronic Equipment (WEEE) has been driven by both environmental and economic motivations [1, 2]. From an environmental point of view, recycling reduces considerably the volume of plastic waste that ends up in landfills and oceans, thereby mitigating pollution and protecting terrestrial and marine ecosystems [3, 4]. It also conserves natural resources by reducing the need for virgin materials, thus preserving fossil fuels and reducing the environmental footprint of plastic production [5]. Economically, recycling lowers production costs, as recycled plastics are often cheaper than new materials. Additionally, it can support the circular economy by creating jobs in the recycling and manufacturing industries, driving technological innovation and leading to more efficient recycling processes and the development of sustainable materials [6]. Thus, by investing in WEEE recycling, one can reduce greenhouse gas emissions and promote sustainable economic growth [7].

However, it is equally important to ensure that the properties of recycled materials meet the necessary standards for industrial use. In fact, effective recycling processes should produce materials with sufficient mechanical strength, durability, and performance consistency. This ensures that recycled plastics can be reliably used in manufacturing and other industrial applications, maintaining their functionality and economic value. For instance, studies have shown that optimizing recycling techniques and incorporating suitable additives can enhance the quality of recycled plastics, making them viable alternatives to virgin materials in various sectors [8, 9]. More particularly, industrial engineers require predictive tools to rapidly estimate the mechanical properties of their products, especially when using recycled materials. These tools enable manufacturers to anticipate the performance and durability of recycled plastics, ensuring they can

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be useful for the desired application. Accordingly, the predictive modelling issues are essential to optimize materials properties, reduce the need for extensive physical testing and save both time and energy required by the multiple experimental tests.

Nevertheless, in the literature there are few studies focusing on the polymer mechanics and even less on the recycled polymers for which both scientific and industrial challenges in this field are particularly significant in the current context of sustainable development and green production. Also, it is fairly acknowledged the lack of mechanical laws to describe the behavior of these polymers over a wide experimental range [10]. In fact, the mechanical behavior of polymers and especially amorphous polymers is versatile and very complex [11, 12] because the major obstacle lies in the partially disorganized nature of the amorphous phase which is the site of relaxation processes whose characteristic times can extend over more than a decade. These processes are responsible for non-elastic deformation [13]. Moreover, polymers exhibit elementary deformation processes which are discrete and discontinuous to accommodate the deformation at the macroscopic scale. Their microstructure is subjected to local and global conformations representing the random and spatial arrangements of molecular chains, leading to specific mechanical behavior. These elementary processes, which distinguish polymers from other common materials, are often masked by the continuous media mechanics theory generally used for the analysis of the experimental data derived from the mechanical tests [14].

In this framework, different mechanical relations can be found in literature to describe the mechanical behavior of polymers [15]. Some of them focus on their responses to small deformation like the rheological models, for instance, adapted to viscoelastic materials [16]. Other relations are based on the molecular scenarios [17, 18] dealing with the description of the molecular motions to evaluate the non-elastic deformation. More generally, “complete” models have been developed to describe the viscoelastic-viscoplastic behavior of amorphous polymers [19]. These phenomenological models enable to reproduce all or part of the intrinsic physical phenomena observed during simple tests up to medium and large deformations, namely the softening and hardening effects [20]. Based on additive, multiplicative and differential formulations, these relations have shown their reliability to faithfully describe the mechanical behavior of thermoplastic polymers across a wide range of deformations.

In this context, the novelty of the present research is to focus on the exploration of the mechanical behavior of a polymer blend totally derived from WEEE. It shall be recalled that this work is involved in the frame work of a broader research program dealing with the compatibility of polymers recovered from WEEE. In a previous paper by the authors [21], an experimental work dealing with the sorting and characterization of WEEE batches collected by Ecosystem (France) was carried. This preliminary step was useful to identify the predominant polymers present in the waste and potentially recyclable. The choice was set on two thermoplastic amorphous polymers: the acrylonitrile–butadiene–styrene (ABS) and the polycarbonate (PC). The combination of these two polymers was motivated by both industrial and scientific challenges since it was proved in many previous researches the synergistic effect gained by compounding ABS and PC polymers [22, 23]. Let recall that coupling ABS and PC is particularly attractive thanks to the high impact strength of PC, on the one hand and the good processability and low cost of ABS, on the other one. Based on the stress/strain experimental data performed in this work, a phenomenological constitutive law is considered in this research and adapted numerically for the description of the mechanical behavior of recycled ABS/PC blends.

Phenomenological Constitutive laws are mathematical relations governed by a set of constants which can be readily identified on the basis of the experimental data. However, the latter are often subjected to some uncertainty sources including instrument precision, environmental conditions, and human factor. These uncertainties propagate through the experimental data, potentially leading to significant deviations in the predicted mechanical behavior of materials and structures. Some works in the literature have emphasized that uncertainty can be propagated analytically, by application of Taylor series variance propagation, or numerically, through repeated Monte-Carlo simulations [24]. Accordingly, understanding and quantifying these uncertainties are essential for improving the reliability of experimental results and for developing robust predictive models [25]. This would be useful for both scientists and industrial communities to provide not only more insights on the uncertainty propagation in the data, but also to draw a confidence region for the functional properties of their products. In this framework, the originality of the present research is to couple the uncertainty study to the constitutive modeling in order to guide manufactures in selecting or processing materials to achieve desired properties and offers by this way a decision-making tool in the context of recycled polymers. On this basis, a parametric study of uncertainty was developed here by performing Monte Carlo simulations of the constitutive law parameters subjected to uncertainty. This study, coupled to the behavior modelling approach, have emphasised the crucial role of experimental dispersion on the evaluation of some basic and useful mechanical characteristics of the polymer blend, such as the modulus, the yield stress and the stress at failure.

Materials and methods

Materials description

In this study, two waste polymers were considered: the acrylonitrile–butadiene–styrene denoted (ABS) and the polycarbonate (PC). These materials were derived from WEEE, extensively investigated in a previous study by the authors [21]. The considered WEEE consists of a mixture of flat screens, cathode-ray tube screens (CRT) and small household appliances (PAM) collected by Ecosystem company from four different sites in France. Figure 1 illustrates a batch example of WEEE flat screens provided by Ecosystem.

The choice of these polymers (ABS and PC) was motivated firstly, by the predominance of these materials in the explored WEEE batches, which implies naturally waste recycling and recovery, and secondly, by the synergistic engineering effect which can be achieved by the combination of these two amorphous thermoplastic polymers. Indeed, ABS is a terpolymer obtained by copolymerization of three monomers of acrylonitrile (23%–41%) known for its good chemical resistance and high surface hardness, butadiene (10%–30%) appreciated for its toughness properties, and styrene (29%–60%) known for its transparency quality and processing performance [26]. Thus, the combination of these monomers leads to a polymer with high mechanical properties. On the other side, the polycarbonate is an ideal engineering material, popularly used in the industry thanks to its high strength which makes it resistant to impact and fracture. It's also appreciated for its high dimensional stability, good electrical properties and toughness. All these characteristics make polycarbonate a compatible polymer which can be easily blended with other different polymers like ABS, PMMA and PET owing to its eco-friendly processing and recyclability qualities.

Fig. 1 Example of WEEE batch of flat screens

The physical properties of ABS and PC polymers are recalled in Table 1.

Extrusion and injection of blends

Prior to their processing, the waste ABS and PC polymers were first dried during 48 h in an EP ENGIN PLAST DUE oven. After drying, the polymers were extruded in PIMM laboratory (France) using a co-rotating twin-screw extruder (TSE) with interpenetrating and intermeshing screws from Thermo Haake (PTW 16-40D model). Four compositions of blends were obtained by extrusion: ABS/PC (0/100), ABS/PC (30/70), ABS/PC (70/30) and ABS/PC (100/0). It's worth noting that the extrusion parameters, notably the temperature values were previously optimized by taking into account the temperature degradation of both polymers in the blends. For further details about the optimization work of the extrusion parameters, the readers could consult the previous research of the author [27]. After extrusion, the ABS/PC blends were injected using a computer-controlled injection molding machine (model DK CODIM 175/410) to obtain A1 specimens for mechanical tests. The machines used for the extrusion and injection processes are shown in Fig. 2.

Mechanical tensile tests

The materials considered for the mechanical study are WEEE-blends of ABS/PC obtained by extrusion and then injection processes at different proportions (0/100), (30/70), (70/30) and (100/0).

Uniaxial tensile tests were conducted at room temperature ($T = 25$ °C) using an Instron 5966 testing machine (Fig. 3) with a 10 kN load capacity and a maximum speed of 1500 mm/min. The elongation was recorded at a constant strain rate of 0.01 s^{-1}, using a video tensile device model Instron SV2. Each test was performed at least ten times on the specimens of type A1 with dimensions specified according the ISO527-2,1996 so that an average stress/strain response is considered. The results obtained in this section will be used in the following, as data to calibrate the constitutive law adopted for the modelling of the mechanical behavior of ABS/PC blends.

Table 1 Physical properties of ABS and PC polymers

	Density (Kg/m^3)	Vicat softening temperature (VST B)	Melt volume rate (MVR) cm^3/10 min
ABS	1040	96	19
PC	1020	140	21

Fig. 2 Co-rotating twin-screw extruder machine (left), injection molding machine (right) used for the manufacture of ABS/PC blends

Fig. 3 Instron machine used for the tensile experiments

Theoretical background and modelling

It's well known that the mechanical behavior of thermoplastic materials is strongly dependent on several parameters such as the strain level ε (dimensionless), the strain rate $\dot{\varepsilon}$(expressed in s^{-1}) and the applied temperature T (expressed in Kelvin (K)). Accordingly, a constitutive law can be phenomenologically expressed as a mathematical relation linking these variables to the mechanical stress:

$$\sigma = F(\varepsilon, \dot{\varepsilon}, T) \tag{1}$$

where σ denotes the mechanical stress expressed in (Pa). Numerous forms of constitutive laws have been postulated in the literature, broadly categorized as multiplicative, additive and differential relations [14, 28].

In the case of multiplicative laws, the mechanical constitutive law developed by G'Sell and Jonas [29] is one of the most used relations to describe the mechanical behavior of thermoplastic amorphous polymers. This relation has also the advantage to be easily used because of its multiplicative form and its formulation captures the material's response to different strain rates and temperatures and clearly distinguishes between the different contributions to the mechanical behavior such as elastic, viscoelastic and strain-hardening effects. This model is expressed as follows:

$$\sigma = f(T)g(\varepsilon)h(\dot{\varepsilon}) \tag{2}$$

where:

$$f(T) = A\exp(\frac{B}{T}) \tag{3}$$

$$\begin{cases} g(\varepsilon) = g_1 g_2 g_3 \\ g_1 = \left[1 - \exp(-C\varepsilon)\right] \\ g_2 = \left[1 + D\exp(-E\varepsilon)\right] \\ g_3 = \exp(F\varepsilon^n) \end{cases} \tag{4}$$

Here, A and B characterize the temperature dependence, while C, D, E, F, and n are dimensionless material-specific parameters reflecting viscoelasticity, necking, and strain hardening.

The first term g_1 of Eq. (4) is useful to describe the viscoelasticity of the polymer at the beginning of the tensile test. The term g_2 is representative of the necking phenomenon while the term g_3, inspired from the finding of the rubbery elasticity of Mooney, traduces the hardening of the material at high deformation.

$$h(\dot{\varepsilon}) = \dot{\varepsilon}^m \tag{5}$$

m is a dimensionless material parameter which takes into account the material dependency on the strain rate.

These equations allow the modelling of the thermoplastic mechanical behavior under tensile solicitation. When the material is subjected to different mechanical tests such as compression, shear or torsion, the term $g_3(\varepsilon)$ is modified and can be expressed as follows:

- in case of shear solicitation [30]:

$$g_3(\varepsilon) = \exp(F\varepsilon) \tag{6}$$

Or:

$$g_3(\varepsilon) = 1 + F\varepsilon \tag{7}$$

- in case of multiaxial impact [28]:

$$g_3(\varepsilon) = 1 + F_1\varepsilon + F_2\varepsilon^2 \tag{8}$$

It's worth noticing that the model of G'Sell and Jonas given in Eqs. (2) to (5), can also be expressed in differential form as follows:

$$\frac{\partial\sigma}{\partial\varepsilon} = K[1 - \frac{\varepsilon}{\varepsilon_e}\exp(\frac{\mu(\sigma - \sigma_i(\varepsilon) - \sigma_e}{kT})] \tag{9}$$

where.

$K$is a material parameter expressed in (Pa) whereas μ is a dimensionless material parameter.

kis the Boltzmann constant expressed in (J/K).

σ_e and $\varepsilon_e$are respectively the effective stress and strain recorded at the solicitation peak, these parameters traduce the activation of the visco-plasticity mechanism and take into account the strain rate dependency.

$\sigma_I$is the internal stress which represents the material hardening induced by the orientation of molecular chains at high deformation. This stress is defined as [14]:

$$\sigma_i(\varepsilon) = K_1[\exp(2\varepsilon) - \exp(-\varepsilon)] + K_2[\exp(\varepsilon) - \exp(-2\varepsilon)] \tag{10}$$

where K_1 and K_2 are material parameters expressed in (Pa).

In the following, the G'Sell and Jonas constitutive law will be considered for the modelling behavior of the WEEE blends, rather in its multiplicative form since the differential form model can raise problem due to its numerical integration requirement.

Results and discussion

Experimental part

The evolution of the stress/strain averaged curves of the ABS/PC blends, derived from the mechanical uniaxial test, is presented in Fig. 4. It can be seen that the different curves exhibit similar tendencies and that the intermediate proportions of ABS/PC (30/70) and (70/30) are located within a spectrum delimited by ABS/PC (0/100) at the top and the ABS/PC (100/0) at the bottom. Additionally, it can be observed that blending ABS and PC polymers results in good compatibility, since the addition of polycarbonate leads to improvements in tensile strength, elongation at break, and toughness. This enhancement can be attributed to several factors, including the excellent mechanical properties of PC, such as its high tensile strength and impact resistance.

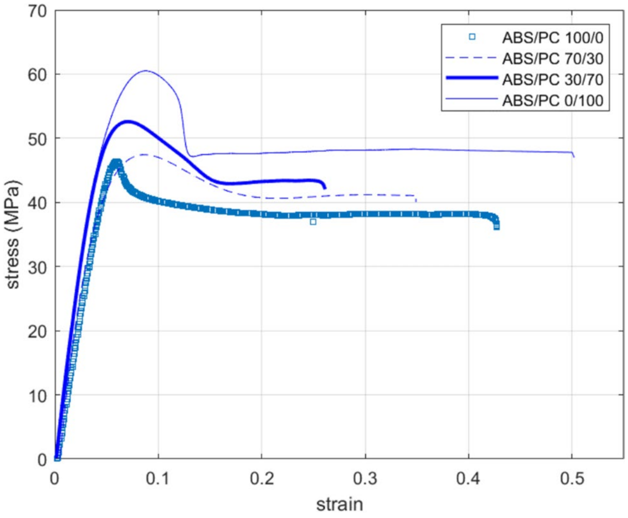


Fig. 4 Evolution of the mechanical stress versus strain for the different blend proportions

Furthermore, the presence of PC acts as a toughening agent by absorbing and dissipating energy during deformation, thereby increasing the material resistance to crack propagation. The compatibility between ABS and PC polymers at the molecular level promotes better interfacial adhesion and dispersion of PC particles within the ABS matrix, resulting in a more homogeneous material with enhanced mechanical integrity.

These findings corroborate well with the literature results obtained for non-recycled ABS/PC blends, where several studies have highlighted the beneficial effects of incorporating polycarbonate into acrylonitrile butadiene styrene to enhance ductility and break elongation. For instance, the study by Zhang et al. [31] provided insights into the underlying mechanisms, suggesting that the compatibility between ABS and PC promoted better polymer chain mobility and interfacial adhesion, leading to enhanced ductility and break elongation in the blends. Similarly, researches by Park et al. [32] and Hsu et al. [33] corroborated these findings, showing that ABS/PC blends exhibited superior ductility compared to pure ABS, with higher break elongation values attributed to the presence of PC. These findings collectively support the notion that incorporating PC into ABS blends can effectively improve ductility and break elongation, offering promising prospects for various engineering applications.

Modelling of the mechanical behavior

Parameters identification

In the present section, we focus on the ABS/PC (30/70) blend for modelling the mechanical behavior of the polymer mixtures based on the aforementioned constitutive law of G'Sell and Jonas presented in Sect. "Theoretical background and modelling". This model is governed by several parameters given in Eqs. (3) to (5) to describe, through its multiplicative form, different contributions including yield stress, strain hardening, and train rate dependence of the material. The mechanical model enables a detailed description of its mechanical behavior from small deformations to large strains.

In this study, a numerical parametric identification of the G'Sell and Jonas model is performed to fit the experimental data obtained in the previous section on injected blend specimens. The parameters of the constitutive law were identified numerically using an optimization approach based on the Generalized Reduced Gradient (GRG) nonlinear algorithm. This method used in Excel's solver is particularly useful for complex optimization problems where linear methods are insufficient. The objective function considered in the optimization process is the quadratic error between the mathematical relation given by the constitutive law and the experimental data gathered from the mechanical tensile test. The objective was to minimize this error in order to fit the experimental values as accurately as possible.

It's worth noticing that in the present particular case of constant temperature, the parameters *A* and *B* are interdependent since they are both part of the temperature dependence function *f* given in Eq. (3). This function describes how the mechanical behavior of thermoplastic polymers is influenced by temperature. Therefore, when temperature is constant, the function *f* remains constant as well. Thus, in the following the parameter identification will focus on the product term *f* rather than *A* and *B* independently, as this product captures the combined temperature-dependent effects. Identifying *f* directly makes the optimization process more straightforward and reduces potential issues arising from ill-conditioning, ensuring thereby numerical stability. Based on this approach, the parameters to be identified will be reduced to 7, since the combined effect of *A* and *B* is encapsulated by the product term *f*.

The results of the parametric identification are presented in Fig. 5.

It can be seen from Fig. 5 that the considered constitutive law is well adapted for describing the mechanical behavior of the blend of polymers, exhibiting an excellent agreement between the experimental data and the numerical model. Therefore, the use of G'Sell and Jonas model can also be extended to blends of WEEE amorphous polymers like ABS and PC couple, as it clearly demonstrates its ability to faithfully describe the mechanical behavior of this mixture from small to large deformations.

Table 2 displays the optimal parameters (f^*, C*, D*, E*, F*, m*, n*) governing the mechanical constitutive law, which were identified numerically.

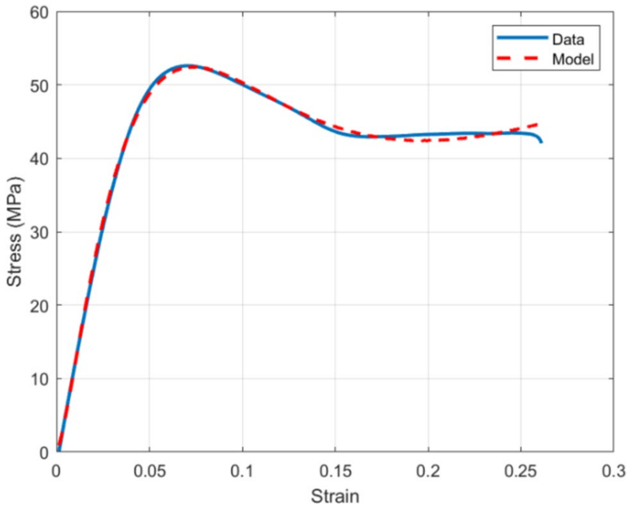


Fig. 5 Confrontation of the predictive model with the experimental data (Case of the blend ABS/PC (30/70))

Table 2 Optimal parameters derived from the numerical parametric identification approach

(ABS/PC)	f^*	C*	D*	E*	F*	m*	n*
0/100	1.24	12.18	10.54	17.58	9.44	0.7	0.05
30/70	0.68	14.56	10.36	19.50	9.48	2.02	0.05
70/30	1.81	21.97	5.50	14.35	7.76	3.05	0.03
100/0	1.92	17.01	4.09	15.28	8.06	0.89	0.06

Analysis of parametric uncertainty, Monte Carlo simulations

Based on the parameter identification from the previous section, a parametric study is performed to investigate the effect of uncertainty on the mechanical behavior of the polymer blend. It is worth noting that the input parameters governing a constitutive law can be subjected to uncertainty, which may arise from various sources such as errors in estimating the parameters through the numerical model, a lack of knowledge of the physical sense of these constants (if they have sense), or even from the experiment testing itself.

Accordingly, in order to study the effect of this uncertainty, many numerical simulations were performed by assuming a dispersion of 20% on each parameter while keeping the others constant, so that the sensitivity of each parameter could be assessed independently. It shall be noted that the choice of 20% of uncertainty was selected after preliminary iterations with lower percentages for which the sensitivity to some parameters of the constitutive law was not easily shown. Accordingly, by considering an uncertainty value of 20%, one can more easily distinguish the impact of each parameter on the mechanical behavior. Furthermore, it shall be emphasised that an uncertainty of 20% is not negligible and can be considered as a conservative study case to account for potential uncertainties encountered in the estimation of the constitutive law parameters.

Figure 6 illustrates an example of some random realizations of the parameter *C* in Eq. (4) relative to the optimal value obtained in Table 2. The values of *C* were randomly generated according to a uniform law and then implemented in the numerical model to observe its effect on the mechanical response of ABS/PC (30/70) blend.

Plots of Fig. 7 show the results of the different numerical simulations performed on the blend ABS/PC with proportion (30/70). One can notice that the input parameters can impact differently and considerably the mechanical behavior of the mixture. Although, the parameter *m* seems to be not very significative in the constitutive law, the 6 other constants exhibit, however, potential influence on the mechanical response of the blend.

More particularly, it can be seen that the input parameter *F* stands out from the other ones since it exhibits a much broader spectrum of stress/strain curves. Note that, from a mathematical point of view, this constant plays a crucial role in the constitutive model as it is related to an exponential positive value (Eq. (3)). It's also the case for the parameter *n* linked to the same contribution part g_3 of the mechanical law.

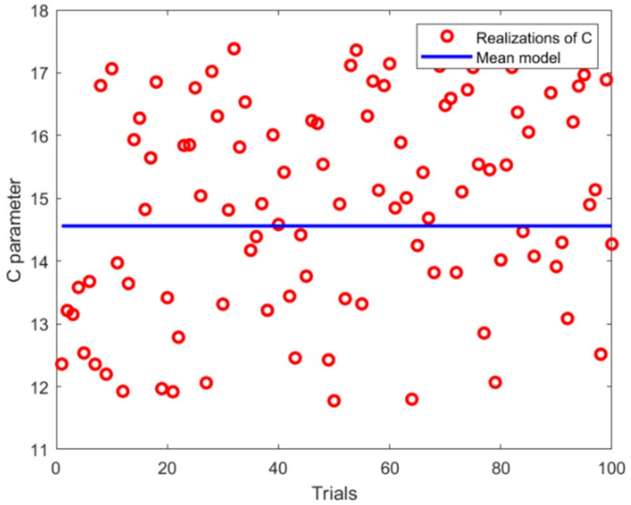


Fig. 6 Illustration of some random realizations of C parameter (100 trials), case of ABS/PC (30/70)

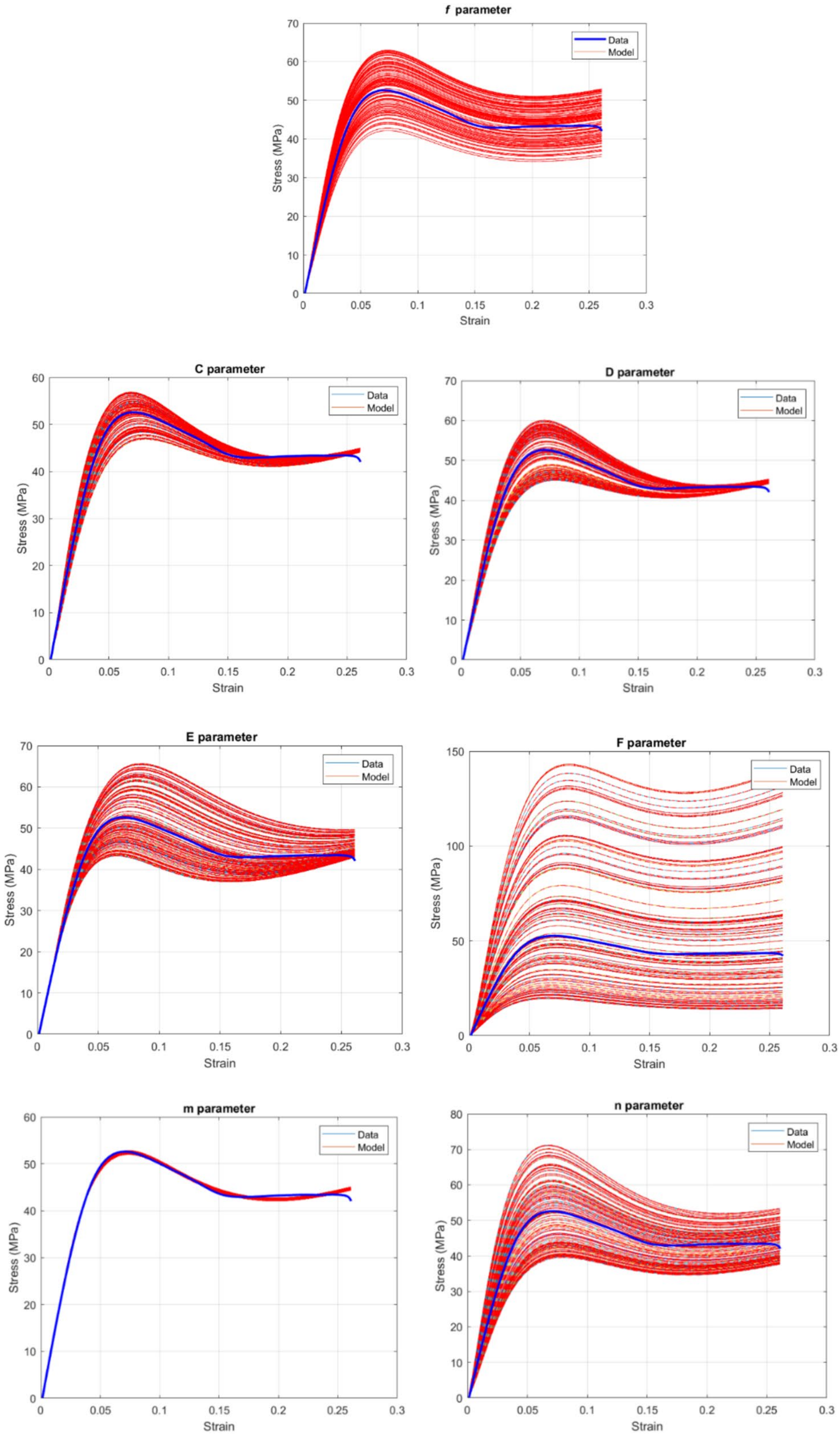
A similar tendency can also be observed for the parameter *f* which traduces the viscoelastic behavior's dependence on temperature. Therefore, some dispersion of *F*, n or *f* parameters leads to a significant mechanical dispersion including mechanical modulus, yield stress and at break.

On the other side, it can be noticed that the uncertainty of parameter *E* affects rather the yield stress while the modulus remains nearly unchanged, since this parameter is rather representative of the necking phenomenon of the material. Finally, the constants *C* and *D* seem to influence similarly the mechanical behavior affecting mostly the modulus and the yield stress.

Convergence of Monte Carlo simulations

The propagation of uncertainty can be studied analytically, for instance, by focusing on Taylor series variance propagation, for instance or numerically by managing multiple Monte-Carlo simulations [24]. The convergence of Monte Carlo simulations is typically assessed by monitoring the stability of key statistical measures, such as the mean and standard deviation of the results [34, 35]. For this purpose,

Fig. 7 Results of the parametric study performed on the constitutive law, case of ABS/PC (30/70)



Monte Carlo simulations were carried out in this section by considering a simultaneous 10% of uncertainty in the input parameters of the constitutive law. By analogy, 100 random realizations were performed for each parameter, and the stress/strain curve evolutions were observed accordingly, as depicted in Fig. 8. It can be seen from the stress/strain

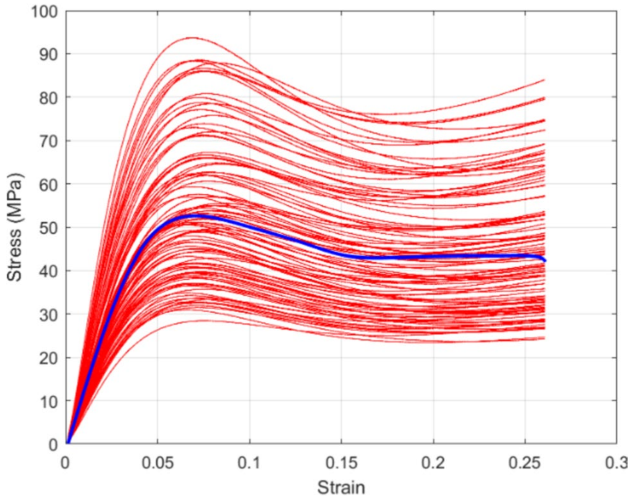


Fig. 8 Monte Carlo Simulations with 10% of dispersion, case of ABS/PC (30/70): Evolution of stress/strain curves

evolution curve that an uncertainty of 10% can lead to a significant error of approximately 80% in the estimation of the yield stress. This finding highlights the importance of controlling the input parameters of the constitutive law, on the one hand and considering the uncertainty aspect for accurate prediction of the mechanical properties, on the other one.

In the framework of an uncertainty analysis, it is essential to connect the uncertainty propagation to some application-level performance metrics such as modulus, yield and break stresses, for instance. Accurate estimation of these parameters is crucial from a practical point of view, particularly for industrial applications, where safety and material reliability depend on stable mechanical performance. Figure 9 displays the convergence of Monte Carlo simulations shown in terms of means and standard deviations of the numerical results related to the yield stress, the stress at break and the modulus. This figure clearly demonstrates how the input uncertainty propagates to key mechanical performance

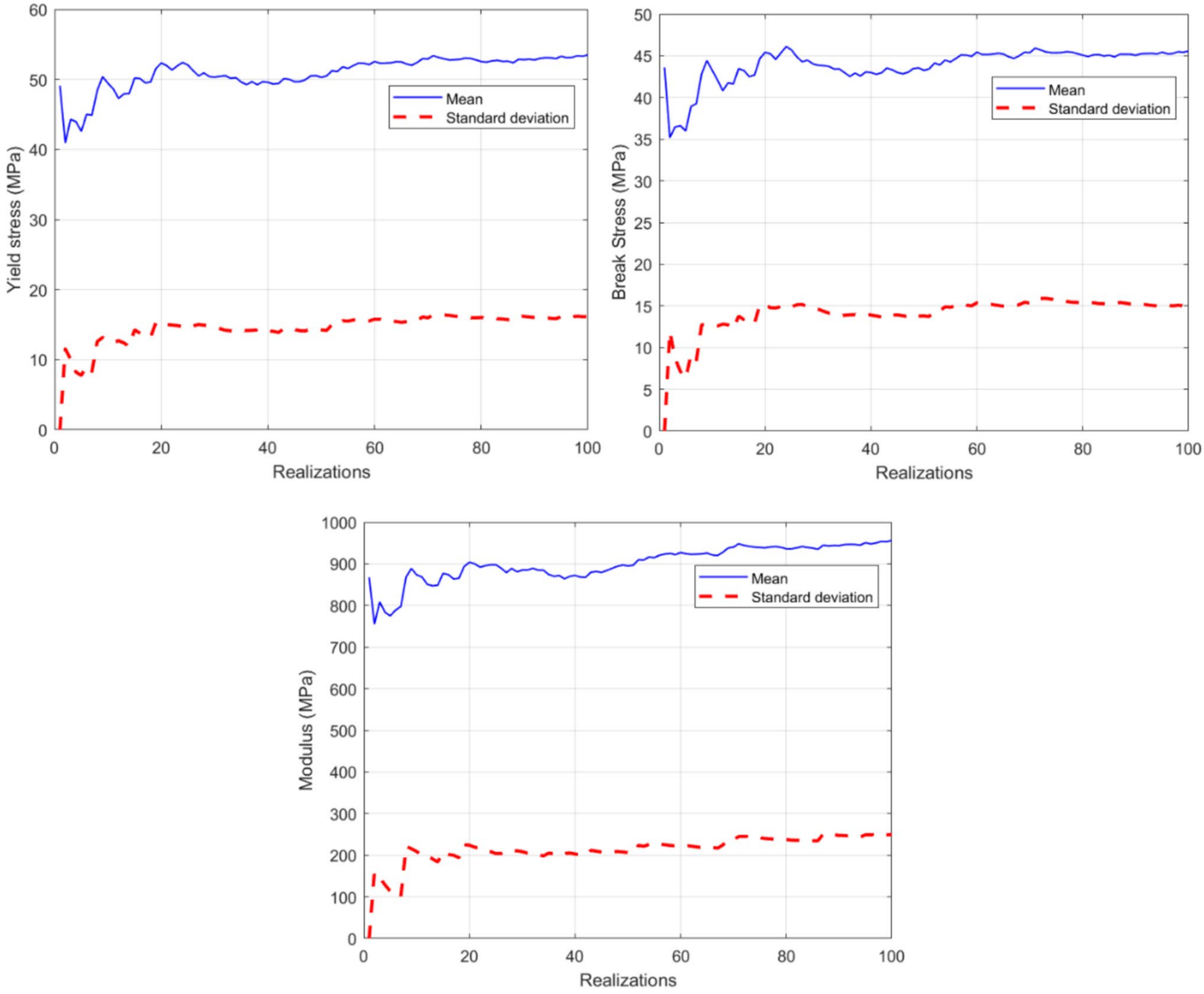


Fig. 9 Convergence of monte carlo numerical simulations (Mean and standard deviation of yield stress, stress at break and modulus)

metrics. Additionally, it can be observed that convergence was reached at approximately 80 realizations, where the numerical results were statistically reliable and showed not significant changes with additional sampling. The stabilization of both the mean and standard deviation confirms the relevance and reliability of the mechanical behavior law under uncertain conditions.

Conclusions

This research work has dealt with an experimental and modelling investigation of blends of ABS and PC amorphous polymers derived from WEEE recycling. The experimental work enabled the manufacture of different mixtures of recycled ABS/PC blends using extrusion and injection techniques, on the one hand, and mechanical tensile tests, on the other one. The modelling part of this research focused on the constitutive law of G'Sell and Jonas to predict the mechanical behavior of the polymer blend. The input parameters governing the mechanical model were identified numerically based on the experimental data obtained from the tensile test. A parametric numerical approach was then assessed to investigate the effect of parameter uncertainties on the mechanical behavior of the blend.

It can be drawn from the results gathered through the mechanical tests, a good compatibility between ABS and PC polymers reclaimed from WEEE, offering promising prospects for various engineering applications of the recycled blend. On the other hand, the numerical identification of the constitutive law has proved its reliability to faithfully describe the mechanical behavior of this recycled mixture. The optimization numerical model is a promising tool since it provides the opportunity to study other proportions of ABS/PC blends in order to have a fast estimation of their properties.

Furthermore, the uncertainty parametric study enabled the identification of the significant input parameters of the constitutive law which could considerably affect the mechanical response of the system leading therefore to significant errors (up to 80%) in the estimation of key mechanical properties of the blend, such as modulus, yield stress and stress at break. Monte Carlo simulations were performed to achieve random realizations of the different parameters, and the numerical model has shown its convergence in terms of mean and standard deviation results.

In conclusion, this work opens up innovative prospects for researchers in the mechanics of recycled polymers which remains still an under-researched area compared to virgin polymers and other materials. Moreover, it was highlighted from this research that although G'Sell and Jonas constitutive law can be readily adapted for predicting the mechanical behavior of blends of amorphous polymers, parametric uncertainty must be considered as a complementary approach for accurate estimation of mechanical properties of the material. This finding provides a valuable tool for decision-making in the context of recycled polymers, particularly for industries seeking to meet performance standards while using sustainable materials.

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Data Availability The data that support the findings of this research are available from the corresponding author upon reasonable request.

Declarations

Competing interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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