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ABC MULTICRITERIA CLASSIFICATION WITH ANALYTICAL HIERARCHY PROCESS: HOW TO FORCE CONSISTENCY OF PAIRWISE COMPARISONS MATRIX

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Resumo: *Multicriteria classification is usually a crucial step in the decision-making in the manufacturing management process. For such classification, the attribution of weights to the criteria strongly influences the coherence of the categorization. Saaty's Analytic Hierarchy Process (AHP) is an eminent method for assigning weights to multiple criteria. AHP's logic is not complicated at all. However, since criteria's pairwise comparison matrices are usually generated manually and based only on some employee know-how, there is high complexity in elaborating a consistent pairwise matrix, especially when comparing several criteria. This paper presents a constructive algorithm that can adjust inconsistent matrices, forcing such matrices to have a better consistency rate. We tested this algorithm by applying the AHP method for ABC multicriteria classification to companies in three sectors. As a result, we observed that the algorithm adjusts the pairwise matrices in just a few seconds, avoiding the manual work of several hours, then showing that it is an essential resource for applying the AHP method.*

Palavras-chave: *ABC multicriteria classification, analytic hierarchy process, consistency rate, constructive algorithm, COPSolver library*

1. INTRODUCTION

"Manufacturing decisions can be classified into three categories: strategic, tactical and operational ... Operational decisions pertaining to issues such as order processing, detailed production scheduling, follow up, maintenance routines, and inventory control rules, drive the day to day activities" (Singhal *et al.*, 2013). Manufacturing decisions are closely related to sales decisions. "In today's competitive market the diversity in customer's need have resulted in a high level of variability in the products which have to be manufactured" (Ebrahimi *et al.*, 2014) or acquired from other companies. Such diversity brings to light the need for the use of complex techniques for purchasing / production management, especially at the operational decision level (Kiran, 2019). In such a scenario, prior optimized operational planning becomes impressible for better use of the productive capacity and to avoid investment losses in unnecessary or unprofitable material. And, given the wide variety of products, it is crucial to start any planning by understanding the importance of all products marked by the company.

One of the approaches that widely applied to clustering products according to their importance is the multicriteria ABC classification. The scientific literature broadly emphasizes the value of multicriteria ABC classification for inventory management and presents several multicriteria methods. The Analytical Hierarchy Process is one of the most common techniques applied for this purpose (Flores *et al.*, 1992; Altay Guvenir and Erel, 1998; Lolli *et al.*, 2014; Balaji and Kumar, 2014). Some recent studies also emphasize the importance of applying multicriteria analysis to strategic planning (*e.g.*, Barbosa de Paula *et al.*, 2022; de Moura Pereira *et al.*, 2023; Mariano Ribeiro *et al.*, 2023). Odu (2019) emphasizes that, when applying some multicriteria methods, it is crucial to pay particular attention to the objectivity factors of criteria weights. The author provides a detailed overview of different weighting methods applicable to multicriteria techniques.

In this work, we present a study with three companies from three different sectors, which market a wide variety of products, in some cases, highly personalized products. The interest of this study is to identify the principal products, that is, the products that each company must prioritize so that this information can guide the optimized operational planning. We opted for the method ABC for multicriteria classification and adopted the Analytic Hierarchy Process (AHP) (Saaty,

1987) to assign the weights to the different criteria. It is important to note that the Analytic Hierarchy Process derives the weights of each criterion based on the eigenvector of a pairwise comparison matrix, which is constructed manually according to an empirical evaluation. According to Saaty (1987), this matrix must be antisymmetric and have a consistency rate of less than 0.1. The author reports that a software package supporting the AHP, called Expert Choice, for the IBM PC, was used in his work for making eigenvector calculations and guiding the decision maker to improve matrix inconsistency if needed. During the execution of the work we present in this paper, we found that there is a substantial difficulty in the calculation of the eigenvector, as well as in the construction of consistent pairwise comparison matrices. Since we had no access to the Expert Choice software package, we developed an open-source COPSolver library for the Analytic Hierarchy Process and multicriteria ABC classification based on a simple algorithm for forcing the consistency of such matrices. We present this algorithm in this paper. We coupled the Eigen library from eigen.tuxfamily.org to COPSolver for the eigenvectors calculation of the matrices. Also, we identified that it is possible to use different criteria types (cumulative sum, qualitative, and binary) when assigning weights to ABC classification, depending on each specific criterion chosen, and we observed that such an assignment generates a bias in the multicriteria ABC classification. Therefore, we also developed a new methodology for assigning weights in a balanced way for ABC classification, and we proposed a new multicriteria weighting equation for the multicriteria classification COPSolver library. We also present both propositions in this paper, as well as an in-depth analysis of the results found by the new library developed for COPSolver.

The rest of this paper is structured as follows. Section 2 presents the algorithm developed to force the consistency of pairwise comparison matrices. Section 3 explains the proposed approach for assigning the weights for the ABC classification and the equation for calculating the weights for the multicriteria classification. Section 4 briefly exhibits COPSolver software and the new library developed for multicriteria classification. Section 5 presents the results and analysis informing about the precautions someone must have when elaborating the COPSolver input file for multicriteria classification. Section 6 reports the credits in carrying out this work. Sections 7 and 8 conclude this article with conclusions and acknowledgments, respectively.

2. ALGORITHM FOR FORCING LOW CONSISTENCY RATE

Algorithm (1) illustrates the method developed to reduce the consistency rate (CR). This algorithm takes as input the pairwise comparison matrix ($M[m_{ij}]$) and the tolerance (tol) defined for the consistency rate and returns the matrix adjusted as well as the CR of this new matrix (see Saaty (1987) for more information on calculating the consistency rate).

Algorithm 1 forceConsistency($tol, M[m_{ij}]$)

Require: $tol, M[m_{ij}]$
Ensure: $CR < tol$
  $n \leftarrow size(M[m_{ij}])$
  $CR \leftarrow$ consistencyRate($M[m_{ij}]$)
  topLeftCorner($CR, tol, M[m_{ij}]$)
  bottomLeftCorner($CR, tol, M[m_{ij}]$)
  return $CR, tol, M[m_{ij}]$

The topLeftCorner() function (alg. 3) performs a peer-to-peer comparison of each element of the pairwise matrix starting from the third row, $M[m_{\{sz\}j}]_{sz=3}^{n}$, with each element of the matrix $M[m_{jk}]_{j=1,k=j+1}^{n-1,n}$. In this comparison, the consistency of each pair is verified according to alg. (2). If any inconsistency is found, the value of one of the elements is reduced or increased, seeking to improve the consistency rate. Initially, the reduction of values is done through the reduce() function. If, after the reduction, the convergence rate is still greater than the tolerance, the increment of values is made through the increase() function.

Algorithm 2 consistency checking

Require: $M[m_{ij}]$
  if $m_{\{sz\}j} * m_{jk} = m_{\{sz\}k}$ **then**
    $consistent \leftarrow 1$ ▷ values are consistent
  else
    $consistent \leftarrow 0$ ▷ values are not consistent
  end if
  return $consistent$

The bottomLeftCorner() function is similar to the topLeftCorner() function. In the topLeftCorner() function, the peer-to-peer comparison starts with the elements of the third row ($M[m_{\{sz\}j}]_{sz=3}$), and then the elements of the next rows are evaluated, following the order from top to bottom. In the case of the bottomLeftCorner() function, on the other hand, the pair-by-pair comparison is made starting with the elements of the anti-penultimate row ($sz = n - 3$), then the elements of the previous rows are evaluated, following the order from bottom to top.

Algorithm 3 topLeftCorner($CR, tol, M[m_{ij}]$)

Require: $CR, tol, M[m_{ij}]$
  if $CR \geq tol$ **then**
    for $sz \leftarrow 3, n$ **do**
      for $j \leftarrow 0, n-1$ **do**
        for $k \leftarrow j+1, n$ **do**
          $g \leftarrow 0$
          $s \leftarrow 0$
          if $m_{\{sz\}j} * m_{jk} > m_{\{sz\}k}$ **then**
            $g \leftarrow j$
            $s \leftarrow k$
          else if $m_{\{sz\}j} * m_{jk} < m_{\{sz\}k}$ **then**
            $g \leftarrow k$
            $s \leftarrow j$
          end if
          if $g > 0$ or $s > 0$ **then**
            reduce($CR, tol, sz, g, s, M[m_{ij}]$)
            if $CR \leq tol$ **then**
              break
            else if $m_{\{sz\}g} > m_{\{sz\}s}$ **then**
              increase(sz,g,s)
              if $CR \leq tol$ **then**
                break
              end if
            end if
          end if
        end for
        if $CR \leq tol$ **then**
          break
        end if
      end for
      if $CR \leq tol$ **then**
        break
      end if
    end for
  end if
  return $CR, tol, M[m_{ij}]$

Algorithm 4 reduce($CR, tol, n, g, s, M[m_{ij}]$)

Require: $CR, tol, n, g, s, M[m_{ij}]$
  while $m_{ng} * m_{gs} > m_{ns}$ and $m_{ng} \neq 0$ **do**
    $auxCR \leftarrow CR$
    $m_{ng}++$
    $m_{gn}--$
    $CR \leftarrow$ consistencyRate($M[m_{ij}]$)
    if $CR > auxCR$ **then**
      $m_{ng}--$
      $m_{gn}++$
      $CR \leftarrow$ consistencyRate($M[m_{ij}]$)
      break
    else if $CR <= tol$ **then**
      break
    end if
  end while
  return $CR, tol, M[m_{ij}]$

Algorithm 5 increase($CR, tol, n, g, s, M[m_{ij}], it(M[m_{ij}])$)

```
Require: CR, tol, n, g, s, M[m_ij], it(M[m_ij])
  while m_ng * m_gs < m_ns and it(m_ng) ≠ n − 1 do
    auxCR ← CR
    m_ns ++
    m_sn −−
    CR ← consistencyRate(M[m_ij])
    if CR > auxCR then
      m_ns −−
      m_sn ++
      CR ← consistencyRate(M[m_ij])
      break
    else if CR <= tol then
      break
    end if
  end while
  return CR, tol, M[m_ij]
```

Algorithm 6 bottomLeftCorner($CR, tol, M[m_{ij}]$)

```
Require: CR, tol, M[m_ij]
  if CR ≥ tol then
    for sz ← n − 2, 1 do
      for j ← 0, n − 3 do
        for k ← j + 1, n − 2 do
          g ← 0
          s ← 0
          if m_{sz−1}j * m_jk > m_{sz−1}k then
            g ← j
            s ← k
          else if m_{sz−1}j * m_jk < m_{sz−1}k then
            g ← k
            s ← j
          end if
          if g > 0 or s > 0 then
            reduce(sz-1,g,s)
            if CR <= tol then
              break
            else if m_{sz−1}g > m_{sz−1}s then encrease(sz-1,g,s)
              if CR <= tol then
                break
              end if
            end if
          end if
        end for
        if CR <= tol then
          break
        end if
      end for
      if CR <= tol then
        break
      end if
    end for
  end if
  return CR, tol, M[m_ij]
```

3. ON MULTICRITERIA ABC CLASSIFICATION

As discussed earlier, in our study, we observed that one of the crucial points for correctly applying multicriteria ABC classification is correctly attributing the weights for the initial ABC classification.

When we built the input data file, we considered three types of criteria for ABC analysis, cumulative sum (for billing and lead time criteria), qualitative, and binary criteria. While we were testing the solver, we noticed that an incorrect assignment of the weights can generate a strong bias in the multicriteria classification, since the criterion with the top percentage difference will always be dominant.

Therefore, to assign the weights, three procedures were adopted, according to the different nature of each type of criterion used.

In the case of the binary criteria, the choice of a binary parameters (0 and 1) results in a distribution of the percentage among the criteria that are critical. This seems to be consistent with the desired goal. However, in the case of the other criteria types, the consistency is no longer so clear.

We can verify this inconsistency through a brief analysis of the two criteria classified according to the cumulative sum. For the data collected from the furniture trades company, the product with the highest billing (242,280.00 reais) has a billing corresponding to 12% of the total amount; and a product with a longer lead time (30 days) represents 0.46% of the total lead time, that is, a percentage 0.25% higher than products with a lead time of 20 days (0.31%) and 0.35% higher than products with a lead time of 7 days (0.11%).

The question is: is the difference between the importance of a product with a 30-day lead time and a product with a 7-day lead time only 0.35%? This value can only be appreciated when compared with the difference in importance of 12% between the product with the highest and the product with the lowest billing.

Make a multicriteria classification for the billing and lead time criteria based only on the accumulated sum is like calculate a weighted average of the annual sales of vehicles and bananas, hoping that this average will have some meaning. For there to be real meaning in the weighted average found by the multicriteria method, it is necessary to apply some procedure to balance the weights assigned to each criterion.

Odu (2019) cites CRITIC as one of the methods applied for weight assignment in multicriteria classification. This method starts with normalizing the weights using the following equations:

$$\rho_{ij} = \frac{w_{ij} - w_j^{\min}}{w_j^{\max} - w_j^{\min}} \qquad i = 1, ..., m; j = 1, ..., n \qquad \text{for benefit criteria} \tag{1}$$

$$\rho_{ij} = \frac{w_j^{\max} - w_{ij}}{w_j^{\max} - w_j^{\min}} \qquad i = 1, ..., m; j = 1, ..., n \qquad \text{for cost criteria} \tag{2}$$

Where $w_j^{\min}$ and $w_j^{\max}$ are, respectively, the lowest and highest weights assigned to criterion j, w_{ij} is the weight and ρ_{ij} is the normalized weight of criteria j for product i.

The problem with this normalization method is that the largest values of the different criteria will have exactly the same weight. In the case of the companies studied, this may not correspond to the assessment of experts.

The solution that we adopted in this work for multicriteria classification with lead time and billing criteria, was inspired on the work of Willians. A single measure was adopted for these two criteria (lead time billing weight) dividing the billing by the complement of the lead time for each product and then normalizing the weights.

In the case of qualitative criteria, the initial ABC classification was made using three weights, one weight assigned to products A, pa, a second weight assigned to products B, pb, and a third weight assigned to products C, pc, where pa > pb > pc. For qualitative criteria, pa, pb and pc must be assigned using the following steps:

- order the products, in descending order, according to their respective values for lead time billing;
- classify products into three groups, A, B and C, for each qualitative criterion;
- do pc = 0 for all group C products, for each qualitative criterion;
- for each qualitative criterion, do peer-to-peer comparison with the groups A and B and the products ordered according to the lead time billing criterion, answering the following question: the degree of importance of the products of this group to the qualitative criterion is equivalent to what degree of importance of the other product evaluated according to the lead time billing criterion ?;
- assign to pa and pb the value of the lead time billing of the product with corresponding importance.

Equations (3) and (4) can be used for calculation of multicriteria classification weights of each product, ρ_p:

$$LtBW(p) = \frac{\frac{b_p}{1+(lt^{\max}-lt_p)}}{\sum_{p=1}^{\mathrm{NP}} \left\{ \frac{b_p}{1+(lt^{\max}-lt_p)} \right\}}, \quad p = 1, ..., \mathrm{NP} \tag{3}$$

$$\rho_p = (wb + wlt) * LtBW(p) + \sum_{q=1}^{\text{NQ}} w_{\sigma_q} * LtBW(e_{p\sigma_q}) + \sum_{b=1}^{\text{NB}} w_{\beta_b} * w_{p\beta_b}, \quad p = 1, ..., \text{NP} \tag{4}$$

where:
NP is the number of products;
NQ is the number of qualitative criteria;
NB is the number of binary criteria;
Σ is the set of qualitative criteria, $\quad \Sigma = \{\sigma_q\}_{q=1}^{NQ}$;
B is the set of binary criteria, $\quad \text{B} = \{\beta_b\}_{b=1}^{NB}$;
p is the index used to represent each product, $\quad p = 1, ..., \text{NP}$;
c is the index used to represent each criterion of qualitative or binary type , $\quad c \in \Sigma \cup \text{B}$;
$LtBW(p)$ is the lead time billing weight of product p;
b_p is the billing of product p;
lt_p is the of product p;
wb is the multicriteria weight of criterion billing.
wlt is the multicriteria weight of criterion lead time.
w_c is the multicriteria weight of criterion c.
w_{pc} is the weight percentage of the product p according to criterion c;

4. RESULTS AND DISCUSSIONS

4.1 Analysis on the Algorithm for Adjusting Inconsistencies

Table 1 presents the modifications made by the software 'COPSolver: library for solving the multicriteria classification problem' in the pairwise comparisons matrix and the consequent changes in the consistency rate (CR) for the data collected from the three companies selected for this study.

As we can see in this table, the pairwise comparison weights are adjusted primarily according to the weights assigned to the first three criteria. Thus, although there is a change in the pairwise comparison weights, which may be significant, the weights assigned to the first three criteria are preserved. The algorithm will change the weights of the other criteria to force the consistency of the pairwise comparisons matrix. Another significant observation is that the algorithm stops when it reaches the desired consistency rate. So, it is more likely that the algorithm changes the weights related to the fourth criterion and the next ones. Therefore, the ordering of criteria in the matrix must follow the following rules:

- the three most relevant criteria for the company are among the first;
- the other criteria are ordered from the last to fourth position, in descending order of relevance.

For the data presented in Table 1, there was no concern with the correct ordering of the criteria. Based on the results and previous observations, we requested the criteria classification according to its relevance to each company. Table 2 presents the modification of results after altering the criteria ordination on the input data.

Speaking about the CR, Tab. 1 clearly shows the inconsistencies before the modification and how the weight modifications made by the algorithm reflect the adjustments of these inconsistencies. For example, in the case of the plastic bag manufacturing company, the billing criterion is more important than the criticality criterion and much more valuable than the lead time criterion. Also, the criticality criterion is more important than the lead time criterion. These statements are coherent. However, the vector of the weights of this matrix clearly shows that the criticality criterion is less relevant than the lead time criterion, which is inconsistent with the two first statements. The assignment of the other weights related to criteria criticality and lead time causes this inconsistency. We can see from the input data matrix that the obsolescence, replaceability, and repairability criteria are more important than the criticality criterion but less valuable than the lead-time criterion. According to the initial statement (that criticality is more relevant than lead time), this new statement generates the inconsistency of the pairwise comparisons matrix. As we can see in the adjusted matrix, the algorithm quickly corrects these inconsistencies and then the weight vector.

5. DISCUSSION AND FINAL REMARKS

6. REFERENCES

7. INTRODUÇÃO

O objetivo destas instruções é servir de guia para a formatação dos trabalhos a serem publicados nos anais. Os anais do XII CONEM serão publicados no formato Adobe^{TM} PDF.

Os artigos **DEVEM** ser formatados de acordo com estas instruções. O presente arquivo pode ser usado como modelo por usuários do LaTeX. Além disso, pode ser usado como um guia de formatação para usuários de outros processadores de texto.

Table 1: **Pairwise comparisons matrix and consistency rate changes for three companies (results found by COPSolver) - legend: sb = substitutability; lt = lead-time; rp = repairability; cr = criticality; ob = obsolescence; bl = billing; cm = commonality; CR = consistence rate; w = normalized weights vector.**

car mechanics company

CR = 0.216

$w = (0.35, 0.26, 0.18, 0.11, 0.05, 0.03, 0.01)$

	sb	lt	rp	cr	ob	bl	cm
sb	1.00	3.00	3.00	5.00	7.00	9.00	9.00
lt	0.33	1.00	3.00	5.00	7.00	9.00	9.00
rp	0.33	0.33	1.00	3.00	9.00	9.00	9.00
cr	0.20	0.20	0.33	1.00	5.00	9.00	9.00
ob	0.14	0.14	0.11	0.20	1.00	5.00	9.00
np	0.11	0.11	0.11	0.11	0.20	1.00	9.00
cm	0.11	0.11	0.11	0.11	0.11	0.11	1.00

CR = 0.085

$w = (0.37, 0.26, 0.12, 0.12, 0.06, 0.05, 0.02)$

	sb	lt	rp	cr	ob	co	cm
sb	1.00	3.00	3.00	3.00	7.00	9.00	9.00
lt	0.33	1.00	3.00	3.00	5.00	9.00	9.00
rp	0.33	0.33	1.00	1.00	3.00	3.00	9.00
cr	0.33	0.33	1.00	1.00	3.00	3.00	9.00
ob	0.14	0.20	0.33	0.33	1.00	1.00	9.00
np	0.11	0.11	0.33	0.33	1.00	1.00	9.00
cm	0.11	0.11	0.11	0.11	0.11	0.11	1.00

furniture trades company

CR = 0.151

$w = (0.05, 0.10, 0.14, 0.21, 0.02, 0.45, 0.02)$

	lt	sb	rp	cr	cm	bl	ob
lt	1.00	0.20	0.14	0.20	7.00	0.11	5.00
sb	5.00	1.00	0.33	0.33	5.00	0.14	7.00
rp	7.00	3.00	1.00	0.33	5.00	0.14	3.00
cr	5.00	3.00	3.00	1.00	9.00	0.33	9.00
cm	0.14	0.20	0.20	0.11	1.00	0.11	1.00
np	9.00	7.00	7.00	3.00	9.00	1.00	9.00
ob	0.20	0.14	0.33	0.11	1.00	0.11	1.00

CR = 0.096

$w = (0.07, 0.16, 0.25, 0.20, 0.02, 0.26, 0.03)$

	lt	sb	rp	cr	cm	np	ob
lt	1.00	0.20	0.14	0.33	7.00	0.20	5.00
sb	5.00	1.00	0.33	1.00	5.00	0.33	7.00
rp	7.00	3.00	1.00	1.00	7.00	1.00	3.00
cr	3.00	1.00	1.00	1.00	7.00	1.00	9.00
cm	0.14	0.20	0.14	0.14	1.00	0.11	1.00
np	5.00	3.00	1.00	1.00	9.00	1.00	9.00
ob	0.20	0.14	0.33	0.11	1.00	0.11	1.00

plastic packaging manufacturing company

CR = 0.625

$w = (0.39, 0.10, 0.22, 0.09, 0.12, 0.07)$

	np	cr	lt	ob	sb	rp
np	1.00	3.00	7.00	7.00	5.00	5.00
cr	0.33	1.00	3.00	0.20	0.20	0.20
lt	0.14	0.33	1.00	5.00	7.00	7.00
ob	0.14	5.00	0.20	1.00	0.33	3.00
sb	0.20	5.00	0.14	3.00	1.00	3.00
rp	0.20	5.00	0.14	0.33	0.33	1.00

CR = 0.085

$w = (0.50, 0.18, 0.14, 0.06, 0.09, 0.03)$

	bl	cr	lt	ob	sb	rp
np	1.00	3.00	7.00	9.00	5.00	9.00
cr	0.33	1.00	3.00	3.00	1.00	5.00
lt	0.14	0.33	1.00	3.00	3.00	7.00
ob	0.11	0.33	0.33	1.00	1.00	3.00
sb	0.20	1.00	0.33	1.00	1.00	3.00
rp	0.11	0.20	0.14	0.33	0.33	1.00

Os trabalhos (*draft* e *final paper*) estão limitados a no mínimo **6 páginas** e no máximo **10 páginas**, incluindo tabelas e figuras. O arquivo final em formato PDF não deve exceder 2 MB.

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O artigo deve ser digitado no *template* "CONEM2024.tex" e as principais configurações (ex.: formato do papel, tipo e tamanho da fonte do título/Seção/Subseção, espaços, margens, alinhamentos, indentação, etc.) já estão previamente configuradas no arquivo "abcm.sty". Título, nomes dos autores, instituição, endereço, resumo e palavras-chave devem ser recuados 0,1 cm da margem esquerda e marcados por uma linha preta na borda esquerda com largura de $2\frac{1}{4}$ pontos.

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As referências devem ser listadas no final do manuscrito de acordo com as instruções fornecidas na Seção 4.

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8.1 Títulos e Subtítulos das Seções

Os títulos das seções são com letras maiúsculas (Exemplo: **MODELO MATEMÁTICO**), enquanto os subtítulos só têm as primeiras letras maiúsculas de cada palavra (Exemplo: **Modelo Matemático**). Eles devem ser numerados, usando numerais arábicos separados por pontos, até o máximo de 3 subníveis. Uma linha em branco de espaçamento simples deve ser incluída acima e abaixo de cada título ou subtítulo.

8.2 Corpo do Texto

Conforme já se encontra definido no arquivo "abcm.sty", o corpo do texto é justificado e com espaçamento simples. A primeira linha de cada parágrafo tem recuo de 0,5 cm a partir da margem esquerda.

As equações matemáticas são alinhadas à esquerda com recuo de 0,5 cm. Elas são referidas como "Eq. (5)" no meio de uma frase, ou "Equação (5)" quando usada no início de uma sentença. Os números das equações são numerais arábicos colocados entre parênteses, e alinhados à direita, como mostrado na Eq. (5). Os símbolos usados nas equações devem ser definidos imediatamente antes ou depois de sua primeira ocorrência no texto.

O tamanho da fonte usado nas equações deve ser compatível com o utilizado no texto. Todas as grandezas físicas devem ter suas unidades expressas no Sistema Internacional de Unidades, como já mencionado.

$$\sigma = E \cdot \epsilon. \tag{5}$$

onde: σ é a tensão, E é o módulo de elasticidade longitudinal (ou Módulo de Young) e ϵ é a deformação longitudinal.

As figuras e tabelas devem ser colocadas no texto o mais próximo possível do ponto em que foram mencionadas pela primeira vez e devem ser numeradas consecutivamente em algarismos arábicos. As tabelas devem ser centralizadas e referidas por "Tab. 2" no meio de uma frase, ou por "Tabela 2" quando usada no início de uma sentença. Uma linha em branco, em espaço simples, deve ser introduzida entre a tabela e o texto subsequente.

Anotações e valores numéricos incluídos na tabela devem ter tamanhos compatíveis com a fonte usada no texto do trabalho e todas as unidades devem ser expressas no Sistema Internacional de Unidades. As unidades são incluídas apenas na primeira linha ou primeira coluna de cada tabela, conforme for apropriado. O estilo de borda é livre. As explicações, se houver, devem ser fornecidas ao pé das tabelas e não dentro das mesmas.

Table 2: **Exemplo de tabela.**

Propriedades do compósito	CFRC-TWILL	CFRC-4HS
Resistência à Flexão (MPa)	209.0 ± 10.0	180.0 ± 15.0
Módulo de Flexão (GPa)	57.0 ± 2.8	18.0 ± 1.3

As figuras devem ser centralizadas. Elas são referenciadas por "Fig. 1" no meio de uma frase ou por "Figura 1" quando usada no início de uma sentença. Sua legenda deve ser centralizada e localizada imediatamente abaixo da figura. As anotações e numerações devem ter tamanhos compatíveis com a fonte usada no texto e todas as unidades devem ser expressas no Sistema Internacional de Unidades. As figuras devem ser colocadas o mais próximo possível de sua primeira citação no texto. Deve ser deixada uma linha em branco, de espaçamento simples, entre a figura e o texto subsequente.

Figuras coloridas e fotografias de alta qualidade podem ser incluídas no trabalho. Para reduzir o tamanho do arquivo e preservar a resolução gráfica, os arquivos das imagens podem ser convertidos para o formato GIF (para figuras com até 16 cores) ou para o formato JPEG (alta densidade de cores), antes de serem inseridos no trabalho.

9. AGRADECIMENTOS

Se houver, esta seção deve ser colocada antes da lista de referências.

10. REFERÊNCIAS

Referências aceitas incluem: artigos de periódicos, dissertações, teses, artigos publicados em anais de congressos, livros, comunicações privadas e artigos submetidos e aceitos (com fonte identificada) e citações a páginas da internet.

A lista de referências deve ser uma seção específica denominada Referências, localizada no fim do artigo.

A primeira linha de cada referência deve ser alinhada à esquerda, sendo que as demais terão recuo já configurado a partir da margem esquerda. Todas as referências incluídas na lista devem aparecer como citações no texto do trabalho.

As referências devem ser postas em ordem alfabética, usando o último nome do primeiro autor, seguida do ano da publicação. Exemplo da lista de referências é apresentado abaixo.

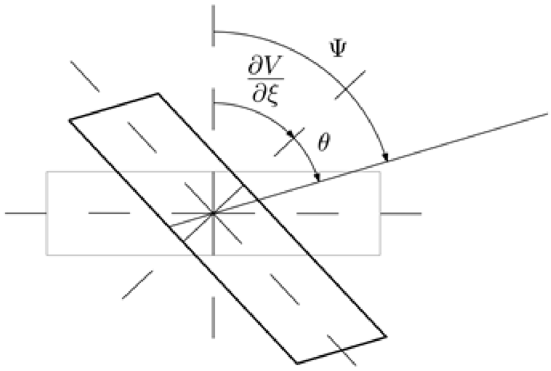

Figure 1: **Exemplo de figura.**

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11. RESPONSABILIDADE AUTORAIS

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