Study Of Defects In Aluminium Extrusion Process And Evaluation By Using Quality Tools

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Keywords: Extrusion Process, Defects, Quality Tools, Process, Cause

Abstract: The present work aims to classify and quantify the defects during the extrusion process by the data previously collected in an industry. Various quality tools have been used to identify the causes, correct possible deviations and find improvements by brainstorming, Pareto diagram, Ishikawa diagram, Why- Why analysis and Preventive / Corrective action methods have been used. The principal purpose of using these tools is to provide operators and managers with appropriate indicators that control the production process and identify critical extrusion variables or others responsible for excess waste, defects, and productivity. In carrying out this work, the defects in the extrusion process were typified and quantified, and whose causes and possible corrective measures investigated. From the results obtained, we can see that the Dents and Bend & Twist defects are a significant part of the total examined defects, demonstrating the relevance of monitoring this defect. During the study, it is concluded that several variables influence the occurrence of these defects. Some action plans have been suggested to reduce the rejection rate and get under or any comparable value of the in-house rejection target.

1. Introduction

The economic internationalization combined with the growing demand for aluminium by the world's major powers has resulted in a rise in competition and among firms concerned with aluminium extrusion. Today, one company's product is competing by multiple companies worldwide as we live in a digital age where media and transportation create a global market **[1]**. As a result, companies are being forced to develop new processes that focus on handling the raw material to the finished product and build a stable relationship with the customer. This attitude that is critical to ensuring that companies can build efficient and long-lasting businesses and sell their products in the present and the future. However, company’s chances of survival and further development are impaired if they do not constantly improve their processes to reduce costs and waste [2]. One way of identifying waste is to keep the process under control. It is necessary to know the whole process for control because "being in control means locating the problem, analyzing the process, Standardize and establish control elements so that the problem never repeats". These are the only way to increase productivity because they "always produce more and better products at a lower cost" [3]. The reduction of defects and the production of high-quality products do not result from inspection activities but mainly from improvement processes that are more efficient, simpler, safer and fundamentally less compliant. Minimizing the number of rejections **[4]**. Similar to some authors who define quality as a consumer-oriented approach. Hence, it must be the starting point for an organization that wants continuous quality improvement **[5]**. On the other hand, link the concept of quality with the concept of management and assign it two definitions **[6]**. Quality defined by the degree of consumer satisfaction (products according to specification or quality as faultless (fewer defects = lower costs) **[7]**. Hence, to satisfy customer needs and ensure product delivery according to their requirements, it is necessary to find solutions by gathering information about the entire production chain, analyzing it, and making better decisions. It can help companies improve their operational efficiency and overall product quality. Of the many process control (PC) tools to safeguard better quality control and optimal quality, Statistical Process Control (SPC) enables optimizing and monitoring quality based on data created during the entire production process. In the broadest sense, the PC is a collection of production methods, concepts and management practices that are used in the entire organization.

2. Methodology

3. Different Types of Quality Tools

Any types of devices or tools used to aid the quality of all products can take the form of a diagram, technique, or strategy to ensure that quality is maintained during production techniques. The increase in information in an organization creates a growing need for tools to collect and process data to aid effective decision-making **[8]**. Quality tools are methods used to define, measure, analyze and propose solutions that affect the performance **[9]**. In Professor Ishikawa's view, 95% of a company's problems can be solved with simple essential quality tools. Furthermore, the key to solving the problem is identifying the problem and using the right tools quickly. According to the nature of the problem and communicate the decision to others **[10]**. Quality tools consist of simple problem-solving tools that all employees can use to promote teamwork because everyone can understand their visualization. Although there are many quality tools, the most important are the seven basic quality tools proposed by Ishikawa, **[11]**. These methods are often referred to as the "Magnificent Seven" (MS) because they are an essential part of the quality control developed by SPC, especially **[12]**. Therefore, SPC is a collection of statistical methods included in quality control tools. The SPC, like the other quality tools, consists of a set of methods usually referred to as Quality Management (QM) methods. Quality Management was born in the United States of America, but the Japanese first recognized, imported and implemented its value. It was ignored in America for decades and helped Japan become the world leader in quality. In the past two dozen years alone, the West has rediscovered SPC to begin the search for quality improvements **[13]**. Some of the other quality tools used with these seven quality tools are root cause analysis tools. It is usually used for problem-solving in organizations wherein the system, process flow or any other policies that people use to make decisions in an organization are faulty. The tool can find the significant problems through the Pareto chart and plot the Ishikawa diagram for that. Through root cause analysis, the potential cause for the problems can be verified through a potential cause table. And then, by differentiating the impact of different causes in the Ishikawa diagram, the root cause can be found through the Why-Why analysis. And finally, actions for the root cause can be taken through Preventive / Corrective Actions, where the corrective action deals with the problems occurring after the event. In comparison, preventive action deals with the problem occurring before it occurs **[14, 15, 16]**. Pareto analysis is a never-ending process can measure the progress of corrective actions. It also helps improve safety, reduces waste, save energy, reduce costs etc., problems with different data sets to analyze and analyze before and after the effects of changes [17]. The cause and effect diagram, also known as the Ishikawa diagram or Fishbone diagram, is a systematic way of listing and organizing all possible causes of an effect of the quality problem [18]. The flowchart identifies the flow of the process and the interaction between the process steps. It can help identify potential control points [19]. Histogram is one of the quality statistical tools used to graph many of numerical data. Analyzing the histogram makes it possible to identify longer data ranges and interpret this information more quickly and more superficial than following a large table or report with just numbers and values [20]. A control chart represents a quality feature recorded at some time intervals. The diagram shows information about the mean value of the process (X), represented by a centre line and two different reference lines, which represent the upper control limit and the lower control limit. In order to assume that a process is under statistical control, all samples must be included in the range defined by the limit values [21].

4.1 The Company

The company specializes in the development and production of aluminium profiles. It is a national company that produces aluminium profiles, including engineering, architectural and industrial works in general. Its central pillar is the demanding market (ISO 9001: 2015 certified) Quality Management System (QMS). This company stands out as a productive and exporting member of the group of companies to which it belongs and, given the existing situation. The company's quality policy is aimed at absolute customer satisfaction with punctual delivery times and other functional requirements. The company's pursuit of excellence is a constant pursuit, committed to developing and improvising the products and services.

4.2 Data Collection Methodology and Process Flow of Quality Tools for Identification, Analysis and Control of Defects

To carry out this study, several data sources were analysed, namely company documents and technical datasheets. In the first phase, an assessment of the types of nonconformities with the highest incidence was carried out by collecting data for six months of production. A theoretical framework was used to support this entire process that relied on a literature review on the critical concepts addressed, i.e., the theoretical development of the aluminium extrusion process, statistical process control, and other quality tools. According to the different stages of this study, several quality tools were used: Flowchart to represent the production process, Pareto diagram to identify the major rejections, the Ishikawa diagram to identify and structure the possible causes leading that give rise to the various defects, among others. Then, the root cause analysis is done using why-why analysis. Finally, Preventive / Corrective Action is suggested for the root cause to overcome the rejection rate as depicted in Fig 1.

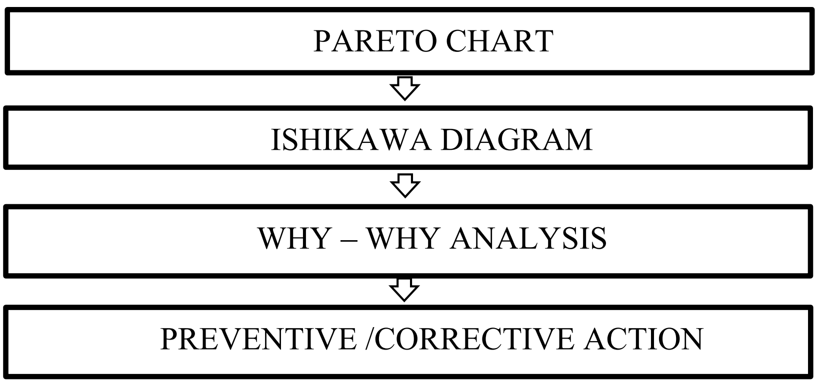

Fig. 1 – Process flow of Quality tools

4.3 Description of the Production Process of Extrusion

The company's production process begins in the sales department, where orders are received, separated and confirmed. At this point, the whole production plan is drawn up based on the installed capacity of extrusion. The process is divided into five parts: billet heating, aluminium extrusion, stretching, finish cutting and ageing or heat treatment combined by small processes. To illustrate all process phases as mentioned above, a flow chart can be used, as shown in Fig**.** 2.

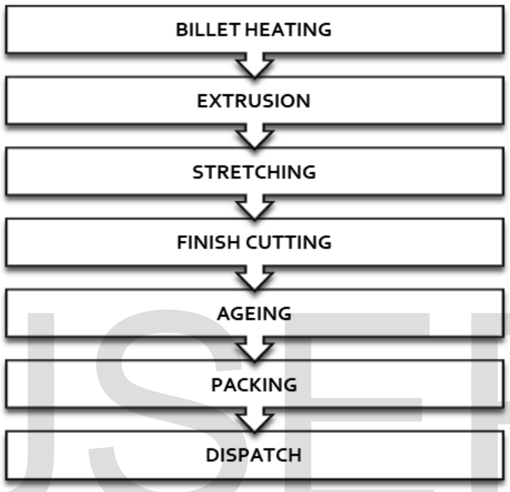

Fig. 2 - Typical Aluminium Extrusion Process Flow in the Company

Aluminium extrusion process involves, forcing a cylindrical block of aluminium against a die, extruding products of constant cross-section. Aluminium billets are stored in batches according to the alloy and the supplier who supplied the raw material. There is a first look, dimensional quality control and confirmation of the quality certificates supplied with the billets. When a batch is selected for extrusion, the billets are transported to the feed ramps, and the process begins with a simple cleaning of the surface to remove dirt and some surface impurities that may be present. After cleaning, the billets go to the preheating furnace, where they are heated homogeneously. This gas-fired oven consists of heating zones allowing gradual heating and avoiding the billet exposed to high temperatures for an extended period. After the production planning, the production system starts the extrusion process of the profiles. The extrusion is prepared by heating the ingot on the specified alloy and already prepared dies. At the exit of the furnace, billets are cut, and the container is transported to press, which remains heated to a constant temperature. The billet is then extruded. Before extrusion, the die is also heated to avoid thermal shock. Depending on the alloy profile, profiles can be cooled with air or water at the exit from the die. Usually, the profile is pulled by a puller which guarantees a constant output speed to ensure uniformity. In the same production series, the profiles are continuously extruded and cut to each billet to be pressed with a hot saw. This cut is made precisely when a billet joins the previous one; the already cut profile is attached at both ends and stretches to be straight and without bends. The areas of the billets near the joint are eliminated (scrap), as these are areas with significant heterogeneity. After passing the stretcher, the bars are cut into shorter bars and placed on racks transported to the ageing ovens. After ageing, the profiles can also be anodized or powder-coated, depending on customer requirements. The starting conditions of the billet are decisive on an excellent extrusion and for an end product with the desired properties and qualities, from the mechanical properties to subsequent heat and surface treatments, to the surface quality and adhesion of paints or coatings.

4.4 Description of Rejections due to Defects in Extrusion Production Process

Based on data collected and direct observations of the extrusion process, several situations were identified that contribute to the occurrence of rejects. There are several criteria to consider in the phases of the extrusion process, namely in terms of specifications of the production order and the process conditions. The operators often neglect these criteria, resulting in several defects that run through the entire process. It often happens that these products are not found to have defects until the end of the production line, which is problematic both financially and in terms of time.

Table 1 – Last 6 Months Rejection Data of the Company

Defects	Quantity (in kgs)	Cummulative Qty	Cummulative %
DENTS	28991.7	28991.7	35
BEND & TWIST	14183.5	43175.2	52
SCRATCHES	5739.6	48914.8	59
PICK UP	4492.0	53406.8	64
TEARING	3991.1	57397.9	69
BLISTER	3750.8	61148.8	74
DAMAGE	3612.2	64760.9	78
DEPRESSION	3045.1	67806.0	82
POROSITY	2162.0	69968.0	84
HARDNESS	2004.1	71972.1	87
SURFACE NOT OK	1967.0	73939.1	89
ANGULARITY	1745.1	75684.2	91
LIGHT SECTION	1604.3	77288.5	93
FLATNESS NOT OK	1496.7	78785.2	95
SAGGING	1399.3	80184.5	97
DIE LINE	891.7	81076.2	98
PITTING	585.6	81661.8	98
STOP MARK	375.0	82036.7	99
FINS DAMAGE	366.1	82402.9	99
PIN HOLE	283.0	82685.8	100
ANGLE NOT OK	198.8	82884.6	100
CAUSTIC MARK	25.4	82910.0	100
JOINT MARK	24.3	82934.2	100
MATCHING NOT OK	20.6	82954.8	100

1. The last six months data related rejections in X & M (referred to as three different aluminium extrusion production locations) collected from the company.
2. The data is computed and sorted in the excel sheet for each defect, as shown in Table 1.

4.5 Data Analysis through Quality Tools

4.5.1 Pareto Chart Analysis

Based on the information extracted from the rejection data of the last six months according to Table 1, the Pareto diagram was created for the highest frequencies of defects. The graph ranks the frequency of occurrence of a particular characteristic to be measured from highest to lowest. It provides the information so that improvement efforts can be focused on the areas where the most significant gains can be obtained.

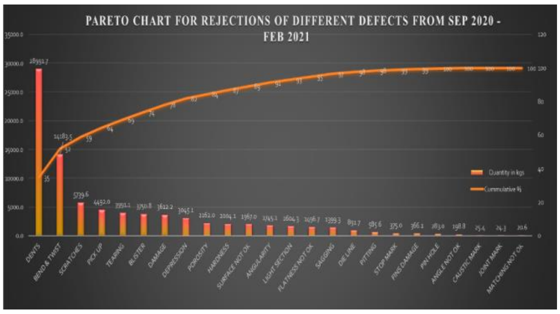

Fig.3 – Pareto Chart Analysis for Company Data

4.5.2 Selection of Major Rejections due to Defects for Further Analysis

The total production from September 2020 – February 2021 is 3693 Metric Ton (MT), whereas out of which the total rejection was found to be 92.9 MT (i.e., about 2.51%). In the Fig. 3, 18 different defects that caused the rejection were plotted in a Pareto chart for the last five months. Out of 18 different defects, two major rejections, namely as below, were selected as they had 52% (Combined) Rejection contribution among other defects. Avoiding these defects can bring down the rejection rate to about 1.20%. And hence, Ishikawa & Why – Why analysis were conducted to find the root cause of these rejections. Finally, Corrective / Preventive Action was suggested to avoid further occurrence or recurrence. Hence, framing actions for these two defects (Dents, Bend& Twist) will fulfil the control of rejection rate or any comparable value to 1.1% (i.e., the inhouse target of rejection rate).

5. Major Rejection Analysis through Quality Tools

5.1 Dents

As shown in Fig.4, dents can occur during transferring long extruded sections from one place to another by moving rollers or overhead cranes [22]. According to the last five months, dents have a 35% contribution in rejection according to the company's data.

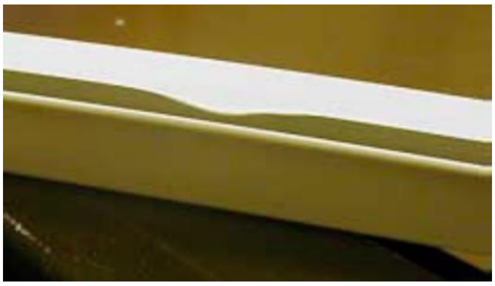

Fig.4 – Example of Dents

5.1.1 Ishikawa Diagram for Dents

Fig 5, below depicts cause and effect diagram or Ishikawa diagram of dents shows the different means of causes like hooks of the crane, over stacking in the racks comes under method. Like this, other issues or problems are categorized into the machine, man, measurement, material, and die. These root causes provide us with additional insight into process behaviour.

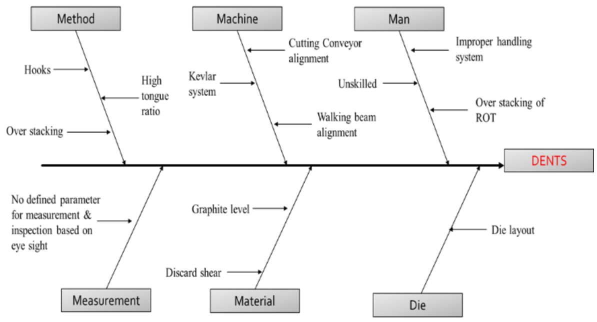

Fig 5 – Ishikawa Diagram for Dents

5.1.2 Potential Causes for Dents

Table 2 – Potential Cause for Dents

Cause	Verification	Impact
Hooks	During material movement, Handling system hooks hitting on the profiles resulting in dents on the profiles	Low
Over stacking/material stacking in racks	Over stacking of profiles resulting in excess load on the bottom profiles, resulting in dents	Medium
High tongue ratio	Tongue ratio should be 1:3 & if it more then the leg portion of the profiles will results in dents during handling, stacking & material movement.	Medium
Conveyor system	In 6" press the conveyor movement resulting in dents on the profiles, due to the CAM movement type	Low
Walking beam alignment	Variation in the height of the walking beam will result in the dents on the profiles, when profile moves over this system	Low
Cutting Conveyor alignment	Height variation in the cutting table resulting in dents on the profiles	Low
Unskilled	While material handling during inspection & stacking resulting dents on the profiles	Low
Over stacking of ROT	Material not being stretched on time & delay in cutting, resulting in over stacking. Due to over stacking manual movement of material on handling system resulting in dents & scratches	Low
Improper handling system	Improper handling system on the press resulting in damages during material movement from one conveyor to another	Low
No defined parameter for measurement & inspection based on eye sight	Dents are defined by visual inspection & there is no defined parameters of depth of dents.	Low
Discard shear	During the shear discard the material movement will result in dents on the profiles	Low
Die layout	Flat area of the profiles, leg portion when made to rest on	High

From the above table, causes are verified, and impact status is given to each cause for selection to the further root cause analysis and action plan. Further, the cause with high or medium impact status was taken for analysis. Hence, the three causes, namely over stacking/material stacking in racks, high tongue ratio and die layout, were selected for further analysis.

5.1.3 Why-Why Analysis for Dents

5.1.3.1 Over stacking/material stacking in racks

The cause is **" Over stacking of profiles resulting in excess load on the bottom profiles, resulting in dents"**. Further, why-why is conducted to find the root cause as below.

Why 1: Over stacking of profiles resulting in dents.

Why 2: Due to placing of heavy section upon the light section Also due to wrong stacking pattern

Why 3: There is no standard instruction for stacking profiles rack wise. Also, unskilled labours stacking material.

Why 4: Because of different types of shapes being extruded daily. Daily altering workforce.

5.1.3.2 High tongue ratio

The cause is due to "**Tongue ratio should be 1:3 & if it more than the standard ratio profiles will results in dents during handling, stacking & material movement**". Further, why-why is conducted to find the root cause as below.

Why 1: As per customer design, the tongue ratio is not within the 1:3 ratio

Why 2: During the feasibility stage, the 1: 3 tongue ratio not being considered & die developed

Why 3: Due to customer-specific requirements application-wise, a higher tongue ratio being accepted.

Why 4: The rejection due to higher tongue ratio being communicated & additional conversion cost being collected for this specific requirement.

5.1.3.3 Die layout

The cause is due to **"Flat area of the profiles, leg portion, when made to rest on the ROT & handling system, will results on dents on the profiles"**. Further, why-why is conducted to find the root cause as below.

Why 1: Improper orientation of the die resulting in dents on the profile

Why 2: Flat surface in contact with Run out Table (ROT).

Why 3: To obtain the stability of the profile and to avoid the falling

5.1.4 Preventive / Correction Action for Dents

5.1.4.1 Over stacking/material stacking in racks

Safe stacking of materials is a part of a suitable material handling and storage management system. While stacking the material, the width and height of the rack should be considered.

Present: Over stacking of profiles resulting in dents, damages and scratches on the profiles. Different finish material stacking in the same racks will also result in multiple handling, which will result in surface defects.

Fig. 6 – Over stacking of materials in the rack.

Suggested Remedies: Stacking racks up to rack level with sufficient gap will avoid the surface defects on the profiles. One section per rack will avoid multiple handling. One Point Lesson (OPL) prepared to create awareness on the shop floor**.**

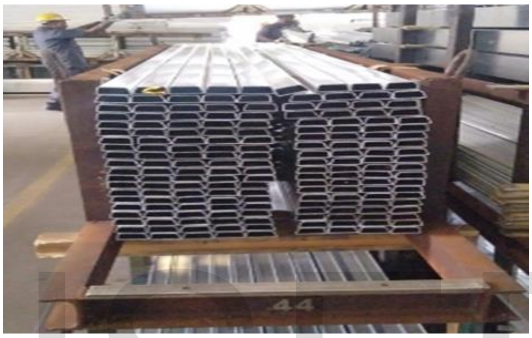

Fig. 7 – Properly stacked materials in the rack

5.4.1.2 High tongue ratio

The tongue ratio also plays a vital role in determining a part`s extrusion performance. The tongue ratio of extrusion is determined by squaring the slightest opening to the void, calculating the total area of the shape, and then dividing the opening squared by the area. The higher the ratio, the more difficult the part will be to extrude.

Present: Profile with a high tongue ratio will face the dents on the profiles when moving on the handling system and stacking of profiles. Also, due to flow variation, bulging & dents can be observed on profiles.

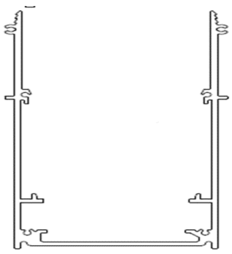

Fig. 8 – Example of profile section

Suggested Remedies: Profiles with a higher tongue ratio to be rejected during the feasibility stage or rib to be proposed in the profiles. Die must be unloaded if there is any flow variation & bulging of the profiles.

5.4.1.3 Die layout

Each die layout drawing should include information: Title Block should contain general information such as part name, part number, tool name, tool operation number. Material and thickness of sheet metal.

Present: Wrong die layout will result in dents on the profiles. The leg portion of the profiles on the handling system must be avoided.

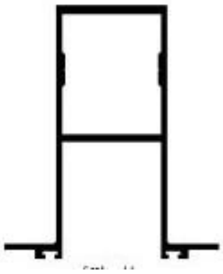

Fig. 9 – Present profile layout

Suggested Remedies: During feasibility & die development, the die layout need to be checked & fixed to avoid dents. Leg area must be avoided on the handling systems, and the die must be placed in orientation as in Fig. 10.

Fig. 10 – Suggested profile layout

5.2 Bend and Twist

Several factors can cause different metal flow in a multi-hole die: the openings in the die (cavities) are not perfectly aligned (centred) concerning the container; different wall thicknesses in profile design etc. It means that the flow of material is faster on one side, which leads to bends or twist, as shown in Fig. 11. Similar problems can occur if the billet is not heated evenly on all sides, resulting in uneven temperature distribution. Some bending can also occur due to improper stacking.

Fig. 11 – Example of bend and twist

Bend and Twist have a 17% contribution in rejection according to the last six months trend provided through the company's data.

6. Conclusion

The main objective of this paper was the use and implementation of quality tools, in particular statistical process control tools, to reduce the variability of the process and thus the amount of scrap. One of the main mistakes that can result from the misuse of extrusion parameters has also been made. This challenge presupposes high demand, which is essentially motivated by quality standards, reduces manufacturing costs, and increases productivity. In process control, the collected data is routinely used, and this information is available in a practice-oriented manner so that all employees involved can improve the process. All the defects usually encountered within the industry are outlined and explained with visual illustrations. Flaws are categorized into metal-flow connected, surface, weld, metallurgical, temperature and speed-related, instrumentation and tooling related, and many different reasons. Causes and mechanisms of defect formation are mentioned on the idea of mechanics and science in most cases. According to literature, various defects, categories, and mechanisms have been represented that do not seem to be heretofore. With this in mind, it is of the utmost importance to develop a new culture in the company that enables the motivation and cooperation of everyone in the search for continuous improvement of the entire process so that the SPC effect has a significant impact on quality and productivity. Also, by adding many gains to the organization and also effectively reflect the goals of the company. The Preventive / Corrective Action Plan is suggested for the two defects, i.e., Dents and Bend & Twist, which contribute to about 52% of the total rejection considering the company's last six months. The rejection rate was found to be 2.51% among the total production of the last six months. The rejection rate will be reduced from 2.51% to 1.2 % by introducing the Action Plan, almost close to the company target of rejection rate, i.e., 1.1%.

Acknowledgements

The present work was supported by Department of Mechanical Engineering, The National Institute of Engineering, Mysuru, India.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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