Managing Tolerance Stack-up through Process Integration Team in Steel Industry

Sungwoo BYUNa)

Abstract: Tolerance is defined as “the difference between the maximum and minimum dimensions that can be allowed in terms of product functionality.” Company A, a steel manufacturer, follows the textbooks in presetting and managing tolerances so that its processes can flow seamlessly without any adjustments, as long as conditions remain within the range of tolerance. However, tolerance stack-up risk has been observed in the production of high-grade products such as automotive steel sheets because the quality measurements have approached the tolerance limits in several consecutive processes even though the said measurements have stayed within the tolerance range (which means that the products are not classified as defective). On the other hand, Company B (also a steel manufacturer) has been successful in managing tolerance through a method that is entirely different from the textbook model by having its Integrated Quality Control Group adjust the tolerances between processes and
Introduction

Tolerance can be defined as “the difference between the maximum and minimum dimensions that can be allowed in terms of product functionality” that a company will predetermine for a particular design (Namiki & Endo, 1989). In fact, tolerance requirements are not limited to dimensions. For example, Asahi Breweries measures the content volume of its bottles and cans by using a weight checker in the final inspection process of the Super Dry production process and does not ship products that deviate from the set tolerance. Thus, companies impose their own product inspection rules whereby products that deviate from the tolerance during the inspection process are deemed defective, while those within the tolerance range are allowable. Furthermore, strict implementation of the following two principles results in gaining customers’ trust (Fujimoto, 2001).

(1) Although the companies themselves set the tolerance level, customer satisfaction should be the top priority. Hence, the tolerance level should be set on the basis of the limits of what a customer would perceive as being “defective” rather than on the basis of the conveniences of development and production.

(2) Once the tolerance level is set, it should never be changed without due cause, and products that fall outside the tolerance range should not be put on the market.

Tolerance is a concept about range. If the range is made narrow
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and tolerance becomes stricter, the number of internal defects would increase; on the other hand, the number of external defects would decrease. However, a balanced approach is important when dealing with internal defects as costs are involved in handling defects, such as scrapping, reworking, and the like. Meanwhile, tolerance is closely related to the capacity of the manufacturing quality assurance processes. Conventional production management theories (particularly quality control theory) have primarily focused on tolerance and cost, as well as tolerance and processing capacity. In the following, we will describe tolerance management practices in the steel industry and discuss the importance of balancing tolerances.

Tolerance Management in Steel Industry

Steelworks products are generally treated and processed in several steps at high temperatures and speeds. Each process is implemented in a dedicated large facility, and almost no assembly work is involved. An operator in the control room controls the parameters, sets the tolerances, and manages the quality (Table 1).

In each steelmaking process, tolerance is set and operated as shown in Table 1. For example, temperature is the most important factor in managing a blast furnace in ②. Tolerance is set for the temperature inside the blast furnace to adjust the amount of oxygen and pulverized coal that is blown into the blast furnace to stay within the tolerance range. Alternatively, in the steelmaking process in ③, the operator controls the parameters, including the amount of oxygen and alloy iron, among other things, so that the component values do not deviate from the tolerance. Thus, tolerance management is at the center of process management for any steel manufacturer.

Normal grade products with loose quality terms will not cause any major problems even if they move to the subsequent process as long
as the tolerance set for each process is cleared. However, in the production of so-called high-grade products, such as automotive steel sheets, as shown in Figure 1, quality measurements may sometimes approach the tolerance limit in multiple processes, which frequently causes quality problems in the end because of its cumulative effect. This is known as the risk of tolerance stack-up. In
such cases, it becomes necessary to adjust and manage the tolerances among multiple processes. The steel industry has been aiming to improve quality through process innovation (Byun, 2018) until now; however, cumulative tolerance that hinders the production of high-grade products not only presents a technical problem but also relates to the said inter-process cooperation.

**Tolerance Stack-Up in Manufacturing High Grade Steel Products**

For steel manufacturers, products geared toward automobile manufacturers are an important source of revenue. There are more than 100 different steel products used in automobiles, from small bolts to steel body plates, which account for about 70% of passenger car weight. These are collectively referred to as automotive steel sheets. The most value-added product among them is hot-dip galvanized steel sheets, used especially as the outer plate material of luxury cars. To prevent the corrosion of the steel sheet,
molten zinc is applied to the steel surface. As proper skin management is necessary to improve the application of makeup, the same holds true for steel quality; it must be managed as it serves as the base to which the molten zinc is applied.

Hot-dip galvanized steel sheet is a product that goes through all the processes in Table 1. The product’s “outer appearance” is primarily influenced by processes ③ through ⑥. (Although the influence of processes ① and ② cannot be denied, it is not as pronounced as that of other processes.)

The steelmaking process ③ entails removing the five major impurities (Carbon (C), Sulfur (S), Silicon (Si), Manganese (Mn), and Phosphorus (P)) from the pig iron extracted from the blast furnace and manufacturing steels with client-specific composition. This process involves a complicated chemical reaction, and an accurate prediction model cannot be constructed. Therefore, the target value of the component is often managed by tolerance. The operator concentrates on removing carbon by blowing oxygen into the converter.

The hot rolling process ④ controls steel crystallization by taking a roughly 250 mm-thick slab that has been reheated to above 1000°C, clamping its top and bottom with a roller to stretch and thin it out to a thickness of up to 1.2 mm. Furthermore, if the operation parameters are adjusted on the basis of the component values, the properties of the steel, such as strength and elongation, can be controlled. In the cold rolling process ⑤, the steel plate rolled in the hot rolling process ④ is further thinned out to less than 1 mm in room temperature.

If the component value in the steelmaking process ③ barely stays within the tolerance range and also barely passes the acceptability criteria in the hot rolling process ④, it causes quality problems such as surface cracks in the cold rolling process. This is because the carbon content involved in steelmaking process ③ greatly affects the
surface quality of the steel plate. Thus, if it keeps barely passing the tolerance test in several processes, such as in processes ③ steelmaking, ④ hot rolling, ⑤ cold rolling, and ⑥ plating, the deviation from target value accumulates, which poses the risk of defects later on.

However, managing tolerance stack-up is a technical issue as well as an organizational issue. Strictly setting tolerance in each process increases the cost of dealing with defects in each process. Of course, setting tolerances for multiple processes requires adjustments and coordination between the processes and organizations. Naturally, the approach to tolerance stack-up varies, depending on the company.

**Case Study: Company A**

Company A, a major steel manufacturer in Korea, has eight production bases in Korea, and most of their equipment, such as blast furnaces, converters, and continuous casting, as well as their IT systems used in controllers, etc., are state-of-the-art. The company is focusing on producing products for automobile manufacturers, such as automotive steel plates and special automotive steels, and is planning to expand its overseas business in full swing in the future. It has only been approximately 10 years since the company started implementing integrated production, spanning from blast furnace to plating and as the company is still fairly young when compared with its domestic rivals, it has enjoyed the latecomer’s advantage (Gerschenkron, 1962). It has gathered attention from the global steel industry because of its ability to launch a steelworks and increase its production volume in such a short time (Byun, 2016).

The company sets a tolerance for each steelmaking process. The company presets and manages tolerances according to textbook so that the processes can flow seamlessly without any adjustments as long as it stays within the tolerance range. When the intermediate
products are carried over to the next process, no information is passed on regarding their quality level, and are plated and processed simply on the basis of whether the intermediate product is “acceptable.” However, the company has been running into a cumulative tolerance problem when producing high-grade products such as automotive steel sheets. Efforts were also made to narrow the tolerances that are managed in each process, but this posed a risk of a rise in costs, and hence, the processes took extra time. However, it was not easy to identify the cause of the quality problems found in the cold rolling and galvanizing processes.

The company has recently begun to recognize the need for integrated quality control, particularly around 2017, when it began to recognize the need for inter-process coordination, such as sharing tolerance information on hot-dip galvanized steel sheets. Company A, which has an IT specialist company under its umbrella, eventually devised a system of sharing tolerance information, etc. using IT systems, instead of relying on the individual, veteran knowhow. This was partly because the company had few veteran employees unlike the typical Japanese manufacturer. There were two reasons behind this.

(a) Even if a specialized veteran team is to be established, it has been rare for talented engineers to be transferred to such teams. Each department wishes to retain a talented engineer.
(b) Hence, even if a specialized team is established, it is an entirely different matter as to whether they are authorized to make such inter-process adjustments. With no authorities, the team merely becomes titular.

The field engineers of Company A, who were strongly aware that the shift to high-grade products would improve competitiveness, investigated the efforts of competitors including that of Japan, and launched a project team around 2017 to build a system. Its members
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comprised those from the production site and technical research labs of the steelworks, and the technical research lab decided to assume its leadership position. In particular, sharing tolerance information was set as an important goal for building the system. The project team has expanded its horizons to share information between production bases so that even a non-steelworks base that is only equipped with a rolling process can be unified into this integrated system. However, even though the sharing of tolerance information via the system has progressed, the problem of figuring out how to make inter-process adjustments still remains unsolved.

Case Study: Company B

Company B, Japan’s leading steel manufacturer, has more than 10 production sites in the country. Above all, their main steelworks in Nagoya supplies automotive steel sheets to automakers, particularly Toyota Motor Corporation. The company actively participates in the development of new cars by automakers from an early stage and strives to meet client requirements (lightweight, workability, high strength, rust prevention, etc.).

Company B, the world leader in automotive steel sheets, handles inter-process management as an organization. The company’s “integrated quality control group” creates an integrated quality team primarily for each category of high-value-added products such as automotive steel sheets, as well as thick plates, electrical steel plates, etc., and implements inter-process adjustments that they call adjusting inter-process tolerances.

Team members consist of those who have worked for many years in each process and have deep technical knowledge about the process. However, they are not merely a collection of onsite veterans with deep knowledge about each process, who congregate in a single location. They need to have the following two characteristics.
(A) Members of the Integrated Quality Control Group have knowledge of inter-process management so that inter-process conflicts, trade-offs, etc. that can occur when producing high-grade products, such as hot-dip galvanized steel sheets, can be adjusted. For example, to produce high-grade products, it is necessary to increase the accuracy of each ingredient by taking time to adjust the ingredients in the steelmaking process. The operators must spend more time in making fine adjustments to the ingredients. During the hot rolling process, the operators spend more time adjusting their vertical and horizontal dimensions than they do with other products. Such efforts may reduce the productivity of the rolling process. The Rolling Department may understand the importance of the aforementioned efforts to produce high-grade products but may also find it difficult to adopt it when considering the overall evaluation that takes the process productivity, etc. into consideration. The members of the Integrated Quality Control Group monitor the production status (processing status, inventory position, etc.) of high-grade products and assume authority in instructing each process department. If necessary, they may oversee production.

(B) Although the products are evaluated as satisfactory or defective on the basis of the tolerance set for each process, the importance of the Integrated Quality Control Group lies in their responsibility to determine a product’s position within the tolerance range even for a satisfactory product. For example, if an ingredient adjustment step in the steelmaking process barely passes the tolerance test, and the intermediate product gets reheated later on in the heat rolling process, it may experience surface quality issues during the rolling process. However, if the power and the passing speed of the rolling mill are adjusted in the hot rolling and cold rolling processes according to carbon
content, operation is still possible. There is still room for adjusting parameters such as the reheating temperature and rolling speed.

The company’s tolerance range is very narrow for both the steelmaking and rolling processes and resembles an integrated management system for high-grade products. Such strict management is made possible by the adjustments made by the Integrated Quality Control Group. Although the same word, “tolerance,” is used here, they use a completely different tolerance management system than that described in the textbooks. Table 2 compares the tolerance management of the two companies.

### Table 2. Tolerance management in Companies A and B

|                     | Company A                                      | Company B                                      |
|---------------------|------------------------------------------------|------------------------------------------------|
| Tolerance setting   | Individually set and managed with range         | Individually set but ranges are extremely narrow |
| Tolerance information sharing across manufacturing processes | Non-existent                                  | Integrated Quality Control Group mediates manufacturing processes |
| Managing tolerance stack-up | Trying to build a new and customized IT system | Organizational mediation efforts (Integrated Quality Control Group) |

**Discussion**

In this paper, we showcased two companies in the steel industry as an example to explain that the “tolerance stack-up risk,” which
occurs when tolerance limits are neared subsequently in multiple processes, even if the products stay within the tolerance range and are not classified as defective, is handled differently by each company.

The Korean Company A has been, in some sense, managing its tolerance in textbook fashion but became quite aware of the challenges involved in producing high-grade products and has been taking initiatives to share information via an IT system to handle the tolerance stack-up risks. On the other hand, the Japanese Company B has established the Integrated Quality Control Group (an inter-departmental team) to alleviate and avoid tolerance stack-up risks. Their tolerance management deviates from standard textbook tolerance management and from the fact that it resembles integrated management as well.

Whether tolerance information is shared in an organizational structure, or via an IT system, depends on the management resources of the company (availability of veterans, ability to operate an IT system, etc.). The coordination capability of a firm implementing strict management that closely resembles integrated management, while adjusting the tolerances, is an onsite capacity that competitors would not be able to imitate (Fujimoto, 2012).

The difference between the tolerance managements of Company A and Company B is the existence of the Integrated Quality Control Group. It can be understood that organizational structures change depends on how the steel manufacturer regards the manufacturing technology of high-grade products, for example, whether the steel manufacturer considers it to involve adjusting the tolerances. It can be said that organizational structure and strategy depend heavily on technology and its recognition (Takahashi, 2016).
Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP17K03921 and JSPS Grant-in-Aid for Publication of Scientific Research Results, Grant Number JP16HP2004.

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