Chapter

Quality Assurance of Aluminium Extrusion for 6xxx Series Alloys

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Abstract

Aluminium extrusion of 6xxx series alloys is gaining more and more importance and indispensable in the market for applications in automotive (great potential for EV in the near future by 2030), construction, architecture, electronics, marine and rail transport. The 6000 series alloys can be divided into soft alloy (e.g. 6060, 6063) and hard alloy (e.g. 6005A, 6061, 6082) for different applications based on customer's requirements for tensile strength, yield strength, elongation, surface finishing (powder coating and anodizing) and heat treatment. To produce good quality extrudates with quality that can meet customer's stringent requirements has become a challenging job nowadays for extruders in developing country like Malaysia. In order to be competitive in the global market, the products have to be produced at minimum cost and just-in-time to meet the committed delivery date. This will require a very good implementation of quality system in the production to ensure customer's satisfaction is achieved from time to time. Based on the real experiences of working in an international scale extruder, the effective methods taken to improve product quality and productivity are elaborated throughout the chapter.

Keywords: aluminium alloy, extrusion, defects, quality assurance, material handling

1. Introduction

Aluminium alloy can be defined as a substance having metallic properties and composed of two or more alloying elements of which the base metal is aluminium. Most aluminium alloys contain 90–96% aluminium, with one or more other elements added to provide a specific combination of properties and characteristics. It is quite usual to have several minor alloying elements in addition to one or two major alloying elements to impart special fabrication or performance characteristics for the sake of manufacturability and desired mechanical properties. The 6xxx series alloys have both magnesium and silicon as their main alloying elements, which combine as magnesium silicide (Mg_2Si) following solid solution [1]. Alloys in this series are heat treatable. This series of aluminium alloys can be divided into soft alloy and hard alloy (jargon used by production people to indicate the tensile strength of the alloys, soft alloy has maximum tensile strength 215 MPa, while hard alloy has maximum tensile strength 310 MPa). Examples of soft alloy are 6063, 6061 and 6463, while the hard alloy encompasses 6061, 6005A and 6082 for the most common applications in consumer products, architectural structures and construction. **Figure 1** indicates

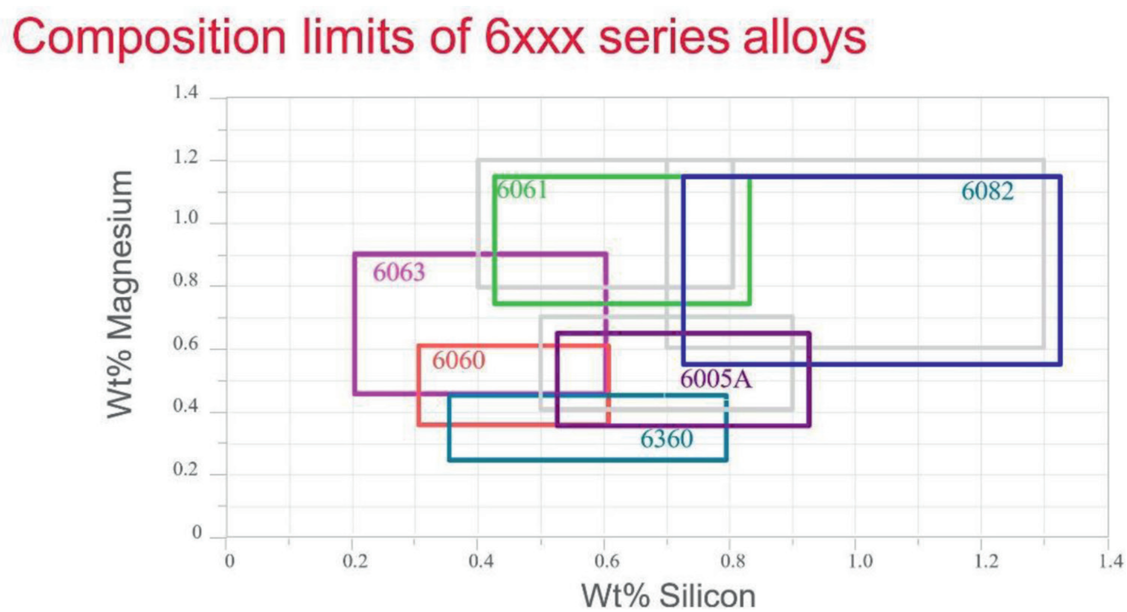


Figure 1.
6xxx series alloy types and their Magnesium and Silicon weight percentages.

the category of 6xxx series alloys according to their silicon and magnesium contents, which corresponds to their mechanical properties.

The 6xxx series alloys are especially suitable for hot extrusion process because of its extrudability to form solid or hollow/semi-hollow cross sections. The alloys are also heat treatable with artificial aging process to achieve the desired tensile strength, yield strength and elongation. There are a number of reasons why the 6xxx series are popular for various applications in extruded profiles, as stated below [2]:

- Density approximately one-third that of steel and has high strength-to-weight ratio with tensile strength ~340 MPa for 6082-T6 alloy.
- Good electrical conductivity of 48–50 IACS for alloy containing ≥97.6% Al and ≤0.19% Fe.
- Good thermal conductivity to be made as heat sink.
- Good corrosion resistance.
- Good ductility and workability (due to the fcc structure) for fabrication by rolling, stamping, drawing, spinning, roll forming, forging, and extrusion.
- Cryogenic toughness, as the fcc structure does not become brittle at low temperatures.
- Variety of surface finishes ranging from clear to colour anodized, colour powder coating and PVDF coating (polyvinylidene fluoride) for functional or cosmetic applications.
- Nontoxic for food storage, cookware, and food processing applications (RoHS and REACH Compliance).
- Recyclable for sustainable manufacturing.

In this book chapter, the focus is on conventional direct hot extrusion process. The word "hot" is referring to the preheating of the billet before the direct extrusion process. The basic process consists of forcing a preheated billet of round shape which is loaded into a container by a hydraulic ram with dummy block at its front end. The ram is linked to the main piston of a main cylinder powered by hydraulic system [3]. The aluminium billet can be preheated from 400 to 500°C in a preheat-oven designed with 3–4 heating zones. The temperature settings are in increasing trend from inlet zone to outlet zone. The billet will be forced to squeeze through a die which is also preheated to about 450–480°C to form a uniform cross-section profile either in solid, hollow or semi-hollow shape according to specific product design. The extruded profile will be subjected to air- or water-cooling process according to its temper requirements [4]. The run-out table on which the profile is placed is installed with cooling fans to blow the profile for continuous cooling process until it is stretched to straighten the material in the long length (ranging from 20 to 40 m). The stretching process also serves to impose strain hardening effect on the material for subsequent effective natural and artificial aging to achieve the desired mechanical properties. The stretched profile will be moved by conveyor to the cutting station to be cut into the desired order length (with tolerance of ±5 mm) and the material will be loaded into trolley and stacked into layers separated by spacer bars.

2. Defects in extrusion

Aluminium alloy in extruded form is easily subject to damage due to external forces because the surface is relatively soft and requires extra precaution to prevent the unwanted damage that can cause the extruded profile deemed to be a reject (unacceptable product that does not fulfil standard or customer specifications). The defects in extrusion can be caused by multiple factors in the process related to the 4Ms in root cause analysis technique, namely man, machine, material and method. There are four main reasons that contribute to the defect's formation in the extruded products [5].

i. Defects in incoming billet (e.g. hydrogen contents exceed 0.2 cc/100 g, lack of homogenization—β to α transformation <80%, inclusion, scales/flakes, internal crack, undissolved oxides etc.).

ii. Physical defects in die-set (e.g. mandrel offset, die bearing worn-out, die aperture oversized cause dimensional inaccuracy etc.).

iii. Extrusion process parameters not optimized (e.g. inappropriate extrusion pressure, billet temperature, ram speed etc.).

iv. Post-extrusion operations suboptimization (e.g. rough material handling, insufficient stretching, saw chips at cutting machine caused scratches etc.).

A local extruder from Malaysia (company's name is not to be disclosed) is willing to share with the authors the extrusion rejection data from Jan till Sept 2022. The data is shown in **Figure 2**.

The top 10 defects in extrusion in descending order are dented surface, bubble/blister, tearing, scratches, die broken, water mark, streaking line, shape out, backend defect and soda mark.

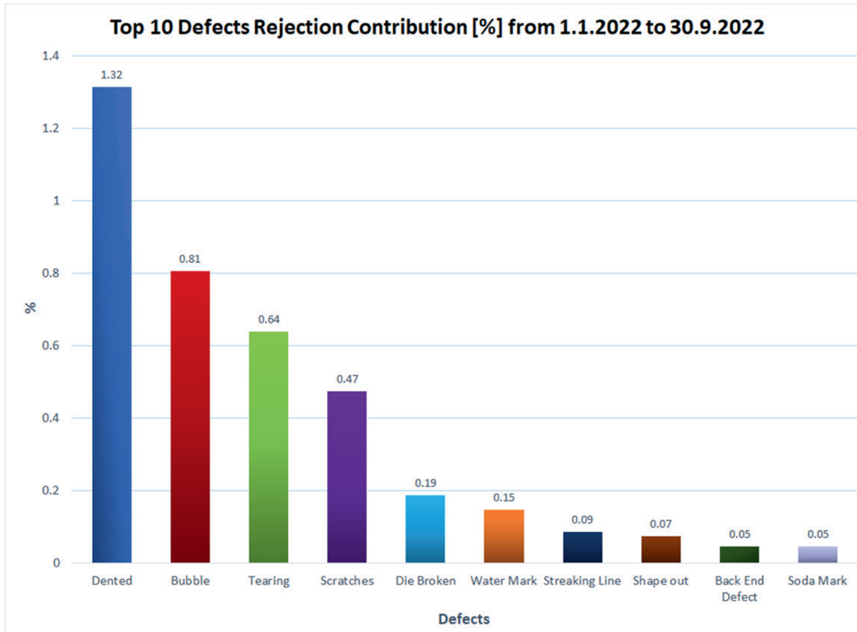


Figure 2.
Top 10 defects of extrusion for 9 months.

To ease understanding, each of the defects are briefly explained below and illustrated with pictures.

i. **Dented**. Depressions appeared generally on the runout face of the extruded profile, **Figure 3**.

ii. **Bubble/blister**. Raised areas on the profile surface most often aligned in the extrusion direction due to subsurface gas expansion, **Figure 4**.

iii. **Tearing**. Fine transverse cracks or tears associated with areas of high friction such as edges. They occur when exit temperature or speed is too high, **Figure 5**.

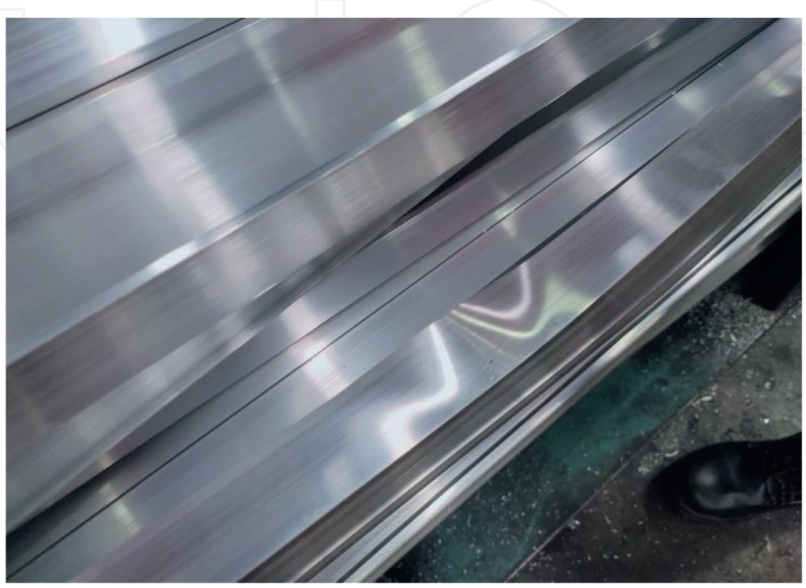


Figure 3.
Dented mark on extrudate.

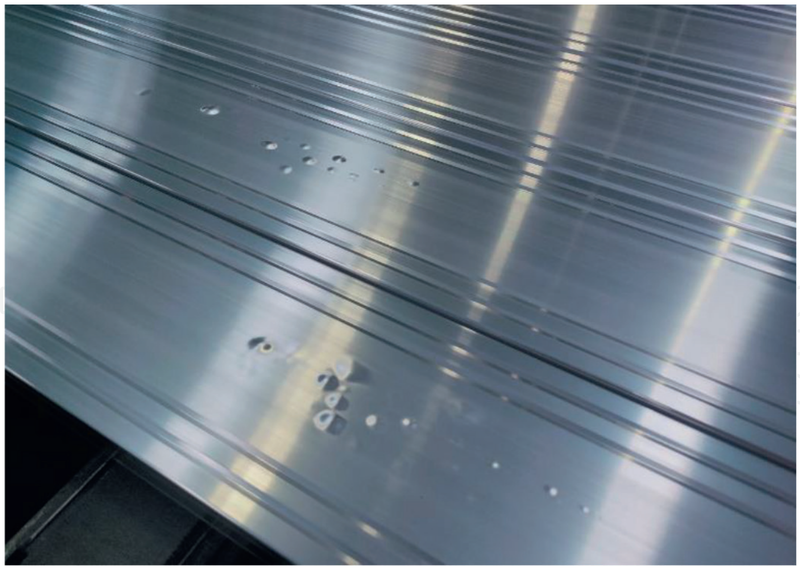


Figure 4.
Bubble or blister appearing on extrudate surface.

Figure 5.
Tearing.

iv. **Scratches**. Superficial marking on surface due to interfacial contact between aluminium and other materials, **Figure 6**. Scratches are undesired in milled finished (MF) products if good surface finishing is required. Scratches which is not deep (<0.3 mm) are acceptable for products that will be powder coated because it can be covered. Light and heavy scratches (above 0.1 mm) are rejected for products that need anodizing process because the anodic layer is too thin (25 micron max) to cover the scratches. Surface that is subjected to sand blasting and anodizing might not be able to eliminate the scratches too.

v. **Die broken**. When die is broken at the die plate bearing area, a non-perfect cross-sectional shape will be formed. The defect will be continuous along longitudinal direction of extrusion, **Figure 7**.

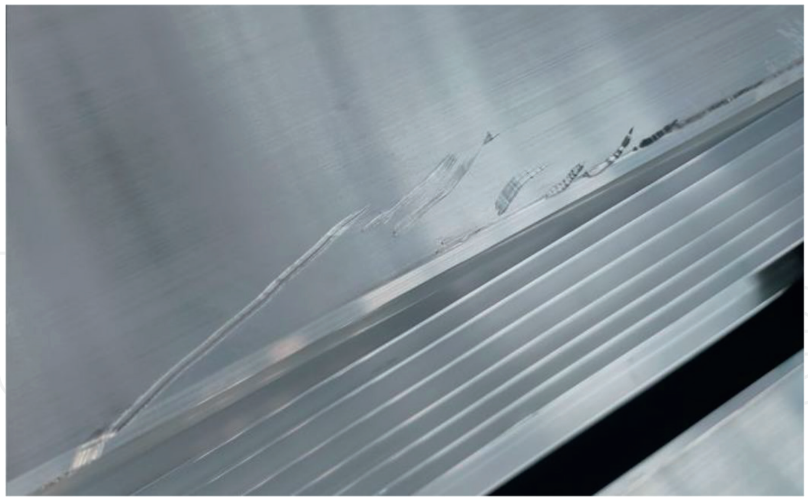


Figure 6.
Scratches.

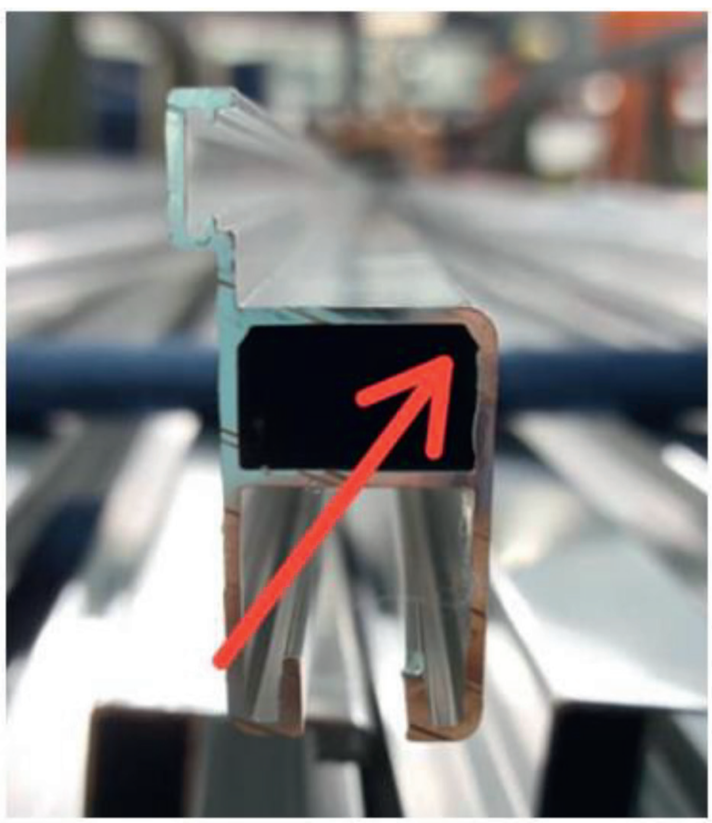


Figure 7.
Die broken.

vi. **Water mark**. Heavy oxidation of surface associated with entrapment of moisture. Could be due to direct contact with rain water, residual cooling water from extrusion machine's cooling box or condensation, **Figure 8**.

vii. **Streaking lines**. They are bands or lines appearing darker or lighter, brighter or duller, in colour and tone different from the remainder of the surface **Figure 9**.

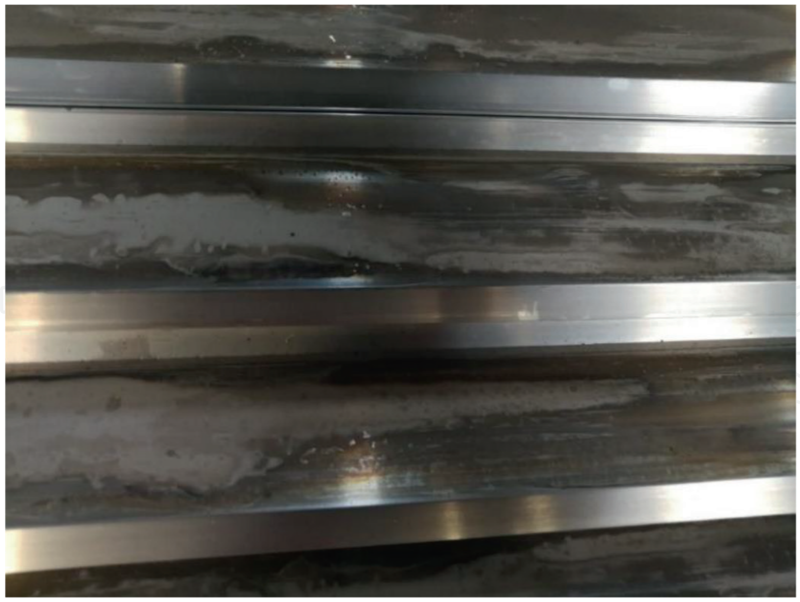


Figure 8.
Water mark.

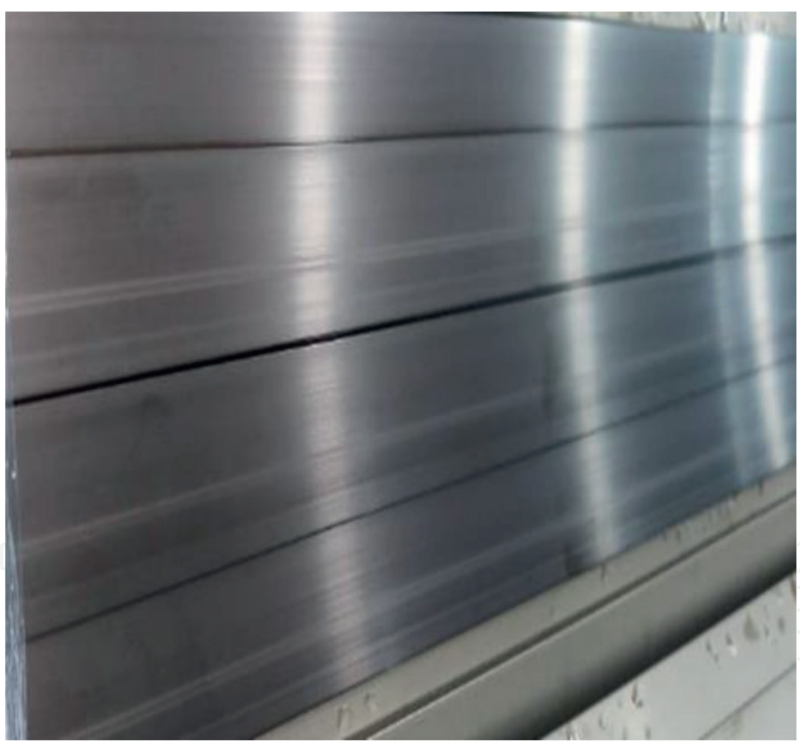


Figure 9.
Streaking lines.

The basic cause of this streaking is a difference in microstructure between the streaked portion of the extrudate surface and the remainder, which leads to a difference in response in etching and anodizing.

viii. **Shape out**. Basically, it is dimension out of spec, linear or angular dimension, **Figure 10**. This is more inclined to happen on hollow profiles than solid profiles. Deflection of mandrel due to high pressure is one of the major causes.

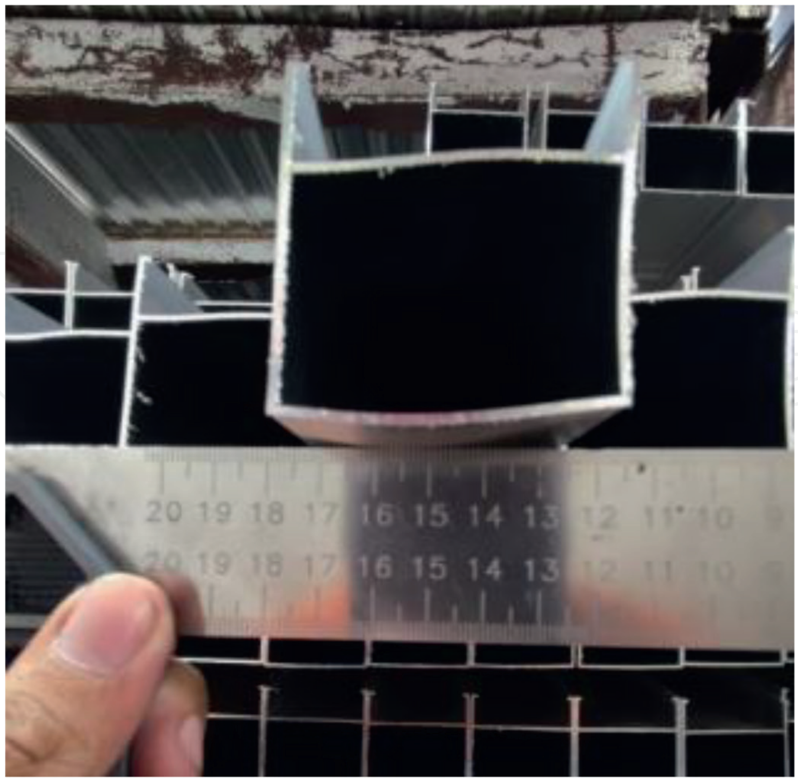


Figure 10.
Shape out.

ix. **Backend defect**. A coned shape defect formed at one third of the extrudate due to the centre material of billet flowing through the die while the billet outer skin remains stationary at the container wall. This forms an annular separation in the cross section where there is a separation of inner core and external zone. After anodizing, it forms dull line underneath the surface, **Figure 11**.

x. **Soda mark**. It is not corrosion or water mark but it will appear after anodizing. If material was delayed for rinsing after etching, the residual caustic soda on the surface can cause soda mark, **Figure 12**.

Figure 11.
Backend defect.

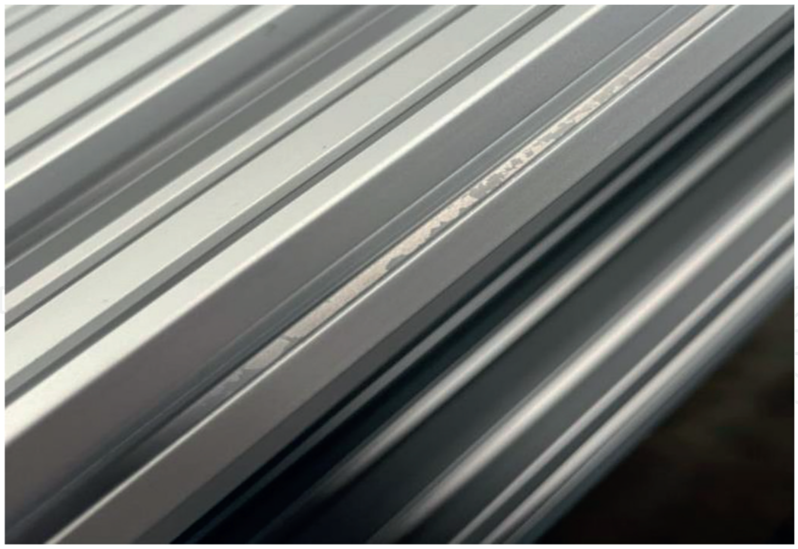


Figure 12.
Soda mark.

3. Customer's requirements for extrudates

As an extruder who is highly reputable for its quality products that can meet the requirements of global customers with competitiveness in quality, delivery and after-sales service, the company is used to gaining the customer's confidence and provide quality assurance by signing agreement with customer for the high volume of orders received. The agreement entrusts the company to manufacture and deliver the aluminium profiles all according to the terms and conditions contained in the agreement. The company must be ISO 9001 certified and undertakes to manufacture the products in strict compliance with all provisions of the agreement signed. Therefore, it is necessary for the manufacturer to understand the quality requirements of the customer thoroughly and execute effective quality management system to fulfil the requirements to ensure customer's satisfaction is achieved to secure long term business relationship.

The extruded products can be categorized into three main categories, namely mill finish profiles, powder coated profiles and anodized profiles. In this chapter, the focus is on mill finish profiles. The mill finish profiles to be used in painting and anodizing applications are required to comply with standards EN 12020-2, EN 755 and EN 573. The dimensional, mechanical and surface aspect requirements are usually specified in the product drawings and quality documents provided by customers.

Aluminium profiles are not only meant to work as structural support, but more importantly they are also for decorative purpose. Therefore, cosmetic criteria for surface of the profile are very important. The surface inspection can be categorized into three types:

- Primary/main—Visually critical surface directly viewed by observer and forms part of the product function, e.g. door frame.

- Secondary—Visible but not critical because observer does not view it directly, but it shall be of uniform surface quality, e.g. door edges.

- Non-visible—Non visible surface which is hidden from normal observation angle.

Typical surface defects characteristics are listed in **Table 1** with their inspection criteria.

Every extruded profile has a specific material specified in the drawing. The correct material must be used (e.g. 6063) and its chemical compositions must be verified by spark test (using arc/spark optical emission spectrometry (OES) analyser). The chemical compositions must comply with EN 755-2 or ASTM B221-14. The customer has the right to cut sample from the delivered lots and send to a third-party laboratory to verify its chemical compositions. Dispute will arise if the compositions vary from the results stated on the mill-cert of supplier. In that situation, the sample will be sent back to supplier for inhouse testing and another third-party testing.

No	Defect characteristic	Direct view quality	Indirect view quality
1	Spot defects (crater, spots, solid-, slag-, oxide-inclusion, pick-up, etc.)	Max 5 defects per meter/per side with a diameter of < 1.0 mm. Defects allowed only if not contrasting appearance. Distance of defects must not be located closer than 100 mm to each other in all sides/direction.	Max 7 defects per meter/per side with a diameter of < 1.0 mm. Defects allowed only if not contrasting appearance. Distance of defects must not be located closer than 100 mm to each other in all sides/direction.
2	Scratches (linear, mechanical damage of the surface)	Max 5 defects per meter/per side, wide, with a diameter of <0.15 mm, length < 15 mm. Defects allowed only if not contrasting appearance. Distance of defects must not be located closer than 100 mm to each other in all sides/direction.	Max 7 defects per meter/per side, wide, with a diameter of <0.15 mm, length <15 mm. Defects allowed only if not contrasting appearance. Distance of defects must not be located closer than 100 mm to each other in all sides/direction.
3	Stains and discoloration	Not allowed.	Not allowed.
4	Roughness, cracks	Not allowed.	Not allowed.
5	Extrusion line (groove/grooving)	Allowed only by regular optical appearance.	Allowed only by regular optical appearance.
6	Mechanical damage of all forms (dented, chipped off, etc.)	Not allowed.	Not allowed.
7	Semi finish related irregularities (bumps, lumps, streaking lines, etc.)	Not allowed.	Not allowed.
8	Water corrosion	Not allowed.	Not allowed.
9	Stop marks (band like pattern visible around the full perimeter)	Not allowed.	Not allowed.
10	Tearing/speed cracks (initial crack at edge of die bearing and propagates to extruded part)	Not allowed.	Not allowed.

Table 1.
Extrusion surface defects characteristic.

Mechanical property is an essential requirement of the extruded profiles. The specifications of mechanical property can be found in EN 755-2 or ASTM B221-14. Usually, the supplier has to possess a calibrated static tensile test machine of 100 kN capacity to do the test internally. On special request, the test can be done externally by a certified test service provider and certified test report is produced. The test results will be included in the mill-cert of the product. Usually the ultimate tensile strength, yield strength and elongation will be reported to qualify the product. The test specimen's dimensions must follow international standard such as that specified in ASTM B557M-15. The mechanical property is related to the temper of the alloy. 6xxx series aluminium alloy is heat-treatable. The correct process must be done to achieve the desired temper. When the products are supplied for marine applications, the mechanical property requirements will have to comply with either Bureau Veritas (BV) Rules on Materials and Welding for the Classification of Marine Units NR216 or American Bureau of Shipping (ABS) Rules for Materials and Welding (Part 2). The standards have specific test specimen's dimensions different from that of ASTM. The tests required to do include tensile test and drift expansion test (to test compression strength). The most common materials used for marine applications are 6061-T6 and 6082-T6.

Dimensional tolerances of the extruded profiles are critical to meet the customer requirements as first priority. Malaysia's extruders are used to following the JIS H 4100 standard for dimensional tolerances. The standard provides clear guidance on linear length, angle, straightness, flatness and twist. Advanced measuring machine like Romidot Vision H300 is used to measure the linear and angular dimensions of the profiles. The profiles have to be cut and deburred before measurement. Measurement of straightness, flatness and twist has to be done on a granite measuring table that has to be calibrated for levelling.

Quality can be defined by the degree of consumer satisfaction where the products are produced according to all technical specifications stipulated on drawings and customer-supplier quality agreement. Quality is also considered as faultless products where fewer defects is equivalent to lower costs. Hence, to satisfy customer needs and ensure product delivery according to their requirements, it is necessary to find solutions to overcome quality issues by gathering information about the entire production chain, analysing it, and making better decisions to implement continuous improvement by using PDCA methodology. It can help companies improve their operational efficiency and overall product quality [6].

4. Quality assurance activities in extrusion

The company is specialized in the development and production of aluminium profiles for applications in engineering, architectural and industrial works in general. The products are supplied to local market and also to global market in South East Asia, North America, Europe and Australia. The company's quality policy is aimed at absolute customer satisfaction with punctual delivery and meeting the product functional requirements. The company's pursuit of excellence is a constant pursuit to strengthen business relationship, committed to developing and continuously improving the product quality and satisfactory after sales service. Therefore, Quality Management System (QMS) is its central pillar and various quality assurance activities have to be planned and implemented systematically to achieve the quality objectives. The following sub-sections will elaborate activities that have been implemented in the production system to ensure the right product quality at the right cost.

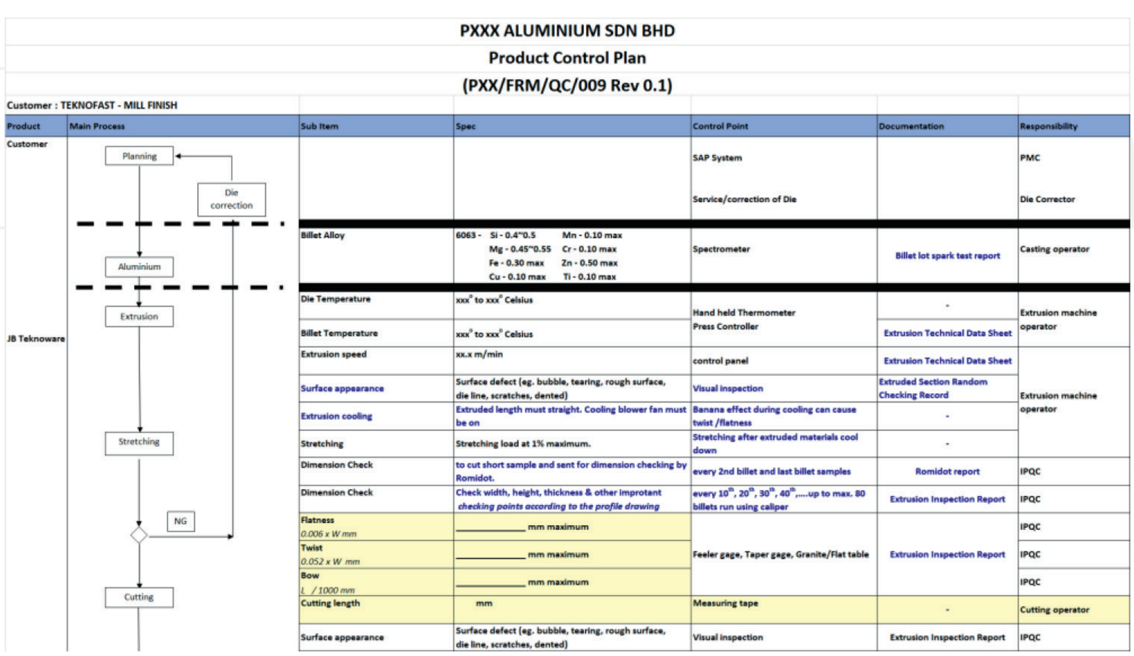
4.1 Control plan

A control plan describes the methods for controlling product and process variation in order to produce quality parts that meet customer requirements. Control plans are a critical part of the overall quality process. They are living documents that are updated as processes change and improve throughout the product lifecycle [7]. The product control plan consists of process flow in its second column; therefore, it is also considered as process control plan incorporated. The control plan is designed specifically for a customer who has stringent quality requirements and they will conduct supplier audit to confirm that their products have product/process control plan to ensure good quality. Technical specifications are specified in the control plan which include process parameters, QC inspection criteria and chemical compositions. Control points are the location where measurement is done and specific equipment is listed. Related document or record is also specified and responsible persons are stated. **Figure 13** shows an extracted example of control plan (specific data is obscured for confidential purpose).

4.2 FMEA

Failure Mode and Effects Analysis (FMEA) is a guide to the development of a complete set of actions that will reduce risk associated with the system, subsystem, and component or manufacturing or assembly process to an acceptable level [8]. The FMEA concerned here is Process FMEA (PFMEA) which is used to analyse the already developed or existing processes. PFMEA focuses on potential failure modes associated with both the process safety/effectiveness/efficiency, and the functions of a product caused by the process problems. PFMEA is a structured approach designed to achieve the following objectives:

- Predict failures and prevent their occurrence in manufacturing and other functional areas that generate defects.



PXXX ALUMINIUM SDN BHD

Product Control Plan

(PXX/FRM/QC/009 Rev 0.1)

Customer : TEKNOFAST - MILL FINISH

Product	Main Process	Sub Item	Spec	Control Point	Documentation	Responsibility
Customer	Planning; Die correction			SAP System		PMC
				Service/correction of Die		Die Corrector
	Aluminium	Billet Alloy	6063 - Si - 0.4~0.5 Mn - 0.10 max Mg - 0.45~0.55 Cr - 0.10 max Fe - 0.30 max Zn - 0.50 max Cu - 0.10 max Ti - 0.10 max	Spectrometer	Billet lot spark test report	Casting operator
JB Teknoware	Extrusion	Die Temperature	xxx° to xxx° Celsius	Hand held Thermometer Press Controller	-	Extrusion machine operator
		Billet Temperature	xxx° to xxx° Celsius		Extrusion Technical Data Sheet	
		Extrusion speed	xx.x m/min	control panel	Extrusion Technical Data Sheet	Extrusion machine operator
		Surface appearance	Surface defect (eg. bubble, tearing, rough surface, die line, scratches, dented)	Visual inspection	Extruded Section Random Checking Record	
		Extrusion cooling	Extruded length must straight. Cooling blower fan must be on	Banana effect during cooling can cause twist /flatness	-	
	Stretching	Stretching	Stretching load at 1% maximum.	Stretching after extruded materials cool down	-	
		Dimension Check	to cut short sample and sent for dimension checking by Romidot.	every 2nd billet and last billet samples	Romidot report	IPQC
	NG	Dimension Check	Check width, height, thickness & other improtant *checking points according to the profile drawing*	every 10th, 20th, 30th, 40th,....up to max. 80 billets run using caliper	Extrusion Inspection Report	IPQC
		Flatness *0.006 x W mm*	________ mm maximum	Feeler gage, Taper gage, Granite/Flat table	Extrusion Inspection Report	IPQC
		Twist *0.052 x W mm*	________ mm maximum			IPQC
		Bow *L / 1000 mm*	________ mm maximum			IPQC
	Cutting	Cutting length	mm	Measuring tape	-	Cutting operator
		Surface appearance	Surface defect (eg. bubble, tearing, rough surface, die line, scratches, dented)	Visual inspection	Extrusion Inspection Report	IPQC

Figure 13.
Product control plan.

- Identify the ways in which a process can fail to meet critical customer requirements.
- Estimate the Severity, Occurrence and Detection (SOD) of defects.
- Evaluate the current Process/Product Control Plan for preventing these failures from occurring and escaping to the customer.
- Prioritize the actions that should be taken to improve and control the process using a Risk Priority Number (RPN).
- Minimize loss of product performance or performance degradation.
- Develop Preventive Maintenance plans for in-service machinery and equipment.

A partially extracted example of PFMEA for extrusion process is shown in **Figure 14**.

Failure Mode and Effect Analysis (FMEA)

Title	Extrusion Process at 7B	Department	Extrusion	Approval	
Authors	Mhd Noor	Revision Date	1/9/2020		
		Revision No.	0		

Process	Failure Mode	Failure Effect	Severity (S)	Criticality (S×O)	Root Cause	Occurrence (O)	Current Control	Detection (D)	RPN (S×O×D)	Actions Recommended	Responsible Person	Evaluation After Actions: Severity (S)	Occurrence (O)	Criticality (S×O)	Detection (D)	RPN (S×O×D)
What is the process step or feature under investigation?	In what ways could the step or feature go wrong?	What is the impact on the customer (internal/external) if this failure happened?			What causes the step or feature to go wrong? (how could it occur?)		What controls exist that either prevent or detect the failure?			What are the recommended actions for reducing the occurrence of the cause or improving detection?	Who is responsible for making sure the actions are completed?					
Die Preparation	Using wrong or unqualified die	Dimensional rejection at Fabrication	7	16	Die number and copy number on dies difficult to see.	2	Visual check by Tooling worker	2	32							
		Failure to assembly at customer site	8													
	Die in oven less than 4 hours.	Die MC during extrusion	6	30	No other dies available for extrusion or too late put dies into oven.	5	Record time of die put into the oven and extrusion time	4	120	Install screen monitor to shows the time in and duration in oven. Alert by colour any less and over duration.	Extrusion HOD & Maintenance (June 2020)	6	2	12	4	48
	Oven temperature setting lower than 460°C.	Die MC during extrusion	6	6	Oven temperature setting lower than 460°C.	1	Limit the change of oven setting is done by line leader only	2	12							
	Die in oven more than 1 day.	Die bearing easily wear and tear	6	36	Too early put dies into the oven.	6	Record time of die put into the oven and extrusion time	4	144	Install screen monitor to shows the time in and duration in oven. Alert by colour any less and over duration.	Extrusion HOD & Maintenance (June 2020)	6	2	12	4	48
Billet Loading	Billet lot no used not tally with extrusion record	Profile have surface defect	6	42	Mix of batch lot no of billet on loading table.	7	Visual check billet lot number, arrange billet log with lot batch no in sequence and record in Jobsheet and production record.	2	84							
	Wrong billet alloy used	Profile have surface defect	6	24	Mix of unfinish-used of another billet alloy on loading table.	3	Visual check billet lot number and record in Jobsheet and production record.	4	96							
		Die bearing damaged	7													
		Uneven anodising colour	6													
		Profile too hard for customer to assembly	8													
Extrusion	Billet temperature lower than 440°C	Hardness lower than 11wbs after ageing	8	36	Oven temperature setting lower than 440°C.	4	Using thermometer to check first billet temperature.	5	180	Increase temperature checking frequency for 2nd billet and every 10th billet.	Extrusion HOD	9	2	18	3	54
		Mechanical properties failed after ageing	9													
	Exit temperature lower than 505°C	Hardness lower than 11wbs after ageing	8	36	Billet temperature lower than 440°C.	4	Using thermometer to check first extruded exit temperature	6	216	Increase temperature checking frequency for 2nd billet and every 10th billet.	Extrusion HOD	9	2	18	3	54
		Mechanical properties failed after ageing	9													
	Billet length wrong setting	Too many unnecessary scrap (low recovery)	6	18	Wrong calculation	3	Visual inspection at cutting table	3	54							
	Bubbles	Too many unnecessary scrap at billet joint (low recovery)	8	40	burping cycle setting	5	Visual inspection at press tunnel	3	120	Annual checking burping cycle setting and strictly checking and segregate after cutting.	Extrusion HOD & Maintenance	8	4	32	3	96
	Dimension not within spec	Failure to assembly at customer site	8	48	Using wrong or unqualified die	6	Dimensions check by calliper at press	2	96	IPQC to check dimension for 2nd billet and every 10th billet. Feedback to Dowell if found dimension out.	IPQC	8	5	40	2	80
		Dimensional rejection at Fabrication/Outgoing	8													
	Pick-up on surface	Cosmetic rejection at Fabrication	7	21	Using local billet	3	Visual inspection at press tunnel	3	63							

Figure 14.
Extrusion FMEA.

4.3 Preventive maintenance

The extrusion process is a heavily mechanical process involving the extrusion press machine and other accessories that construct the whole extrusion line. Poor preventive maintenance will cause extensive unscheduled downtime and reduce productivity. Bad condition of machine and accessories will also cause quality problem. The extrusion run-out table is mainly consisting of roller and belt conveyor. The fibre material of the roller and belt are subject to wear and tear after some time. The aluminium profiles are inevitably touching with the roller and belt during material handling process. Poor surface of the fibre material will cause scratches on the aluminium profiles. Therefore, the roller and conveyor belt must be changed whenever the surface has deteriorated. The extrusion press consists of many hydraulic cylinders as its major mechanical force. Oil leakage is a major issue and weekly inspection must be done on the main cylinder, side cylinders, container cylinders and shear cylinder. The line filters for servo control and oil cooler must be changed periodically before they are clogged. The shear blade of extrusion press that cut the butt end and the shear blade of billet preheat oven must be replaced when the blades are blunt. The water volume and pressure of the cooling chamber (usually mist spray at high pressure) must be inspected to be working in good condition because effective cooling is important to T6 tempered products. Rough saw cutting station must be maintained to be free of chips sticking to the conveyor belt and roller to prevent scratches. Operators are asked to always blow the chip off and do thorough cleaning every end of shift. **Figure 15** below shows the good vs. bad conditions in a typical extrusion press.

4.4 Material handling

Aluminium surface is fragile and susceptible to scratched and dented damages when handled improperly. The extruded profile is long ranging from 20 to 40 m.

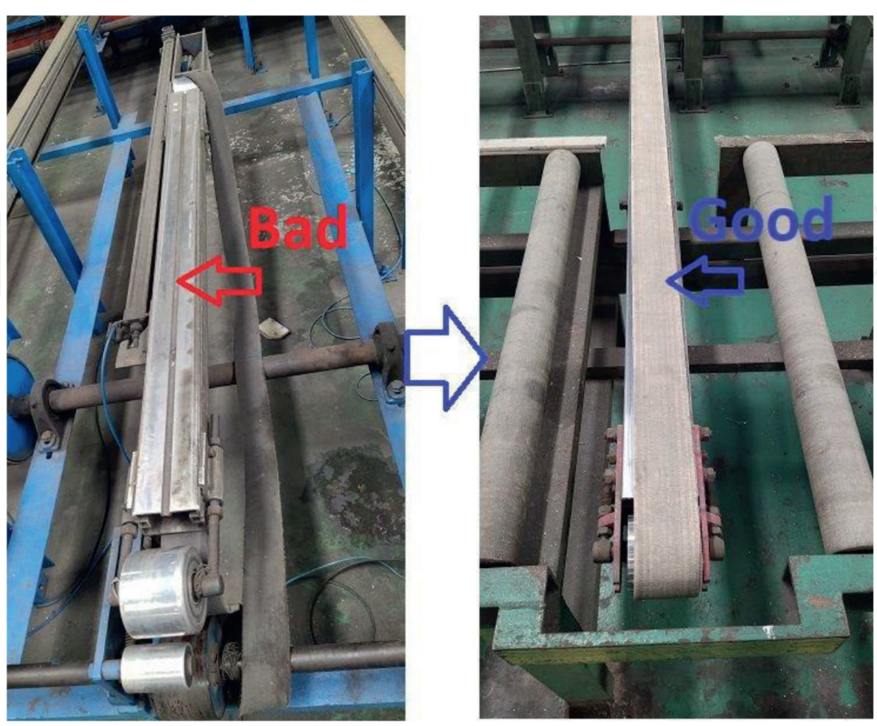


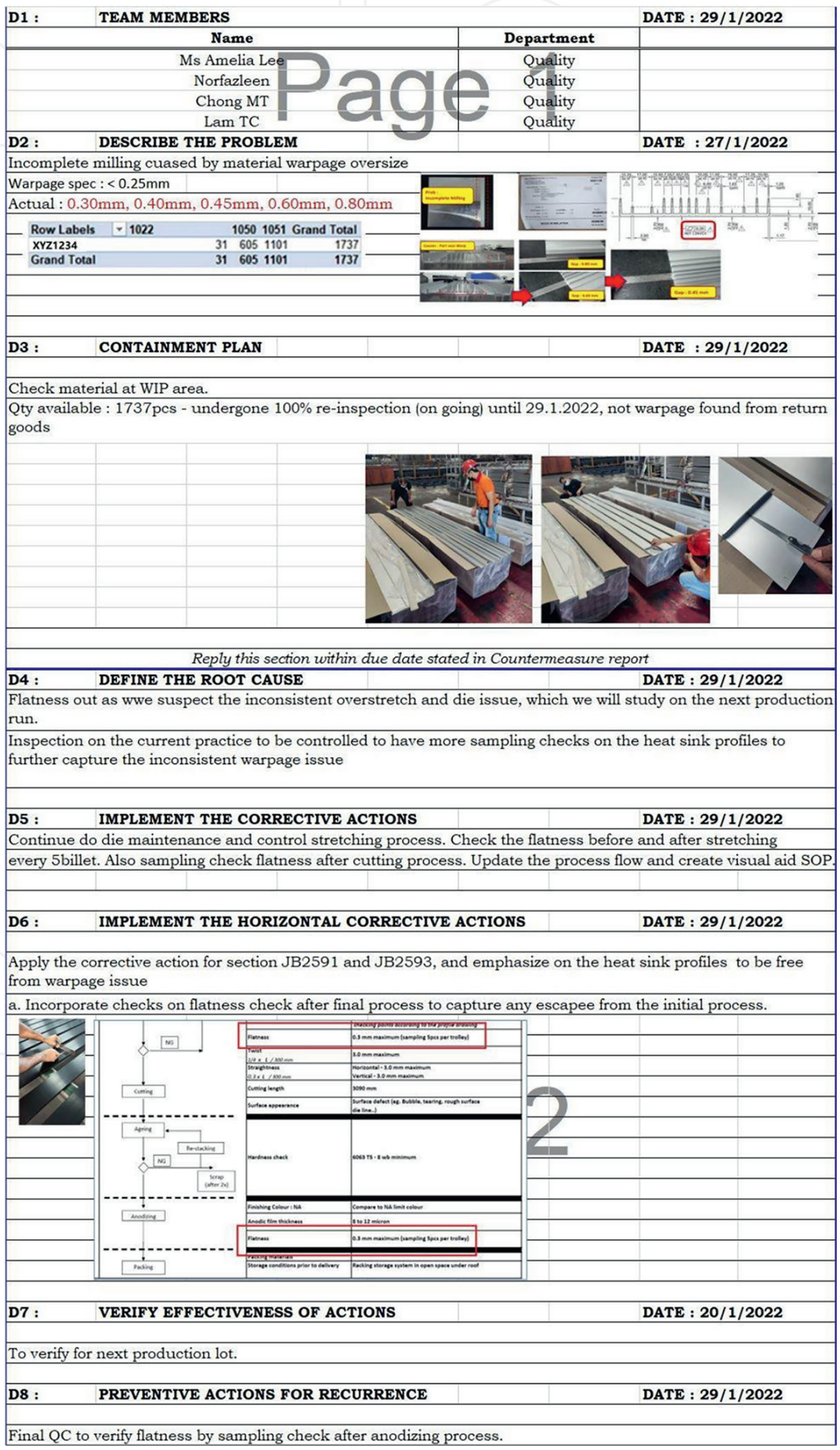
Figure 15.
Good vs. bad conveyor.

Figure 16.
Good vs. bad materials stacking on conveyor table.

Due to asymmetric contraction after cooling the profile tends to be in banana shape on the cooling table. Such a long profile needs two operators to handle at both ends. However, sometimes the operator handles it alone at one end, he will flip the profile and drag it on the belt conveyor surface, and this inclines to cause scratches and dented marks on the profile. When the operators are doing stretching, they have to carry the profile to the stretcher clamping platform, they are not able to lift up the profile from the table but to drag it for positioning and damages will be incurred if the handling is rough. Therefore, the supervisor and line leader are instructed to train their operators to do proper material handling on the conveyor table. The profiles must also align with proper distance in between them on the conveyor table to prevent knocking each other. **Figure 16** shows an example of the improper material handling and arrangement on the conveyor table that prone to cause damages.

4.5 8D report

Defects detected in the shipment lots to customer will trigger "general customer complain report" (GCCR) if a single profile records a defect of 2% out of the total delivered quantity. QA department is responsible to answer the GCCR in 7 days after confirmation of the defects by sales department. The QA engineer has to investigate the complaint by requesting physical sample from customer (for testing purpose) or high-definition pictures. Based on the basic information of sale order no and delivery no, the QA engineer will extract data from SAP system to obtain the information of delivery date, manufacturing date (extrusion, anodizing, powder coating, fabrication or packing), alloy type, surface finishing specification, aging report and QC inspection report. The QA engineer will then do root cause analysis and fill in the 8D report in the GCCR reply form. The 8D report consists of 8 sections of team members, problem description, containment action, define the root cause, implement the corrective actions, implement the horizontal corrective actions, and verify effectiveness of actions and preventive actions for recurrence. Sometimes, the company will send QC inspectors to customer's premise to do sorting or rework. If the reject quantity is huge, materials might be sent back for rework or scrap. The practice of 8D report will be recorded to the drawing file of the profile to alert the production and QC inspector of the complaint so as to take precaution in manufacturing and inspection process in



D1 :	TEAM MEMBERS	DATE : 29/1/2022
	Name	**Department**
	Ms Amelia Lee	Quality
	Norfazleen	Quality
	Chong MT	Quality
	Lam TC	Quality

D2 : DESCRIBE THE PROBLEM — DATE : 27/1/2022

Incomplete milling cuased by material warpage oversize

Warpage spec : < 0.25mm

Actual : 0.30mm, 0.40mm, 0.45mm, 0.60mm, 0.80mm

Row Labels	1022	1050	1051	Grand Total
XYZ1234		31	605	1101	1737
Grand Total		31	605	1101	1737

D3 : CONTAINMENT PLAN — DATE : 29/1/2022

Check material at WIP area.

Qty available : 1737pcs - undergone 100% re-inspection (on going) until 29.1.2022, not warpage found from return goods

Reply this section within due date stated in Countermeasure report

D4 : DEFINE THE ROOT CAUSE — DATE : 29/1/2022

Flatness out as wwe suspect the inconsistent overstretch and die issue, which we will study on the next production run.

Inspection on the current practice to be controlled to have more sampling checks on the heat sink profiles to further capture the inconsistent warpage issue

D5 : IMPLEMENT THE CORRECTIVE ACTIONS — DATE : 29/1/2022

Continue do die maintenance and control stretching process. Check the flatness before and after stretching every 5billet. Also sampling check flatness after cutting process. Update the process flow and create visual aid SOP.

D6 : IMPLEMENT THE HORIZONTAL CORRECTIVE ACTIONS — DATE : 29/1/2022

Apply the corrective action for section JB2591 and JB2593, and emphasize on the heat sink profiles to be free from warpage issue

a. Incorporate checks on flatness check after final process to capture any escapee from the initial process.

D7 : VERIFY EFFECTIVENESS OF ACTIONS — DATE : 20/1/2022

To verify for next production lot.

D8 : PREVENTIVE ACTIONS FOR RECURRENCE — DATE : 29/1/2022

Final QC to verify flatness by sampling check after anodizing process.

Figure 17.
8D report.

subsequent orders to prevent the recurrence of defects. The drawing file is uploaded in the server and the production and QC staff will always access to the latest copy of drawing to check historical customer complaint record when that particular profile is being extruded. An example of 8D report is shown in **Figure 17**.

4.6 Quality campaign

The company has launched a quality campaign with the objective to cultivate quality awareness among the employees to achieve the company's goals of quality products, excellence of services and on-time delivery as the cornerstone of promoting quality culture. Quality campaign involves top and medium management to disseminate some ideas to the workers to help them enhance their quality awareness. One of them is to "look-think-act". When a worker sees something abnormal, he has to think why it happens so? And to take action to do something right. The worker should not be ignorant of what is happening around him. He has to be always concerned about the machine is running properly, process parameters are correct, quality of products are good with minimum rejection, workplace is in proper 5S condition etc. Workers are taught to understand that quality is everyone's responsibility. Quality does not happen by chance; it is the outcome of coordinated efforts from all people involved in the process. Do not finger pointing but to work together for solutions whenever there is problem. After launching the campaign, the campaign committee conducted 5S audits at extrusion, anodizing, powder coating and fabrication departments. Research has shown that 5S is able to improve productivity and quality. Top winner of 5S of the

Figure 18.
Quality with integrity.

workstation's workers will be given certificate of appreciation, souvenir and free meal coupon. Banner and poster of quality campaign are printed and displayed at many places in office and production areas. The slogan of the quality campaign is "Quality with Integrity", **Figure 18**.

4.7 Training

Aluminium extrusion is a process that requires comprehensive knowledge to understand the critical success factors that contribute to quality and productivity. The workers are not solely required to do labour intensive job but also to understand many technical aspects of the process and product. They have to understand the importance of process parameters like billet preheat temperature, die preheat temperature, die exit temperature, container temperature, ram speed, extrusion cooling rate and stretching rate. The billet quality and its impact on product's metallurgy and mechanical properties have to be understood also. The QC inspectors must be able to identify all extrusion defects and have some basic knowledge of the possible causes of defects. The QC inspectors play an important role to verify defects and instruct production to stop and change die whenever necessary to prevent over-production of defective products. The QA department has taken initiative to write a QC Handbook for all QC inspectors to understand and practice. The handbook also serves as a training material to new staff. The company also conducted internal and external training for engineers on the topics of leadership, root cause analysis and problem solving, ISO9001 QMS Awareness, Report Writing Skills, etc.

4.8 Extrusion process parameters control

Hot extrusion is a thermal deformation process done on the solid phase of billet. The management of temperature is significant to the extrusion quality and also productivity. Different alloys of billet must be preheated according to their individual upper limit temperatures. An empirical guideline is given in **Figure 19**, quoted from ASTM B807M-06. The extrusion speed is dependent on the billet temperature. The billet temperature is controlled by setting the temperatures of heating zones in the billet preheat oven. There is a region where we aim to achieve so we can maximize the extrusion efficiency as indicated in **Figure 20**. The die exit temperature is also very important because overheating will cause tearing defect on the surface due to localized melting spot when the material passed through the bearing surface; while lower exit temperature will cause insufficient cooling slope and hence inferior

Alloy	Billet or Log Temperature	
	Upper °F	[Upper °C]
6005, 6005A, 6105	1050	565
6061, 6262	1050	565
6060, 6063, 6101, 6463, 6560	1060	570
6351, 6082,	1050	565
6066, 6070	1020	550
7004, 7005	1000	540
7029, 7046, 7116, 7129, 7146	1000	540

Figure 19.
Extrusion billet temperature high limits.

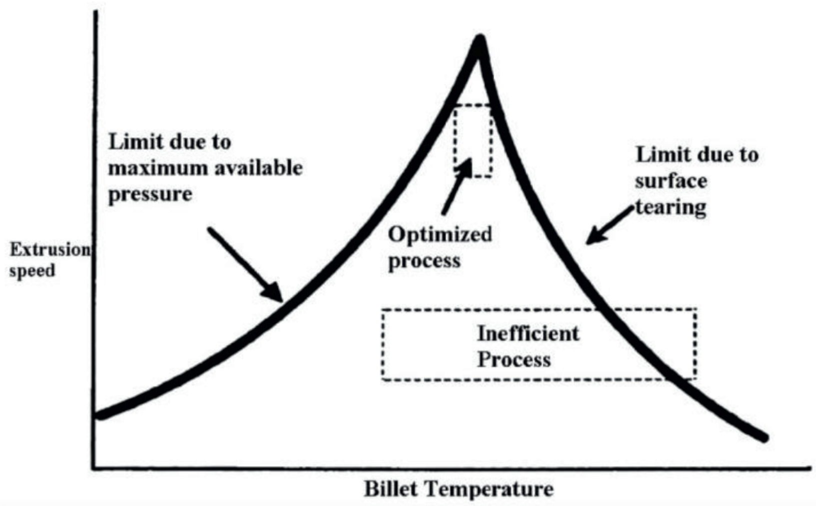


Figure 20.
Extrusion speed and billet temperature windows. Courtesy R. Peris.

Alloy	Min Die Exit °F [°C]	Min Temp Entering Quench °F [°C]	Min Cooling Rate, °F/min [°C/min]
6005, 6105	950 [510]	825 [440]	300 [165]
6005A	950 [510]	825 [440]	360 [200]
6061, 6262	930 [500]	850 [455]	600 [335]
6351, 6082	950 [510]	900 [480]	600 [335]
6060, 6063, 6101, 6463, 6560	930 [500]	825 [440]	150 [85]
6066, 6070	970 [520]	910 [490]	900 [500]
7004, 7005	750 –1000 max/ [400-540] max	725 [385]	120 [65][C]
7029, 7046, 7116, 7129, 7146	900-1000 max/ [480-540 max]	750 [400]	600 [335]

Figure 21.
Extrusion die exit temperature and cooling rate.

mechanical property. If it is T6 tempered material, minimum cooling rate has to be achieved to obtain the desired tensile and yield strength after artificial aging. The ASTM B807M-06 provides guideline on exit temperatures and cooling rates for different alloys as shown in **Figure 21**. The die exit temperature can be monitored by installing Infrared Radiation (IR) pyrometer at the machine as shown in **Figure 22**. Die exit temperature is correlated with billet preheat temperature and extrusion ram speed. These two parameters will be controlled by the operators to achieve the desired die exit temperature which is monitored in real-time by the IR pyrometer.

4.9 7S Lean workplace

The company is promoting the awareness of 7S lean workplace. 7S is defined as sort (seiri), set in order (seiton), shine (seiso), standardize (seiketsu), sustain (shitsuke), safety and spirit. It is a combination of Japanese 5S with two new elements of safety and spirit. The objectives of 7S are:

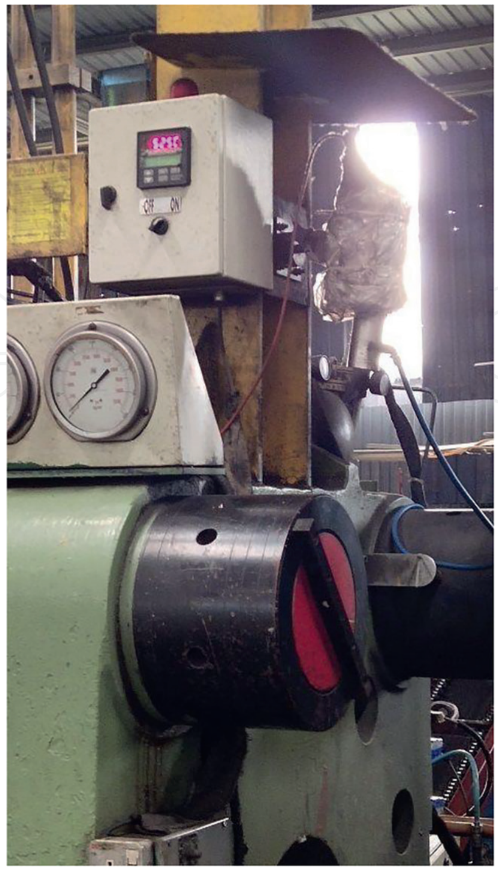


Figure 22.
Extrusion billet infrared temperature recorder.

- Eliminate wastes
- Reduce space used for storage
- Streamline production
- Optimize efficiencies
- Improve safety
- Improve maintenance
- Improve quality and productivity
- Improve morale of employees

It is believed that a company that cares for its employee's safety will truly care for the product quality of its customers. An unsafe workplace will incur threat of life and stress of mind on the workers and cause disruption on their performance. Quality and productivity both suffer when employees are under stress, unsatisfied, or unable to complete their mission due to injury. But when the workplace is safe, it frees up employees to focus on their quality and their productivity. The 5S Method is a standardized process that when properly implemented creates and maintains an organized, safe, clean and efficient workplace. Improved visual controls are implemented as part of 5S to make any process non-conformance obvious and easily detectable [9]. Spirit refers to cultivating the interest and passion in 7S through audit, competition and reward; also to strengthen the spirit of team work among workers from top to down. The audit on safety and 5S will be conducted continuously for one week in the department and score will be given to the outcome of audit. The top scorer will be announced and presented with honorarium and certificate of appreciation.

5. Conclusions

The product quality of 6xxx series aluminium extrusion is dependent on multiple factors in the whole process stream. There are technical and management aspects that play the equivalent importance in ensuring quality and customer satisfaction. The production and QC teams must first be able to identify the extrusion defects correctly and do segregation of defects to prevent them from flowing to downstream process and wasting resources to process defective materials. PFMEA is important to guide production and maintenance team to take appropriate actions to prevent suboptimal process that will contribute to generating defects. There is sufficient knowledge base to determine the correct process parameters especially the temperature settings and control. The process must be stabilized within the controlled windows and operators must be trained to respond to anomaly in process by taking immediate actions to stop process and investigating the root cause to prevent continuous generation of defects. Historical data shows that the top five defects always dominated by scratches and dented damage which are due to improper material handling on conveyor table and trolley stacking. Intensive education and training have been provided to workers to improve their material handling. Quality can be viewed as a culture to cultivate in the workers. The company has taken initiative to launch quality campaign and 7S lean workplace campaign to promote the awareness of quality and importance of safety and housekeeping on product quality, productivity and morale. It is very important to cultivate the attitudes of continuous improvement and lifelong learning because we should not feel complacent with our current achievement and forget to make changes to cope with emerging challenges coming in our way. The extrusion industry has to grow and prosper in a sustainable manner with the commencement from optimizing its internal manufacturing process to improve quality, efficiency and reducing waste.

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