APPLYING LEAN TO WELDING OPERATIONS: A CASE STUDY

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ABSTRACT

A case study is presented to show how the principles of Lean can be applied to the welding operations in a plant producing front-end loaders. A systematic approach to measure welding process parameters and welder skills was used to diagnose areas of applying Kaizen or the process of continuous improvement. Welder training and optimisation of welding parameters resulted in a significant improvement in quality and reduction of waste. Design changes facilitating weldability and eliminating grinding in many areas. Weld Process monitoring was used to measure deviation from optimised parameters and corrective action was implemented through welder coaching on the job. Welding duty cycles were measured to justify robotics in specific areas. An annual savings of $ 400,000 was achieved, in a shop employing 35 welders.

KEY WORDS

Kaizen, Lean, waste, optimization, ISO 3834

INTRODUCTION

Lean manufacturing is focused on eliminating waste in the entire manufacturing process. It deals with minimizing work-in-process, eliminating processes that do not add value to the product, making the process flexible to make products of different design without compromising quality or cost. Many manufacturing companies, historically, have been able to maintain bloated or inefficient methods because of a protected market, strong brand strength or huge profit margins. The global competition is forcing these manufactures to quickly change their methods to be less wasteful, and provide value to their customers through customization and reduced cycle or delivery times.

In the early eighties, the Lean paradigm was invented at Massachusetts Institute of Technology (MIT) and the Toyota Motor company was the first company to successfully apply it to automotive manufacturing. Lean philosophy is universal and can be applied to manufacturing, design, quality control, administration, order taking, accounts receivable or any activity that needs to be improved. The process starts with a macro mapping of the activity called value stream mapping and involves people at all levels to identify areas of inefficiency. Once the problem is identified, groups of people work together for short periods of time, in a well documented activity called Kaizen to solve the problem. Building on small successes slowly embarks the entire enterprise, on a never ending process of continual improvement. Lean and Kaizen are philosophies of work, requiring commitment of the owner or CEO of the enterprise. Results are obtained through employee empowerment and are achieved over time.

This paper describes how Lean principles were applied to the welding activity of a Front End loader manufacturing facility. The five key lean principles were applied to the welding process as outlined below: The Plant Manager was the most visible promoter of the process, and the success was largely related to the appropriation of the continual improvement by the employees at all levels, specific to the welding activity.

KEY LEAN PRINCIPLES

1. **Perfect first-time quality** through quest for zero defects, revealing and solving problems at their ultimate source, achieving higher quality and productivity simultaneously, teamwork, and worker empowerment.
2. **Waste minimization by removing all non-value added activities** making the most efficient use of scarce resources (capital, people, space), just-in-time inventory, eliminating any safety nets.
3. **Continuous improvement** (reducing costs, improving quality, increasing productivity) **through dynamic process of change**, simultaneous and integrated product/process development, rapid cycle time and time-to-market, openness and information sharing.
4. **Flexibility in production** of different mixes or greater diversity of products quickly, without sacrificing efficiency at lower volumes of production, through rapid set-up and manufacturing at small lot sizes.
5. **Long-term relationships with suppliers** and primary producers (assemblers, system integrators) through collaborative risk-sharing, cost-sharing and information-sharing arrangements.

PERFECT FIRST TIME QUALITY

Welding is a four dimensional process, and in-process parameters often determine the final quality of the weld. Besides the three dimensions, the fourth dimension of time influences the final quality as it influences time related parameters like, welding speed, heat input, preheat and post heat time schedules, ultimately affecting the weld microstructures as well as distortion control of the finished parts.

The simplest and most frequently used is the fillet weld. Visually inspecting a fillet weld in two dimensions, does not guarantee adequate weld penetration in the third dimension! Since fillet welds are usually taken for granted, they are mostly ignored by the engineers and shop supervision and assume that the welders have sufficient skills to deposit quality welds to required sizes. However, failure analysis of many failed components often points to faulty fillet welds. For example, in a cyclic load application, fatigue failures usually originate from fillet weld toes. Large oil rigs and barges have capsized, due to failure at small insignificant fillet welds! With this background information, and some fatigue failure history with the front-end loaders, it was decided that applying lean would start at making perfect fillet welds every time to print specification.

Welders were using 0.035” diameter and 0.045” diameter wires for making ¼" fillets in the horizontal position in production. 20 welders were asked to make ¼” fillet welds on test coupons; alongside their production jobs and all in-process parameters were recorded. These appear in tables 1 & 2. The welds were sectioned and quality inspected. The criteria were to accept welds made to print specifications of ¼” fillet size with 20% over welding as an acceptable criterion. 13 welders out of 20 were able to make ¼” fillets. 35% of the welders failed to make good quality welds the first time. See Table 1. This presented a great opportunity to perform a Kaizen event for improving fillet weld quality.

WASTE MINIMIZATION BY REMOVING ALL NON-VALUE ADDED ACTIVITIES

Fillet welds

As a general comment, the data sheets were difficult to read and did not clearly state the size of welds to be applied to specific shop drawings. A good rule of thumb while welding thick to thin materials is to equal the fillet size to the size of the thinnest member being welded. In case of lap fillet welds, the size of the weld should be equal to the plate thickness up to a ¼ of an inch. The pre-qualified joints further indicate that the minimum size for dynamically loaded structures is 3/16 " for plate thicknesses, less than ¼ ". The minimum fillet size required for thicknesses between ¼ " and ½ " base metal thickness is recommended to be 3/16" per American Welding Society standard D1.1. Considering the base metal thicknesses being fillet welded at XYZ Ltd., it was confirmed that a 3/16" fillet would be more than sufficient to cover 90% of the work.

A total of 77 welds were analyzed to design requirements of 3/16" size. Weld leg sizes varied from 3/16" to 3/8" dimension. The over-welding for the measured welds fluctuated from 33% to 206% with the average at around 107%!

The excess weld-metal and effort in depositing the extra 107% non value added wasted manpower was a significant Lean finding. Additionally, the potential for stress risers due to over welding could ultimately produce further problems down the road.
An external design engineering team looked at all the drawings used to manufacture the final product. The shop drawings did not show any welding symbols. It was very soon discovered that 90 percent of the plates used in the construction of the front-end loaders were less than ¼" thick, and 90% of shop welds were ¼" fillets! The design team determined that the fillet welds should be resized to 3/16" fillets.

Weld design changes

The design of the front lift arm assembly was carefully changed to remove expensive flare groove welds to simple lap fillets between the wrapper plate and the structural steel channel. Fit up was improved on the bushing welds and line boring was implemented to save assembly time.

Welding wire waste measurement

The manufacturing facility was using both 0.045" and 0.035" diameter solid wires E 70S-6 for most of the work. As the weld size was optimized to 3/16" size fillets, it became necessary to optimize wire usage to 0.035" diameter consumable and reduce the occurrence of undercuts. All the feeders were converted to feed 0.035" diameter wire. Both these changes resulted in a large improvement in logistics for consumable usage and preventive maintenance. The welder training and welding process monitoring were further simplified.

Welding gas usage and optimization

Initial evaluation of welding macro sections revealed uneven penetration patterns. A 10% CO_2 with balance Argon mixture was delivered through a gas mixer. The uneven penetration profile of the welds indicated significant variation in the gas mixture. The mixer buffer tank had to be resized for a bigger capacity to stabilize the gas mixture.

The measured gas flow rates in some parts of the shop were as low as 17 cubic feet per hour, which resulted in internal fillet weld porosity. Gas flow rates were standardized to 45 cubic feet per hour through throughout the plant.

Leaks in the gas manifold system were verified. The ratio of amount of gas used to deposit one pound of filler metal was pegged at approximately 4.5 cfh/lb, to control the gas waste.

Lean Resources needed for Kaizen applied to Welding

In order to carry out a satisfactory welding related waste measurement, it was necessary to use various measuring devices and instruments. Without going into too much detail, a simple list of items is provided to understand what is needed to make a non subjective welding assessment.

- Calibrated length measuring instruments
- Stop watch
- Wire feed speed measurement device
- Calibrated ampere and volt meter
- Shielding gas flow measurement devices
- Gas saver devices such as the GSS WA Technologies
- Duty cycle measurement device capable of data acquisition, storage and wireless transmission over 24 hour measurement periods, for continuous improvement
- Fillet gauges, manual or electronic systems
- Ability to test fillet welds quickly with destructive tests
- Ability to produce weld macrographs for quality feedback to the welders
- Digital photography equipment
- Annualized gas and wire consumption data and pricing
- Cost calculation software to validate improvements of kaizen activities
- Experienced Welding Engineer/Technician team with excellent, analytical, training and people skills!
- Motivated CEO or Plant manager interested in pursuing opportunities for cost savings

CONTINUOUS IMPROVEMENT THROUGH DYNAMIC PROCESS OF CHANGE

Welding Wire size

Once the initial welding parameters were recorded, as shown in table 1, the task of continuous improvement began with the plant supervision. All welders were using water cooled welding guns of the European design. These guns never leaked any water; however, a lot of undercutting was noticed on fillet welds. 0.045” and 0.035” diameters were used in production arbitrarily. The welders on the floor had implemented a “smart” solution to this problem. On a four drive roll feeder system, two rolls were 0.035 and the other two were 0.045” diameter, so any diameter of the wire could be fed! The front end of the guns was changed so that the contact tip could be properly recessed for spray transfer. All 0.045” diameter wire was removed from production and welding 3/16” fillet welds with 0.035” diameter wire was standardized.

Weld Monitoring

Lots of monitoring and skills training was required to break old habits and assimilate new ones. Every week, the Kaizen team recorded production welding parameters of wire feed speed and welding speed, including quality and extent of over welding. The results were reviewed with the welders not performing to the new standard. To help the welder acquire the required skill, on the job training was provided by the Kaizen group. This process was repeated throughout the plant, until desired results were obtained. The feeder speed potentiometers were physically marked with a sticker to indicate the optimised position for the wire feed speed, to help everyone use the standardized parameters.

After eight months of training, and on the job monitoring of welding technique, the average welding speed increased by an impressive 39%. The welders were able to produce 3/16” fillet welds in the horizontal position, with 90Ar+ 10 CO_2 gas mixture at optimized wire feed speeds of 600”/minute at an average of 24 ipm of welding speed with practically no undercut.

Cost savings
The average welding cost per foot for a 3/16" single pass fillet weld was reduced from $ 1.57/ft to $ 1.13/ft. On an annualized basis, a potential annual saving of $ 526,771/ per year was calculated. In the first year the company was able to realize over $400,000 in added capacity in operations, requiring further work balancing the production line in the following years.

Kaizen Instruments applied to welding

FLEXIBILITY IN PRODUCTION

The management was keen to go to robotics for flexibility of production. However, when the process audit was carried out, actual welding duty cycle measurements were made. Further attention was paid to the existing accuracy of fit-up.

The duty cycles were measured in the various areas of manufacturing.
The following weighted average duty cycles were observed during the audit, over a 3- shift time span. The high duty cycle numbers were for areas where the operator was not interrupted. An average duty cycle of 20% was calculated for the shop for cost calculations by the Kaizen team.

- Lift arm assembly: Average: 22.7%

- Attachments: Average: 16.1%
- Transmissions: Average: 17.1%
- Mainframe assembly: Average: 28.5%
- Quick attachments: Average: 13.5%
- Tanks: Average: 22.3%

The overall through put of the plant was 8 units per day. In order to improve this performance, the initial survey showed that the shop floor layout would have to be significantly improved, reducing a very large amount of work in process. Robotic welding was discouraged at this stage, as part fit-up was less than acceptable and the floor layout was inadequate to feed the robots parts and then remove the finished part efficiently, without creating further work in process pile ups.

The overall operation needed to be more balanced. It was found that even if the welding operation could be significantly improved from a productivity point of view, the bottle neck was still frequent at the final assembly of the machines. More Kaizen needed to be done for the logistics of all electrical, mechanical and hydraulic systems. After the initial one year of welding improvements, it was decided to defer the automation projects until other operations could produce a pull effect on welding to really make flexible robotic welding worthwhile.

LONG TERM RELATIONSHIPS WITH SUPPLIERS

Further to the initial process audit, the President of XYZ Ltd., was very keen to implement corrective actions through focused Kaizen activities. The process was supported with a long term 4 year contract with the local gas and welding products supplier who could provide not only consumables but also welding engineering expertise.

The first Kaizen activity was focused on wire feed speeds and reducing undercuts.

The second Kaizen activity was focused on welding speeds and fillet weld sizes.

After the first eight months of support from the external welding engineering support, the plant inspectors were taught to measure and report key parameters targeted by the two Kaizen activities to ensure that the higher productivity standard was maintained, over the four year period.

CONCLUSION

While applying Lean principles to a metal fabrication facility employing arc welding in the manufacture of front end loaders, a dramatic improvement in productivity was achieved over a 12 month period. The key to success was the keen interest of the management team to succeed in the continuous improvement process.

The auditors performed similar audits in more than 100 metal fabrication shops with good results whenever the Plant Manager or the CEO of the corporation was keenly involved in the results. In order to help create an environment for continuous improvement in fabrication shops, the ISO 3834 standard has now been revised in Part 6 of the series to provide guidance on weld monitoring and highlighting the involvement of the top management in Welding performance, investments and technology. Figure 1, is an excerpt of a table from ISO 3834 Welding Quality standard, that can be used in conjunction with ISO 9000 series standards or independently, as a guide to welding quality in metal fabrication shops.

Fig. 1 : Summary of welding system control measures from ISO 3834 part 6 proposed diagram

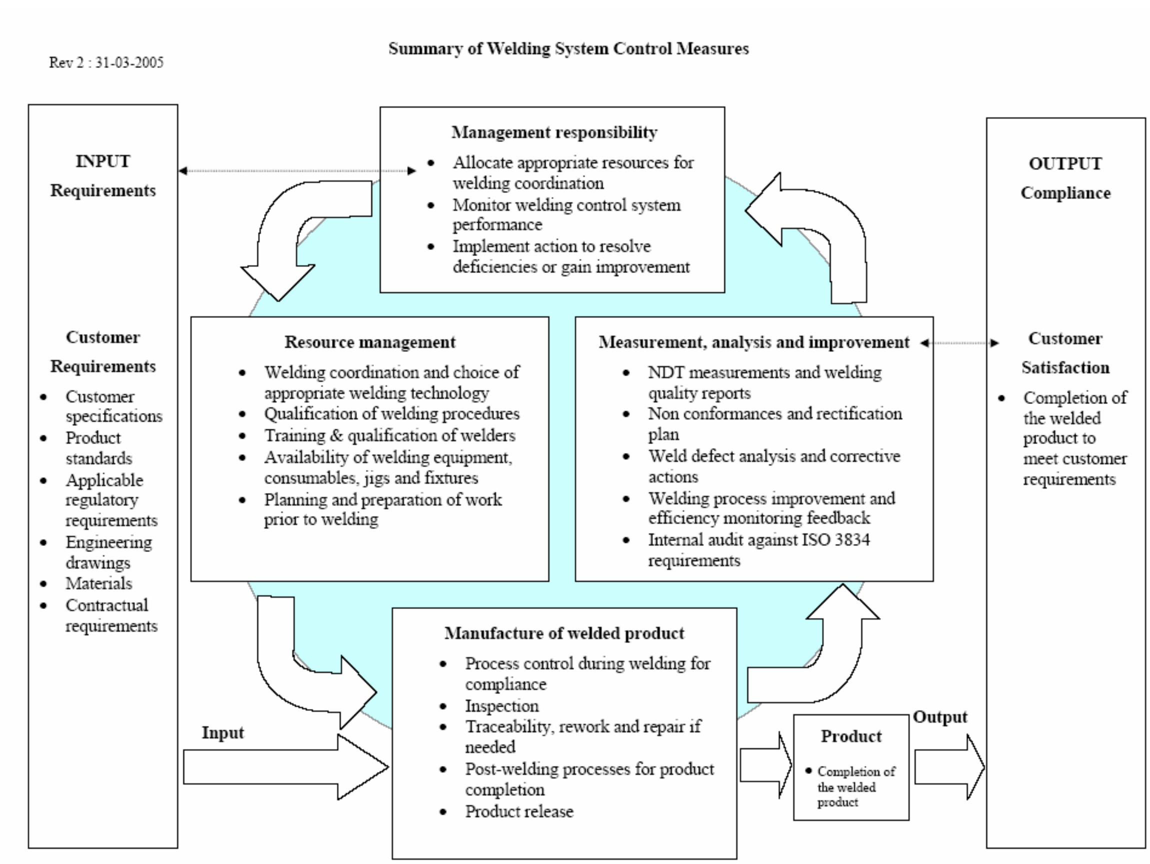

Table 1: Kaizen applied to weld monitoring process control: Starting time data

Process: GMAW **Weld metal type: ER70S-6 , 0.045" diameter wire** **Shielding gas: Ar 90%/CO2 10%**
Type of weld: Fillet weld 1/4" : Welding performed at the work stations, fillet welds made on 12" long test assembly in horizontal 2F position

Working Shift	Sample Number	Required Size (inches)	Over welding %	Wire feed Speed IPM	Voltage (Volts)	Gas flow (pi.3/h)	Welding speed IPM	Penetration Evaluation Acc./Rej.	Visual Evaluation Acc./Rej.	Overall Evaluation Acc./Rej.
Day	1	1/4	0	458	30,2	27	22,2	Acc.	Acc.	Acc.
Day	2	1/4	56	415	31,2	25	13,5	Acc.	Acc.	Acc.
Day	3	1/4	25	466	30,3	40	17,6	Acc.	Acc.	Acc.
Day	4	1/4	56	399	30,6	30	13,6	Acc.	Acc.	Acc.
Day	6	1/4	0	402	29,5	17	17,6	Acc.	Acc.	Acc.
Day	7	1/4	0	400	26,8	27	18,0	Acc.	Acc.	Acc.
Day	8	1/4	0	494	30,1	30	21,2	Acc.	Acc.	Acc.
Day	10	1/4	25	404	30,5	17	14,4	Acc.	Rej.	Rej.
Night	11	1/4	25	454	29,5	27	18,5	Acc.	Acc.	Acc.
Night	12	1/4	0	414	31,4	28	17,6	Acc.	Rej.	Rej.
Night	13	1/4	0	**385**	29,4	40	16,9	Acc.	Rej.	Rej.
Night	14	1/4	25	474	30,5	40	19,5	Acc.	Acc.	Acc.
Night	16	1/4	-25	451	28,1	25	19,5	Rej.	Rej.	Rej.
Night	17	1/4	-34	402	29,0	15	23,2	Acc.	Rej.	Rej.
Night	18	1/4	12.5	406	30,4	22	16,0	Acc.	Acc.	Acc.
Night	20	1/4	0	466	31,5	16	18,5	Acc.	Rej.	Rej.
Average	**16 Welds**		**11%**	**431**	**29,9**	**27**	**17,6**	**15 welds acceptable**	**6 welds Undercut**	**10 welds acceptable**
Optimized parameters after eight (8) months of Kaizen		**3/16"**	**20%**	**625**	**29.5**	**45**	**23**	**good**	**good**	**good**