Art and science of London Good Delivery Bar (LGDB) production

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Agenda for today
Rand Refinery London Good Delivery Bar (LGDB) history

Rand Refinery at a glance

- Established in 1920 – a 97 year heritage of gold refining
- More than 51,000 tons of mined gold refined since 1921
- Most of this has been in London Good Delivery Bars:
  - Krugerrand production since 1969
  - Small cast bar production since 1995
  - Minted bar production since 2013
- If 37,500 tons into LGD Bars then:
  - About 3 million LGDB made in our history to date
- Through the manual pour process we can produce up to 200 LGD bars per day – 2016 performance
- Current mined gold throughput around 300 ton per annum – down from 1000 ton per annum in 1990’s

Despite standard operating procedures, you are only as good as your latest team’s knowledge and experience in the art and science of LGD bar production!
### Refinery and Fabrication value chain

**Processing of high-grade precious metals and Value-Added Products**

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Preparation</th>
<th>Primary</th>
<th>Secondary</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine Doré</td>
<td></td>
<td></td>
<td>Au deposits &gt;9958 purity and no Ir and PGMs</td>
<td>Cast bars (400oz Au)</td>
</tr>
<tr>
<td>Mine Concentrates</td>
<td>Melt House</td>
<td>Miller Process</td>
<td>Au Alloying &amp; Granulation 99505 min</td>
<td></td>
</tr>
<tr>
<td>Recycled</td>
<td>(Evaluation)</td>
<td></td>
<td>Au with any Iridium, PGMs and other contaminants</td>
<td></td>
</tr>
<tr>
<td>Smelter Doré</td>
<td></td>
<td>ElectroGold</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Material is refined to at least 995.8 gold content with traces of primarily silver
- Materials affecting surface finish and content such as palladium, copper and iridium are monitored
- If iridium is present – molten poured into anodes and sent for further processing via electrolysis
- If % gold content is > 9987 – the molten is silvered down
Manual pouring of a London Good Delivery Bar

Basic overview

The manual pour process

- Cure mould
- Smoke mould
- Heat mould
- Mould on Scale
- Melt 750kg +9950 Au
- Alloy to 9950 purity
- Confirm assay
- Pouring pot transfer
- Fill mould to +12.560 kg
- Cool LGD Bar
- Clean LGD Bar
- Mark and Serialize bar

Short video of LGDB pour

Video of manual LGD bar pour
New guidelines for the visual characteristics of LGD bars

Reason for investigation – October 2015

“Button like” defects considered undesirable by Vault Managers – ideally “button like defects” to be completely eliminated on bottom surface of LGDB

- LGDB were rejected by London vault in February 2016 based on visual guidelines published by the LBMA in October 2015
- Reason for rejection – “buttons” and “plug-like” defects
- Order book predominantly LGDB in this time period
- “Buttons” defects historical at Rand Refinery – 50% of bars normally had one or more slight “button like” defect in manual pour process
- With a new reject rate of > 60% (up from <7%) due to zero tolerance of these defects – solution had to be found as a matter of priority
- Impact on business – reputational damage, gold lock-up, work-in-progress increase and missed customer orders
- Costs increase due to additional rework of rejected bars
- Impact on safety, health, environment, risk and quality challenges
LBMA Visual Guidelines
Standards pertaining to RR rejects – internal and external quality

LBMA visual guidelines – challenges facing RR with respect to compliance at this time:

- Plug-like defects on the bar surface – returns
- Manual smoothing of ring not acceptable - returns
- Layering may appear when slowing down pouring – no returns
- High internal reject rates above 50% to prevent a bar with ANY defect being dispatched to customers

*Typical examples of bars returned:*

[Images of bars with defects]
# The Challenge

**Tc**

What we had to do

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## Find a way to make a zero defect bar!

- Team of 18 employees dedicated to resolve the challenges
- Challenge every parameter
- Tract every variable
- Liaise with peers around world to find alternatives/best practices – our acknowledgement and thank you to:
  - Royal Canadian Mint – mould dressing
  - Perth Mint – pouring practices and mould design
  - Metalor – mould surfaces and design

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Want process reject rate of blank bars after pouring of < 5%
Gold Content:
Assay limit:
Lower limit = 995.05
Upper limit = 998.7

Mass Limit:
Lower limit = 12.3500 kg
Upper limit = 12.7500 kg
<table>
<thead>
<tr>
<th></th>
<th>LGD Bar Casting By Hand Pouring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Process parameters investigated</td>
</tr>
</tbody>
</table>

1. Melt temperature at pouring
2. Mould temperature prior to pouring
3. Mould smoking time and dressing alternatives
4. Mould material used and surface texture/finish
5. Hand pouring skill and time to pour
6. Operator experience
7. Flame polishing time
8. Bar cooling time
Parameters Investigated on Bar Casting Process Map

Focussing on the front-end of the value chain

1. Molten Temp
   Induction furnace 1 ton capacity

3. Smoke dressing
   Diesel mould smoking

2. Mould Temp

Gas heating table for moulds – 48 moulds

4. Mould Material

4. Mould Design

4. Mould Texture

5. Pourer skill

5. Time to pour

6. Experience

7. Flame polishing time

Quench Tank

8. Bar cooling time

Stamp Assay

Stamp company name & Logo

Weigh 1

Weigh 2

QC inspection

Send to Final Product Vault

Clean bars

Stamp Number/date on bar
Molten temperature and production of button free bars

Impact of molten temperature

- Molten temperatures monitored from 1100°C to 1400°C
- Mould temp increases with molten temp related to molten mass and time taken to pour
- Mould becomes harder to cool with more rounds poured in single batch
- There is no obvious repeatable correlation between molten temperature and button formation on bars produced
- Increase in molten and mould temperature – safety risks increase for team
- More efficient PPE means thicker material which increases risks with manual handling
- Different mould surface have different cooling times which affects button formation
Experience of Pourers

Reject rate over a 1 month period

- Operator Experience:
  - Operator 1 - more than 10 years experience;
  - Operator 2 - < 3 years experience;
  - Operator 3 - < 1 years experience
- Same moulds used by each operator
- Data collected over a 1 month period alternating between operators
- Different pouring techniques were tried
- Irrelevant of pouring technique and other variables – the good bars were averaging 60 to 63% for each operator

Comparison of pourers - reject bars and good bars produced in a one month period

- Operator 1
- Operator 2
- Operator 3

- good bar
- ring on bar
At any one time – there are at least 48 moulds on the table for production
All moulds are cured the same way and smoked for at least 36 seconds using diesel fumes
Surface finish of mould had most obvious impact on good bar produced
Rough surface finish and sandblasted surface finish had best outputs for addressing reject rate due to button formation
Historically – smooth finish on moulds was the preferred choice
Local foundries changed processes so could not replicate the rough surface finish as required
Mould surface: Temperature and % reject/good bar produced

Variable – mould temperature at pouring

- Rough mould finish produced the lowest reject rate at between 25°C to 50°C
- Sandblasted moulds produced the lowest reject rates in the range from 50°C to 200°C
- Smooth moulds produced the lowest reject rate at temperatures > 300°C
% Reject and good bars produced per mould type vs round poured

Variable – surface finish of mould used

- Calculated as a % of good bars and reject bars produced per round
- More rounds poured – hotter moulds get – the harder to cool down
- 1st round had an average > 60 % reject rate across the board – mould heated on gas heating table. Uneven heating of mould.
- Range of temperatures inspected from 85°C to 200°C
- Once moulds heated after first pour – reject rate did inverse and dropped to 32 %
Reject rate improvement with introduction of sandblasted mould finish

Month on month comparison of reject rates per mould surface finish

- Introduction of the sandblasted finish moulds
- The smooth surface finished moulds decreased in number however the reject rate is still comparable month on month
Bar Casting – Improvement timeline

Operating parameters and production detail

February 2016  
Internal reject rate > 50%

July 2016  
Internal reject rate ~ 35%

September 2016  
Internal reject rate ~ 25%
The Challenge – THIS WAS NOT GOOD ENOUGH!

By mid-April we started a parallel process to develop a technology solution

Find a way to make a low cost, repeatable, zero defect LGD Bar!

• Go back to our primary original research between 1999 – 2002 with IECO to produce Continuous Induction Furnace (CIF) small cast bars - contact the original team from Rand Refinery
• Can we develop an in-house solution for less than Euro 50,000 using our old technology?
• Rebuild a decommissioned kilo bar CIF furnace (from 2011) onsite between 15 April -16 June 2016 to produce LGDB (Inverter, CIF Tunnel and Cooling Tunnel)
• Research operating conditions and moulds between 16 June – 30 September 2016 to produce “the perfect bar”
• All Rand Refinery LGDB since 2 December 2016 has been produced with this technology

1. Must be able to produce 100 LGD bars in 6 hours from granule feedstock
2. Want process reject rate of blank bars after production approaching 1%
3. Preferably no surface treatment required
4. Simple engineering – robust – easy to maintain – fit for African conditions
5. Must only require 3 operators and 1 granulator to do all the work
New process - continuous induction furnace

Completed CIF LGDB line in operation

“Reject rates now primarily relate to top surface blemishes which can be traced back to specific impurities in the 9950 feedstock”

LGDB Line Specifications

- kW setting of Inverter: below 150 kW
- Cycle time of pusher: 170 seconds
- Temperature of mould after furnace: 1250 °C when it passes from the furnace to the cooling zone
- Reject rate of LGDB Line: <3%
New process - continuous induction furnace

Quality of blank bar directly after removal from cooling section

- This is the quality of the bar directly after it being removed from the mould
- The slight “watermark/graphite” mark on the bar below is wiped of and we are working on engineering it out
- Bar was cut through to proof complete melt
New process - continuous induction furnace

Improvement on surface quality

Bottom appearance of hand casted LGD bar

Bottom appearance of CIF produced LGD bar on Line 4

Top surface appearance of CIF produced LGD bar on Line 4 after cleaning of top surface

New CIF bar has exact parameters of old hand poured bar – minimised change management
In conclusion
We are confused

**Should the LGDB be a Fabergé bar?**

- Refiners produce LGDB at zero profit to their businesses – often at a discount (in the case of Rand Refinery)
- Ideally LGDB production is avoided (market conditions dependant)
- A technical solution of Euro 500,000 therefor does not make sense
- What level of investment can reasonably be required from refiners to produce a product that does not generate profit?
- Where do we go from here?
THANK YOU

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