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EXAMINATION OF "TOP-HAT" MINESHAFT GUIDE SUBMITTED BY GECO MINES, LIMITED

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

Metallurgical examination of a failed mineshaft guide from the Anglo-Transvaal Consolidated Investment Company, Limited of South Africa has shown that failure was initiated in brittle martensitic zones produced by welds and arc strikes. The guides were found to have been fabricated of as-rolled or normalized steel containing 0.52% C and 0.87% Mn. Charpy V-notch impact tests revealed a 15 ft-lb transition temperature of 43°C (109°F) and a 50% cleavage fracture temperature of 75°C (167°F).

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INTRODUCTION

Mr. F.E. Hill, Plant Superintendent of Geco Mines Limited, Manitouwadge, Ontario, submitted the central fractured section of a 30 ft length of a 12 in. x 4 in. "Top-Hat" mineshaft guide for metallurgical examination. A covering letter, dated 31 December, 1963, stated that three such broken guides had been received at the mine site. The guides, of a type never having been used in Canada, were imported from South Africa. Subsequently, it was learned that a total of over 700 tons of steel is involved. Five questions were asked, namely:

> "1. Does metal in the sample indicate a mild steel analysis?
>
> 2. Why did all three guides break in the same place?
>
> 3. Is there any evidence of transverse brittle welding in the sample?
>
> 4. Would the guides be brittle enough to break when handled in cold temperatures?
>
> 5. Has the welded bracket at the back of the guide any significance with respect to location of the break?"

Mr. Hill was able to provide a copy of Anglo-Transvaal Consolidated Investment Company Limited, Drawing AVS 121 - Details of Std Shaft Guides, but he has not been able to provide a material specification. However, the enquiry was phrased in a manner which indicated that the guides would be made of mild steel and it was understood from telephone conversation that mild steel would have adequate tensile strength for these guides.

PROCEDURE

Macroexamination

Figure 1 (X 1/2) shows the mating surfaces of the fracture. The failure occurred transversely at the mid-length of the 30 ft guide. The arrows show the direction of the chevron markings pointing back to where the cracks initiated at the ends of the welds which were made to attach a connecting plate to the guide section. The appearance of the fracture surface was characteristic of brittle failure.

The upper section, as shown in Figure 1, was stripped of paint and deep-etched in 1:1 HCl and water at 160-180°F for thirty minutes. This clearly revealed that major points of fracture initiation were on the inner surface of the guide section at or close to the edges of short weld deposits (subsequently termed "return welds") which had been made across the ends of the longitudinal weld deposits joining the connecting plate to the guide. An additional point of fracture initiation, on one side of the guide section, was an arc strike in line transversely with the return weld. A second arc strike, offset transversely from the return weld, was also observed. The arc strikes contained cracks open to the surface.

Microscopical Examination

Figure 2 (X7) shows a partial cross-section, perpendicular to the deep-etched fracture surface, through the end of one of the culprit return welds. This section was polished and etched to reveal the shallow overlay of weld metal, the underlying heat-affected zones of the base metal and the unaffected base metal. Underbead cracks were observed in the zone of martensite. Details of the microstructure are shown more clearly in Figure 3 (X500). The structures in a section through an arc strike were similar, except for a shallow cratering effect instead of a deposit of weld metal.

A Tukon hardness survey, using a diamond indenter and a 500-g load, revealed the hardness of each zone shown in Figure 2, and the abruptness of the change in hardness between zones. The hardness results are shown below in Table 1.

Examination of a cross-section through the welded joint revealed that metal was deposited in four main passes. Underbead cracks and weld metal cracks were observed. Martensite formed during the first three passes was well tempered by subsequent passes. However, brittle martensite was observed in the base metal immediately adjacent to the last weld pass.

Chemical Composition

Representative drillings from the guide were found to have the chemical composition shown in Table 2.

Tensile Properties

Eight tensile bars were machined from the 5/8 in. U-channel portion of the guide. The bars were oriented in the direction of rolling and had a nominal gauge diameter of 9/32 in. and a gauge length of 2 in. The results are given in Table 3.

TABLE 1

Tukon Hardness Traverse Through the Zones Shown in Figure 2

(Diamond Indenter, 500-g load)

Distance from Upper Surface of Weld, inches	Hardness		Zone
	Knoop	Converted Rockwell "C"	
0.004	348	35	Weld deposit
0.008	346	34	" "
0.012	389	39	" "
0.016	362	36	" "
0.020	327	32	" "
0.024	331	33	" "
0.028	367	37	" "
0.032	382	38	" "
0.036	319	31	" "
0.040	311	30	" "
0.044	641	56	Martensite (in base metal)
0.048	688	58	"
0.052	700	59	"
0.056	700	59	"
0.060	713	59	"
0.064	700	59	"
0.068	720	59	"
0.072	713	59	"
0.076	700	59	"
0.080	700	59	"
0.084	578	52	Martensite and bainite
0.088	525	49	" " "
0.092	472	46	Martensite, bainite and ferrite
0.096	417	41	" " "
0.100	371	37	" " "
0.104	265	23	Pearlite and ferrite
0.108	267	23	" " "
0.112	277	25	" " "
0.116	256	21	" " "
0.120	258	21	" " "
0.124	281	25	" " "

TABLE 2

Chemical Composition, wt %

C	Mn	Si	S	P
0.52	0.87	0.16	0.028	0.020

TABLE 3

Tensile Properties

Test Bar No.	Location in Channel	UTS kpsi	YS at 0.2% Offset, kpsi	% El. in 2 in.	% RA
1	sidewall	98.0	54.2	19.0	50.8
2	"	101.0	52.4	21.5	45.8
3	bottom	103.0	53.2	20.0	45.8
4	"	102.2	65.6**	18.0	47.5
5	"	100.2	53.1	19.0	47.6
6	"	98.2	55.8	20.5	47.6
7	sidewall	99.8	52.0	19.5	46.0
8	"	98.2	57.8	20.5	50.1
Mean		100.1	54.1	19.7	47.6
*s		1.9	2.1	1.1	1.9

*s - individual standard deviation.
**Abnormal result not used in calculation of s.

Impact Properties

Charpy V-notch impact bars were cut longitudinally from the U-channel portion i.e. in the direction in which the "Top-Hat" section was rolled. The bars were notched perpendicularly to the plane of rolling. Figure 4 shows average impact energy absorption and per cent of cleavage fracture plotted versus testing temperature. The energy curve is virtually linear over the temperature range from 24°C to 120°C (75°F to 248°F). The 15 ft-lb transition temperature is 43°C (109°F). The 50% cleavage fracture transition temperature is 75°C (167°F).

REPLY TO SPECIFIC QUESTIONS

1. The main body of the guides was made of 0.52% C steel. This cannot be considered to be a mild steel. The weld metal and the connecting plate were low carbon steel.

2. It is probable that each of the three guides failed for the same reason, which is, maximum stress concentration or impact loading in the brittle martensite formed by the covering return weld or by arc strikes or both.

3. There was no evidence of transverse welding in the guide, except for the return welds over the ends of the multi-pass weld joint.

4. The 15 ft-lb impact energy transition temperature of 109°F (43°C) and the 50% cleavage fracture transition temperature of 169°F (75°C) indicate that the guides, having a pearlitic-ferritic structure, are prone to sudden brittle failure under impact loading, even at room temperature.

5. The presence of a connecting bracket serves to concentrate stresses in the region of the welds by its position at mid-length and by increasing triaxial stresses. Also, the spacer plate required to keep the channel from narrowing during the welding operation could possibly result in enough restraint to cause hot-cracking of the weld metal.

DISCUSSION

Plain carbon steel having 0.52% C and 0.87% Mn is not considered to be suitable for use as constructional steel in Canadian climates, particularly if the user is under the impression that he is using a mild steel. One obvious reason for this convention is that this steel is subject to brittle failure even in summer temperatures. Another obvious reason is that welding of this steel requires precautions and technique that are not necessary for mild steel. These reasons are quite apart from inherent production and control difficulties at the steel plant.

The arc strikes, the brittle martensite, the underbead cracks and the weld metal cracks are indicators of improper welding procedures and inadequate inspection. It is, of course, possible that the guides were supposed to have been made of a more weldable steel. In fact, it is difficult to believe that the guides were intentionally made of as-rolled or normalized 0.52% C steel.

In fairness, it should be understood that impact strength or the lack of it is a quality which is difficult for a designer to utilize in a quantitative sense. Impact criteria are of most value in application such as ship construction where through long experience it has been found that some significant correlation exists between impact criteria and the probability of catastrophic failure. It is possible that the service conditions to be imposed on the guides do not require impact strength of a higher order than exists in the guides and do not require greater freedom from sharp notches and internal weld cracks.

The failure which was examined was related to the brittle martensite and it was characteristic of sudden failure. Tempering to toughen the martensite would have reduced the probability of failure occurring. However, no heat treatment can eliminate underbead cracks, weld cracks and cracks formed by arc strikes. Conceivably, these defects could still be serious if alternating stresses in service will be of sufficient magnitude and frequency to propagate existing cracks over a long period of time until failure due to fatigue ensues. Also, it is possible for cracks to be propagated over a long period of time by repeated low-energy impact blows. Such insidious failures may occur at stresses well below the bulk elastic limit of the steel due to stress concentration in the region of cracks. The fatigue limit of steel is drastically lowered if water can enter the cracks.

CONCLUSIONS

1. The failed "Top-Hat" mineshaft guide was made of as-rolled or normalized steel having a content of 0.52% C and 0.87% Mn.

2. The failure was initiated in brittle martensitic zones produced by covering return welds and arc strikes.

3. The weld metal and the connecting bracket were made of low carbon steels.

4. The tensile properties of the guide are good with an average ultimate tensile strength of 100,000 psi and an average yield strength at 0.2% offset of 54,000 psi.

5. The impact properties of the guides are poor with a 15 ft-lb transition temperature of 109°F (43°C) and a 50% cleavage transition temperature of 167°F (75°C).

RECOMMENDATIONS

1. Demand a material specification for the guides.
2. If a material specification is not obtained, a random sample of the guides should be analyzed for carbon content.
3. If high carbon guides must be used they should be handled carefully at all temperatures and especially at low temperatures.
4. If the high carbon steel must be used, consideration should be given to tempering the guides. Localized flame heating, if carefully done in the range of 700-1200°F would be adequate to temper the martensite at or near the surface. Heating through the section is not necessary. It would be more satisfactory to have the guides fully tempered at 1200°F.
5. Ascertain whether or not guides of comparable material and workmanship have given satisfactory service in other mines.

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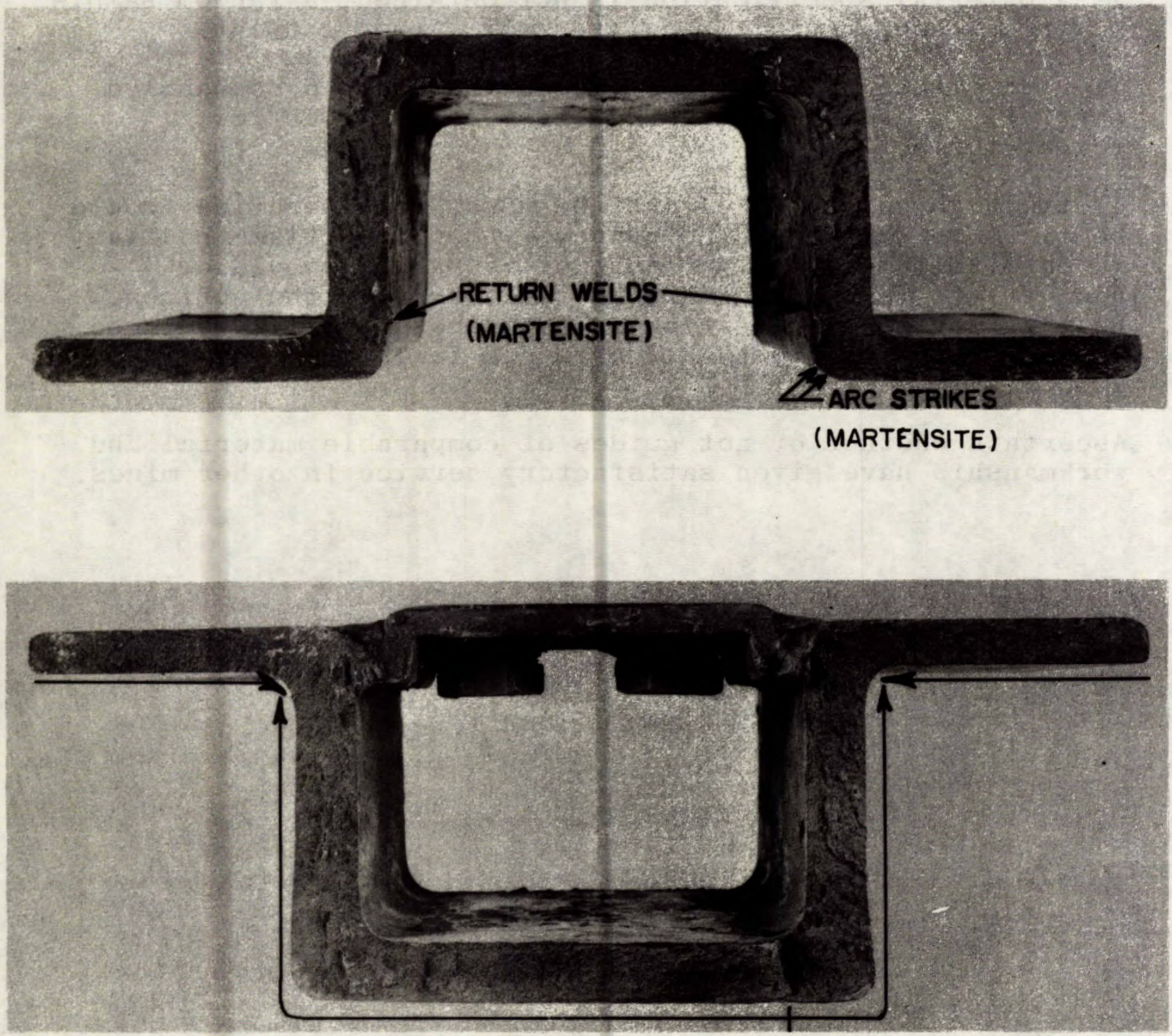


Figure 1. Mating Fracture Surfaces of a Geco "Top-Hat" Mineshaft Guide. (X 1/2)

In the upper view, arrows point to areas where fracture was initiated.

The lower view shows the mid-length connecting plate. Arrows parallel the chevron markings which point back to the areas where cracks initiated.

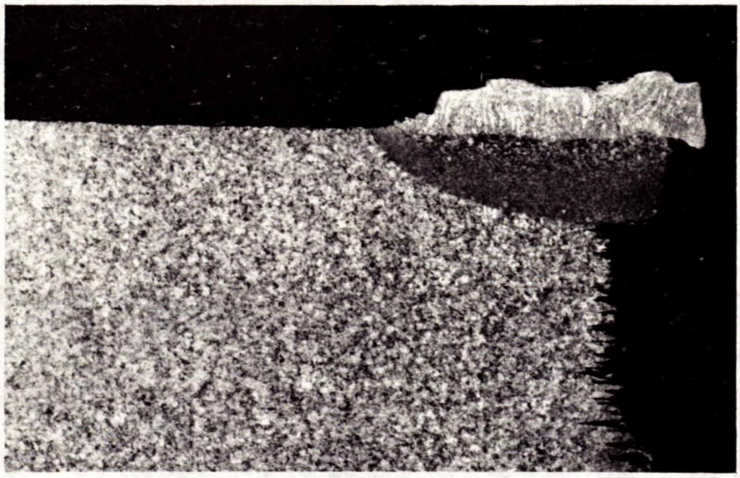
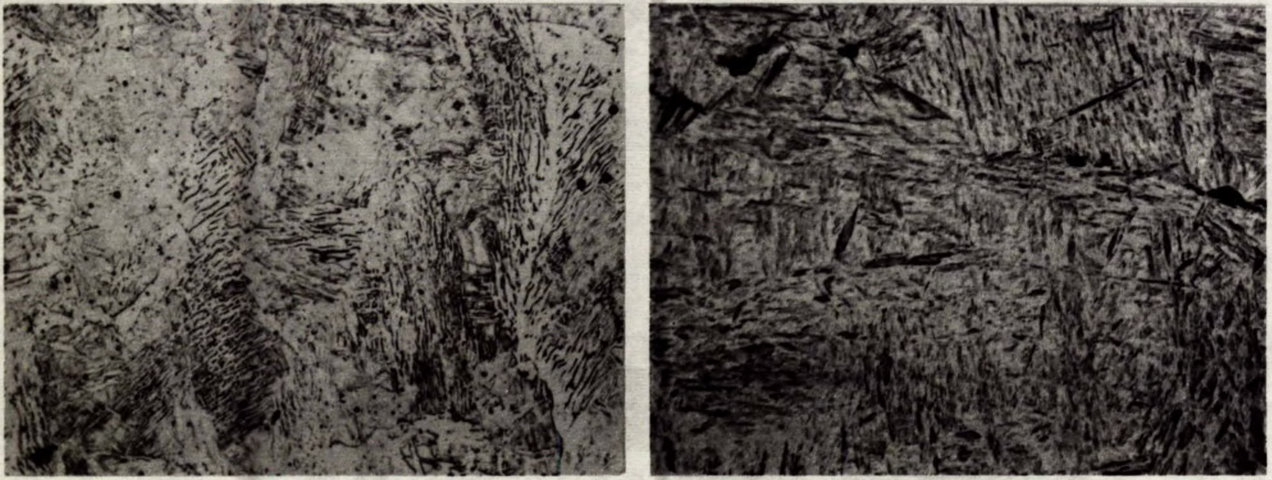


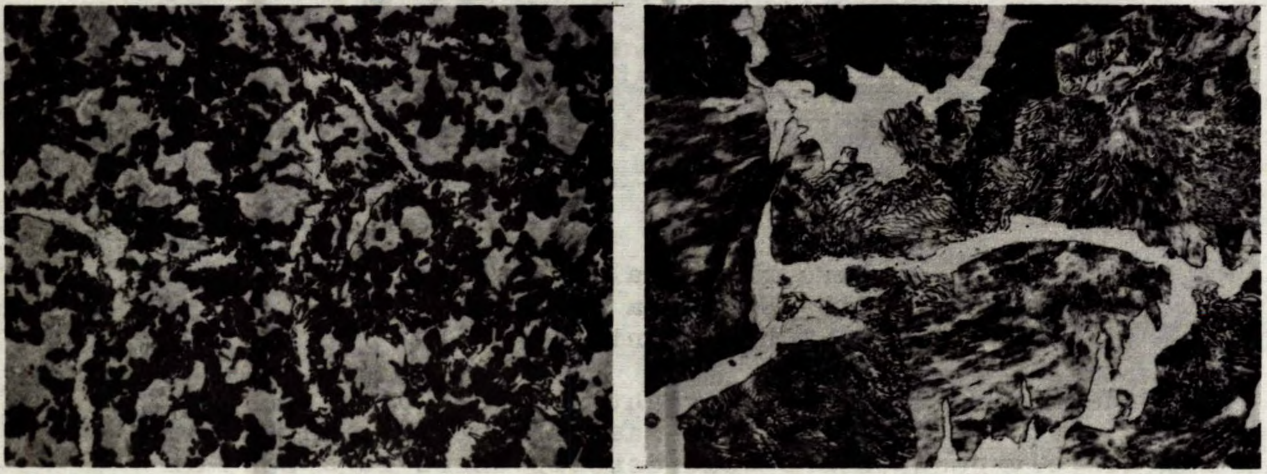
Figure 2. Section Through a Shallow Return Weld Covering the End of a Four-Pass Weld Deposit. Etched in nital (X7)

The fracture surface at the right has been deeply etched. The weld deposit has a columnar as-cast structure. In the base metal immediately beneath the weld deposit there is a zone of brittle martensite (virtually at maximum hardness) and martensite plus bainite. The base metal has a structure of pearlite grains enveloped by proeutectoid ferrite.



Weld Deposit

Martensite in Base Metal
(underlying the weld deposit)



Martensite and Upper Bainite
(transition zone between
martensite and base metal)

Base Metal (as-rolled or
normalized structure)

Figure 3. Representative Microstructures Showing Details of the Zones Shown in Figure 2. Etched in nital X500.
(see also Table 1)

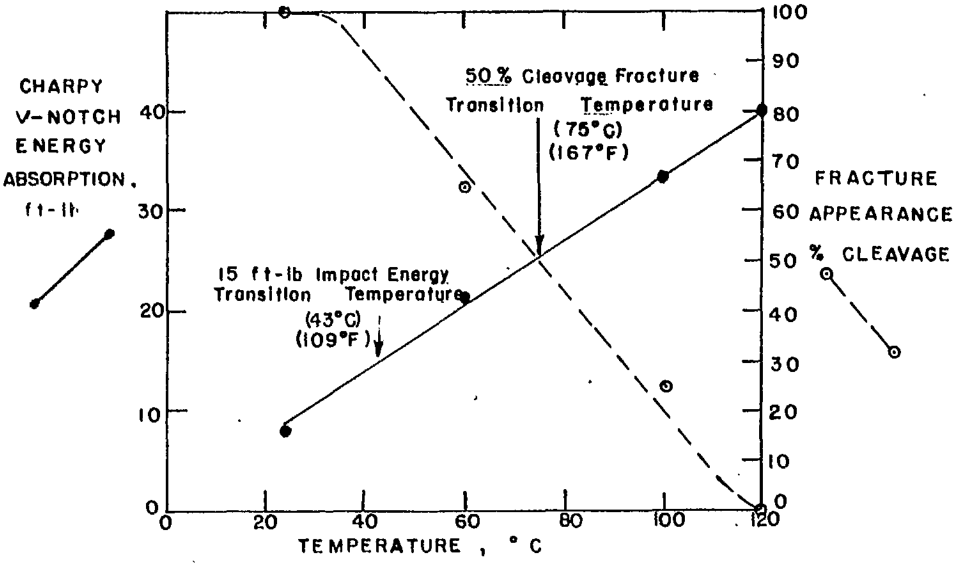


Figure 4. Charpy V-Notch Impact Results versus Testing Temperature.