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露天采场铜钴氧化矿蜂窝状矿石构造 爆破效果的改善

杜军,王明伟,郑俊伟,金宏洋,冯凯,刘增辉,哈守斌

(山西江阳工程爆破有限公司,太原 030041)

摘要: 露天采场尤其铜钴氧化矿,矿石区域较多的呈现蜂窝状矿石构造,并伴随有大量的节理、溶洞等地质缺陷,这对采剥作业造成了较大的困难,尤其在穿爆环节,出现钻孔成孔率低,大块率高,松散度差,根底多等多类质量缺陷。这不仅严重影响了后续的挖装作业效率,同时也带来安全方面的隐患。针对铜钴氧化矿蜂窝状矿石构造的爆破效果,在经济合理的条件下,从降低钻孔深度、减小钻孔孔径提高钻孔成孔率、防静电PVC管及包装型乳化炸药吊装等方式约束装药提高装药高度、调整爆破参数3个方面用于改善爆破质量,以满足后续施工作业的要求。结果表明:该方法对于爆破后的大块率、根底率及松散度指标有较大的改善,基本满足后续挖装运输要求,有利于露天采场下一循环的采剥作业。

关键词: 台阶爆破;蜂窝状矿石构造;大块率;松散度;根底率;约束装药

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Improvement of Blasting Performance for Honeycomb-structured Copper-cobalt Oxide Ore in Open-pit Mines

DU Jun, WANG Ming-wei, ZHENG Jun-wei, JIN Hong-yang, FENG Kai, LIU Zeng-hui, HA Shou-bin

(Shanxi Jiangyang Engineering Blasting Co., LTD., Taiyuan 030041, China)

Abstract: Open-pit mining areas, particularly those containing copper-cobalt oxide ores, frequently feature honeycomb-structured ore bodies with extensive geological discontinuities, including joints and cavities, creating substantial difficulties during stripping operations. This phenomenon is especially pronounced during blasting operations, manifesting as low borehole formation rates, elevated high boulder yield, inadequate fragmentation, and hard toe. All of which significantly compromise subsequent excavation and loading efficiency while simultaneously introducing operational safety risks. To optimize blasting effects in honeycomb-structured copper-cobalt oxide ores while maintaining economic feasibility, three key improvements were implemented: enhancing drilling success through reduced depth/diameter, increasing charge height via anti-static PVC pipe confinement and cartridge hoisting, and parameter adjustments to satisfy subsequent construction requirements. The results demonstrate that this approach substantially enhances post-blasting performance metrics, including boulder yield, hard toe occurrence, and fragmentation quality, effectively satisfying subsequent excavation and haulage requirements while optimizing stripping operations for the following mining cycle.

Key words: bench blasting; honeycomb ore structure; boulder yield; looseness; hard toe rate; constrained charge

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作者简介: 杜军 (1981-), 男, 山西省太原市, 本科、高级工程师, 工程爆破施工管理及技术, (E-mail) dj@northminingdrc.com。

About the author: DU Jun (1981-), male, Taiyuan City, Shanxi province, undergraduate, senior engineer, mainly engaged in engineering blasting construction management and technology, (E-mail) dj@northminingdrc.com.

在露天采场采剥作业中,穿爆作业施工是整体采剥作业的关键工序,穿爆作业施工的进度、质量等都影响到后续的施工环节。在露天采场经常会遇到不良地质条件和地质缺陷的爆破施工^[1-5],而导致爆破效果不理想,致使铲装运效率和成本增加,露天采场的作业计划被延误。对于露天采场铜钴氧化矿矿石区域较多的出现蜂窝状矿石构造,针对该矿石构造杜军等人从提高钻孔成孔率、径向约束装药、优化孔网参数等手段,改善爆破后的大块、根底及松散度不够等问题。

1 蜂窝状矿石构造介绍

该矿石构造是由 喷出地表冷却凝固所形成,由于岩浆温度、压力急剧降低,固结成岩时间相对较短,溶解在岩浆中的挥发份以气体形式大量逸出,有明显的 颗粒,形成气孔状、裂隙发育、结构不均匀等地质缺陷。该种地质缺陷导致在穿爆作业施工时造成以下困难:①钻孔成孔困难,矿渣难以返到地面上,实际深度无法满足设计要求,同时孔柱不是标准的圆柱状,孔壁有残破。②装药过程中裂隙、溶洞等造成漏药,有效装药高度不够,致使封堵长度过长而产生大块。③爆破后矿体破碎不均匀,底盘不平整,松散度差,铲装效率低下。

图 1 为蜂窝状矿石区域爆破后产生的大块图片,图 2 为蜂窝状矿石区域爆破后二次破碎图片。



图 1 蜂窝状矿石区域爆破后产生的大块图片

Fig. 1 The large blocks from honeycomb ore area after blasting

2 试验介绍

试验场地分别为卡莫亚东Ⅱ露天采场和刚波夫主矿体露天采场,卡莫亚东Ⅱ露天采场设计台阶高度为 12 m,刚波夫主矿体露天采场设计台阶高度为 10 m。两个露天采场均为铜钴氧化矿,矿石区域为蜂窝状矿石构造。卡莫亚东Ⅱ露天采场试验 2 次,刚波夫主矿体露天采场试验 2 次,试验中使用的穿

孔设备为履带式潜孔钻机 + Atlas Copco 836 空压机,雷管选用高精度导爆管雷管,延期时间孔间选用 17 ms,排间选用 25 ms/42 ms,孔内选用 500 ms。



图 2 蜂窝状矿石区域爆破后二次破碎图片

Fig. 2 The secondary crushing from honeycomb ore area after blasting

2.1 提高成孔率

履带式潜孔钻机广泛应用于露天矿山采剥作业中,其钻孔原理为通过冲击器带动钻头上下快速冲击和回转磨损达到岩矿石的破碎,压缩空气把破碎的岩矿粉从钻杆与孔壁之间的环形空间排至孔外^[6]。对于蜂窝状矿石构造穿爆区域,由于其蜂窝状构造具有不均匀性,使得钻孔时的冲击和回转磨损效果差,同时孔壁存在着裂隙等,导致岩矿粉无法顺利的吹出孔口,甚至造成卡钻现象^[7,8]。

鉴于以上原因,本试验选用两种方式提高成孔率:①卡莫亚东Ⅱ露天采场钻孔直径 $\phi 140$ mm 不变,改变原爆破台阶的高度。对于蜂窝状矿石构造丰富的水平由设计台阶高度 12 m 一次爆破变为两次分层爆破循环作业。炮孔深度由原来的 13 m 变为 6.5 m,通过减小一次钻孔深度,提高钻孔成孔率。②刚波夫主矿体露天采场钻孔直径由原来的 $\phi 140$ mm 变为 $\phi 115$ mm,爆破台阶高度不变,通过减小钻头与矿石的接触面积提高钻孔成孔率。

2.2 爆破参数优化

2.2.1 卡莫亚东Ⅱ露天采场

针对该露天采场的炮孔深度有较大的变化,因此应对爆破参数进行优化^[9],优化结果见表 1。

2.2.2 刚波夫主矿体露天采场

由于钻孔孔径由 $\phi 140$ mm 变为 $\phi 115$ mm,需对爆破参数进行调整,调整结果见表 2。

2.3 装药结构优化

由于蜂窝状构造会造成炮孔无法形成光滑的孔壁,同时蜂窝状矿石构造伴随着溶洞、裂隙发育等,出现较多的漏药现象。对于这种情况,采用包装型乳化

炸药吊装及防静电 PVC 管径向约束装药等方式,提高有效装药高度,确保爆破质量,装药过程见图 3。

表 1 卡莫亚露天采场蜂窝状矿石构造穿爆区域爆破参数调整统计表
Table 1 Statistical table of blasting parameter adjustment in the honeycomb ore structure
penetration area of Kamoya open-pit mining field

	台阶高度 Bench height/m	孔径 Diameter/ mm	超深 Subdrill/ m	炮孔 深度 Depth/m	孔距 Spacing/ m	排距 Burden/ m	乳化炸药单耗 Emulsion specific charge/(kg·m ⁻³)	单孔装药量 Single hole charge/kg	装药高度 Charge height/m	堵塞长度 Stemming length/m
调整前 Before adjustment	12	140	1.0~1.5	13~13.5	5.2~5.5	4	0.55~0.57	145~150	8.0~8.3	5.0~5.2
调整后 After adjustment	6	140	0.5~1.0	6.5~7.0	4.8~5.0	3.8~4.0	0.42~0.50	50~55	2.7~3.0	3.5~4.0

表 2 刚波夫露天采场蜂窝状矿石构造穿爆区域爆破参数调整统计表
Table 2 Statistical table of blasting parameter adjustment in the honeycomb ore structure
penetration area of Kambove open-pit mining field

	台阶高度 Bench height/m	孔径 Diameter/ mm	超深 Subdrill/ m	炮孔 深度 Depth/m	孔距 Spacing/ m	排距 Burden/ m	乳化炸药单耗 Emulsion specific charge/(kg·m ⁻³)	单孔装药量 Single hole charge/kg	装药高度 Charge height/m	堵塞长度 Stemming length/m
调整前 Before adjustment	10	140	1.0~1.2	11.0~11.2	5	4	0.60~0.65	120~130	6.5~7.0	4.2~4.5
调整后 After adjusted	10	115	1.0~1.5	11.0~11.5	4	3.5	0.53~0.64	75~90	6.5~7.5	3.5~4.0



图 3 采用成品乳化吊装及防静电 PVC 管
组合的方式约束装药

Fig. 3 The charge process by restraining with
anti-static PVC pipe and cartridge hoisting

3 试验过程

3.1 穿孔作业

本文从 E II - C006-1341-001 (矿)、E II - C028-

1323-001 (矿)、GBF- C010-1350-006 (矿)、GBF- C016-1350-010(矿)四个蜂窝状矿石构造区域进行试验,穿孔试验结果如表 3 所示。

3.2 爆破参数统计

蜂窝状矿石构造四次试验的爆破参数统计见表 4。E II - C006-1341-001 (矿)爆破区域采用斜线型逐孔起爆,地表延期时间采用 17 ms/42 ms,见图 4。E II -C028-1323-001 (矿)爆破区域采用“V”型逐孔起爆技术爆破,地表延期时间采用 17 ms/25 ms/42 ms,见图 5。GBF- C010-1350-006 (矿)爆破区域采用斜线型逐孔起爆,地表延期时间采用 17 ms/25 ms,见图 6。GBF- C016-1350-010 (矿)爆破区域采用“一字型”逐孔起爆,地表延期时间采用 17 ms/42 ms,见图 7。

3.3 爆破效果统计

通过爆破区域爆堆隆起情况,并结合铲装作业的最终结果,爆破效果统计见表 5。爆后图片见图 8 ~ 图 11。

表 3 验孔记录统计表
Table 3 Statistical table of hole inspection record

穿孔区域 Drilling area	孔径 Diameter/ mm	孔深 Depth/ mm	允许孔深 误差 Hole depth error range/m	总孔数 Total number/个	合格孔数 Qualified hole number/个	不合格孔数 unqualified hole number/个	成孔率 Success rate
E II - C006-1341-001 (矿) E II - C006-1341-001 (Ore)	140	6.5	±0.3	382	370	12	96.8%
E II - C028-1323-001 (矿) E II - C028-1323-001 (Ore)	140 115	7	±0.3	183 292	170 270	13 27	91.5%
GBF- C010-1350-006 (矿) GBF- C010-1350-006 (Ore)	115	11.5	±0.7	36	32	4	89%
GBF- C016-1350-010 (矿) GBF- C016-1350-010 (Ore)	115	11	±0.7	55	48	7	87.3%

表 4 爆破参数统计表
Table 4 Statistical table of blasting parameters

爆破区域 Blasting area	EII- C006-1341-001 (矿) EII- C006-1341-001 (Ore)	EII- C028-1323-001 (矿) EII- C028-1323-001 (Ore)	GBF- C010-1350-006 (矿) GBF- C010-1350-006 (Ore)	GBF- C016-1350-010 (矿) GBF- C016-1350-010 (Ore)
孔深 Depth/mm	6.5	7	11.5	11
孔距 Spacing/m	5	4.8/4.2	4	4
排距 Burden/m	4	3.8/3.5	3.5	3.5
炸药类型 Type of explosive	多孔粒铵油 ANFO	散装乳化 Emulsion	多孔粒铵油/包装型乳化 ANFO/Cartridge	散装乳化/包装型乳化 Emulsion/Cartridge
单耗 Powder factor/ (kg · m ⁻³)	0.31	0.47	0.51	0.60
单孔装药量 Single hole charge/kg	37.5	55/45	75	84
线装药密度 Linear charge density/ (kg · m ⁻¹)	12.5	17.6/12	8.5	12
装药高度 Charge height/m	3	3/3.5	8	7
堵塞长度 Stemming length/m	3.5	4/3.5	3.5	4
总装药量 Total charge/kg	14325	24000	2700	4700
爆破方量 Blast volume/m ³	46000	50000	5400	8000

4 结论

通过以上 4 组对于蜂窝状矿石构造的穿爆作业施工,结论如下:

- (1)提高成孔率是保证爆破效果的前提。
- (2)采用分层爆破,减小一次钻孔深度、改变钻孔直径方式能够有效提高成孔率。

(3)分层爆破能够有效地减少炸药单耗,爆破效果提升明显。

(4)随着炮孔深度的增加,成孔率降低,炸药单耗增加明显。

(5)采用包装型乳化炸药吊装、PVC 管径向约束装药对装药过程中减少漏药有积极作用。

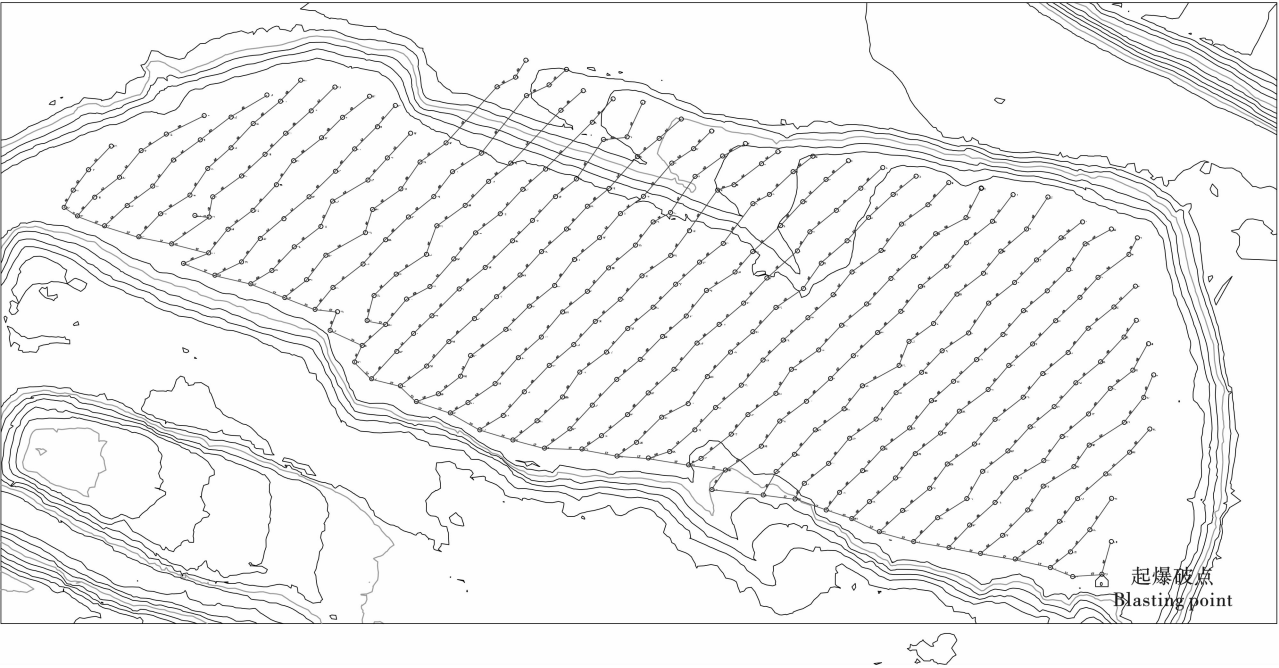


图 4 E II - C006-1341-001(矿)爆破网路示意图
Fig. 4 E II - C006-1341-001(ore) blasting network diagram

表 5 爆破效果统计表
Table 5 Statistical table of blasting effect

爆破区域 Blasting area	大块率统计 Block rate statistics	松散度统计 Looseness statistics	根底率统计 Foundation rate statistics
EII- C006-1341-001(矿) EII- C006-1341-001(Ore)	本炮区共产生 ≥ 650 mm 大块约 150 块,以每块 3.4 m^3 计算,大块率 1.1% There are about 150 pieces of large blocks of more than 650 mm in this blasting area, with each 3.4 m^3 , and the rate of large blocks is 1.1%	爆堆高度平均 ≥ 1.5 m,结合挖运方挖装车数,松散度 ≥ 1.5 The average height of the explosive pile is more than 1.5 m, and the loose degree is more than 1.5 based on the number of excavators and loaders	未出现 ≥ 0.2 m 的根底,根底率 $\leq 1\%$ No foundation depth of ≥ 0.2 m, and the foundation rate is less than or equal to 1%
EII- C028-1323-001(矿) EII- C028-1323-001(Ore)	本炮区共产生 ≥ 650 mm 大块约 100 块,以每块 3.4 m^3 计算,大块率 0.75% There are about 100 pieces of large blocks of more than 650 mm in this blasting area, with each 3.4 m^3 , and the rate of large blocks is 0.75%	爆堆高度平均 ≥ 1.5 m,结合挖运方挖装车数,松散度 ≥ 1.5 The average height of the explosive pile is more than 1.5 m, and the loose degree is more than 1.5 based on the number of excavators and loaders	未出现 ≥ 0.2 m 的根底,根底率 $\leq 1\%$ No foundation depth of ≥ 0.2 m, and the foundation rate is less than or equal to 1%
GBF- C010-1350-006(矿) GBF- C010-1350-006(Ore)	炮区共产生 ≥ 700 mm 大块约 120 块,以每块 3.4 m^3 计算,大块率 7.5% There are about 120 pieces of large blocks of more than 700 mm in this blasting area, with each 3.4 m^3 , and the rate of large blocks is 7.5%	爆堆高度平均 ≥ 1 m,结合挖运方挖装车数,松散度 ≥ 1.2 The average height of the explosive pile is more than 1 m, and the loose degree is more than 1 based on the number of excavators and loaders	部分地区出现标高 ≥ 0.5 m 的根底,0.4% $\leq$ 根底率 $\leq 1\%$ In some areas, the height difference of the foundation is greater than 0.5 m, and the foundation rate is less than 0.4% but more than 1%
GBF- C016-1350-010(矿) GBF- C016-1350-010(Ore)	炮区共产生 ≥ 700 mm 大块约 70 块,以每块 3.4 m^3 计算,大块率 3% There are about 70 pieces of large blocks of more than 700 mm in this blasting area, with each 3.4 m^3 , and the rate of large blocks is 3%	爆堆高度平均 ≥ 1 m,结合挖运方挖装车数,松散度 ≥ 1.2 The average height of the explosive pile is more than 1 m, and the loose degree is more than 1.2 based on the number of excavators and loaders	部分地区出现标高 ≥ 0.5 m 的根底,0.5% $\leq$ 根底率 $\leq 1\%$ In some areas, the height difference of the foundation is greater than 0.5 m, and the foundation rate is less than 0.5% but more than 1%



图 5 EII-C028-1323-001(矿)爆破网路示意图

Fig. 5 EII-C028-1323-001(ore) blasting network diagram

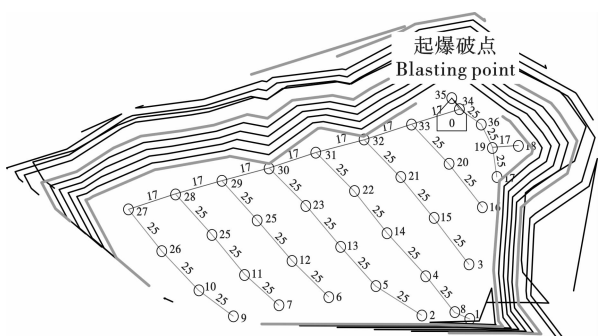


图 6 GBF-C010-1350-006(矿)爆破网路示意图

Fig. 6 GBF-C010-1350-006(ore) blasting network diagram

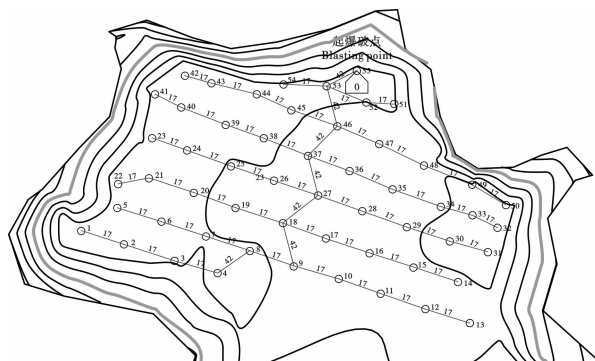


图 7 GBF-C016-1350-010(矿)爆破网路示意图

Fig. 7 GBF-C016-1350-010(ore) blasting network diagram



图 8 EII-C006-1341-001(矿)爆后图片

Fig. 8 EII-C006-1341-001(ore) picture after blasting



图 9 EII-C028-1323-001(矿)爆后图片

Fig. 9 EII-C028-1323-001(ore) picture after blasting



图10 GBF-C010-1350-006(矿)爆后图片

Fig. 10 GBF-C010-1350-006(ore) picture after blasting



图11 GBF-C016-1350-010(矿)爆后图片

Fig. 11 GBF-C016-1350-010(ore) picture after blasting

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