

坚硬软弱复合顶板切顶卸压沿空留巷爆破技术

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摘要: 为在坚硬软弱复合顶板切顶卸压沿空留巷时取得较好预裂爆破效果,通过现场试验和分析,采用合理的双向聚能张拉爆破技术,对巷道顶煤强度较小、直接顶较软弱、基本顶坚硬的复合顶板进行了有效的预裂爆破。结果表明:对于软弱岩层,爆破能量易沿孔壁原生裂隙发生冲楔作用,聚能效果较差,深12 m的炮孔内裂缝长度只有1.2 m,并且孔口易出现爆破漏斗,对巷道原有支护造成破坏;对于坚硬岩层,随着装药线密度增大,聚能方向裂缝率逐渐增大,当单个炮孔装药量为7卷、药卷长度和空气柱长度的比值为3.348、填塞位置位于坚硬岩层时,普氏系数为12的中砂岩段炮孔内沿预裂方向全部产生张拉裂缝,裂缝长度达5 m,裂缝率达100%。因此,对于坚硬软弱复合顶板,使坚硬岩层沿预裂方向产生有效的裂缝,软弱岩层自行垮落,能够取得满意的预裂效果。

关键词: 切顶卸压; 沿空留巷; 坚硬软弱复合顶板; 双向聚能张拉爆破; 预裂爆破

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Blasting technology of gateway retaining along goaf pressure release by roof cutting in hard and weak complex roof

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Abstract: In order to have a good pre-fracturing effect of the bilateral accumulative tensile blasting in the hard and weak complex roof obtained in the gateway retained along the goaf with the roof cutting and pressure released, with the site test and analysis, the rational bilateral accumulative tensile blasting technology was applied to the effective pre-fracturing blasting under the conditions of the complex roof with the low top coal strength above the gateway, soft and weak immediate roof and hard basic roof. The results showed that in the soft and weak rock stratum, the blasting energy would cause a wedging role along the in-situ cracks of the borehole wall and the energy accumulation effect was poor. In the blasting borehole with a depth of 12 m, the cracking length was 1.2 m only, a blasting funnel would be easily occurred at the orifice of the borehole and would cause a failure to the previous support. As for the hard rock, with the charge line density increased, the cracking rate along the accumulative direction would be steadily increased. When an explosive charge of a single borehole was even cartridges, the ratio of the cartridge length and the air column length was 3.348. When the filling location was at the hard rock in medium sandstone section with a Protodyakonov coefficient of 12, all tensile cracking would be occurred along the pre-fracturing direction within the borehole, the cracking length would be 5 m and cracking rate would be 100%. Therefore, as the complex roof, the hard rock would cause effective cracks along the pre-cracking direction and the soft and weak rock would automatically collapse and would have the satisfactory pre-cracking effect.

Key words: pressure release by roof cutting; gateway retaining along goaf; hard and weak complex roof; bilateral accumulative tensile blasting; pre-fracturing blasting

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0 引言

近年来,国内外学者在聚能爆破及爆破对支护体的影响以及爆破对巷道顶板损伤等方面的研究很多。通过数值模拟、相似模拟、现场爆破试验等手段,取得了丰富的研究成果。张国锋等^[1]针对白皎煤矿保护层留煤柱引发的采空区瓦斯积聚、瓦斯突出及应力集中对近距离煤层开采引起的灾害问题,提出了保护层沿空切顶成巷无煤柱开采技术:对沿空巷道顶板实施超前预裂,切断沿空巷道顶板与采场直接顶、基本顶的联系,改善了巷道围岩应力环境,取得了较好的成果;孙晓明等^[2]通过大量的工程实践,从岩石力学和断裂力学的角度研究并确定了薄煤层切顶卸压自动成巷技术关键参数的确定方法;刘小强等^[3]通过现场试验,掌握并实施了薄煤层切顶卸压沿空留巷技术,取得了理想的切缝和留巷效果;文献[4-8]分别从爆破点距离与其损伤变化率之间的关系、坚硬顶板条件下爆破治理冲击地压技术、复合型切缝药包爆破开裂机理、炮孔装药位置及填塞长度对爆破效果的影响等方面进行了研究。然而,上述研究的爆破实施条件及原理与双向聚能张拉爆破有很大差异,爆破目的也与双向聚能张拉爆破有所不同,且传统爆破技术与该技术的试验结果及分析存在明显差异,甚至部分结论正好相反。因此,传统爆破技术及其理论不能完全适用于双向聚能张拉爆破。因此,对双向聚能张拉爆破技术进行深入的研究有着重要的理论价值和现实意义^[9-12]。

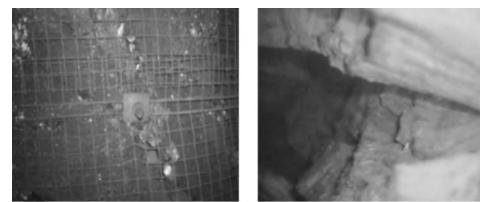
双向聚能张拉爆破技术先后在薄煤层破碎顶板、坚硬顶板、复合顶板条件下得到成功应用并推广^[13-16],而在厚煤层、综放开采、坚硬软弱复合顶板条件下进行双向聚能张拉爆破的研究和应用较少。然而,在该条件下进行双向聚能张拉爆破,掌握其爆破参数和规律是在此类条件下成功实施切顶卸压沿空留巷技术的关键,因此具有十分重要的研究意义^[17-20]。

1 工程地质条件

姚桥煤矿7719工作面为综放开采,主采7号煤层,煤层平均厚为5.5 m,运输巷沿煤层底板掘进,巷道高2.6 m,巷道顶板留有2.8 m厚的煤层,煤层上方由平均厚为2.6 m的泥岩和砂质泥岩组成,直接顶普氏系数为3~4;基本顶由平均厚为15.2 m的中砂岩组成,普氏系数7~8。工作面放煤后,泥岩和

砂质泥岩组成的直接顶随采随冒。

7719工作面运输巷采用锚网索+恒阻大变形锚索支护。在巷道原有支护条件下沿巷道肩窝进行双向聚能张拉爆破,容易导致孔口出现爆坑、炮孔内塌孔、孔口附近锚杆失效、巷道顶板产生破坏性裂缝等,如图1所示;且留巷后巷道顶板下沉量大,导致留巷后巷道无法正常使用。因此,对于这种坚硬软弱复合岩层,如按照原有的爆破技术进行双向聚能张拉爆破,容易造成塌孔,影响聚能爆破效果。



(a) 顶板破坏 (b) 炮孔塌孔
图1 双向聚能张拉爆破后顶板破坏

Fig. 1 Failure of roof after bilateral cumulative tensile explosion

2 双向聚能张拉爆破试验

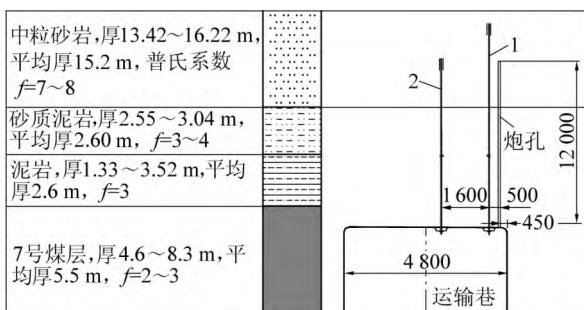
2.1 试验方案设计

双向聚能张拉爆破的技术关键是首先要认识到坚硬软弱复合顶板的特殊性,抓住主要矛盾;其次,在进行双向聚能张拉爆破前要进行恒阻大变形锚索超前加固巷道:一方面能够有效保护巷道顶板,另一方面恒阻大变形锚索的高预紧力有利于提高孔内裂缝率,保证预裂效果,炮孔线布置断面和平面图如图2和图3所示。为了掌握双向聚能张拉爆破的最佳装药结构及装药参数、切断巷道基本顶中砂岩与采空区之间的联系,使巷道顶板压力在成巷过程中大幅减小、减小巷道变形,保证巷道满足下个工作面使用的目的。在认真分析7719工作面工程概况的基础上,设计7719工作面运输巷双向聚能张拉爆破试验参数,见表1。

表1 双向聚能张拉爆破试验参数设计

Table 1 Test parameters design of bilateral cumulative energy tensile explosion

炮孔 编号	试验 方案	炮孔深 度/m	装药 量/卷	封泥区 间/m	封泥长 度/m	封泥段 煤岩性
1	方案1	12	7	0—2	2	7号煤层
2	方案2	12	7	3—5	2	泥岩
3	方案3	12	7	6—8	2	砂质泥岩
4	方案4	12	7	8—10	2	中砂岩



1—恒阻大变形锚索 HS500 ,长 14.3 m ,间排距 1.0 m×1.0 m;
2—恒阻大变形锚索 HS500 ,长 12.3 m ,间排距 1.6 m×2.0 m

图 2 巷道炮孔布置

Fig. 2 Arrangement of blast hole in roadway

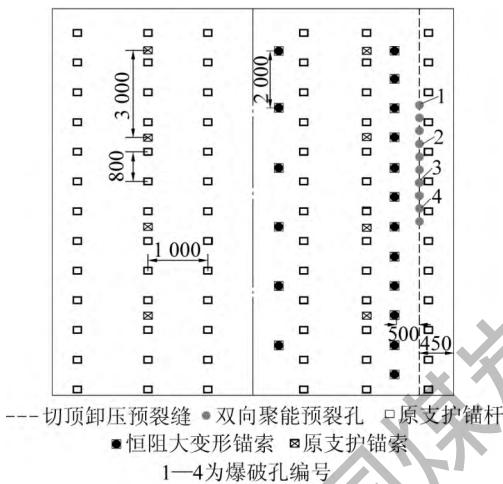


图 3 巷道顶板炮孔布置

Fig. 3 Layout of blast hole arrangement in roof of gateway

双向聚能张拉爆破前巷道加固支护参数及双向聚能张拉爆破所需的其他参数如下:

1) 双向聚能张拉爆破参数。在工作面运输巷距采空区侧巷帮450 mm处沿巷道走向布置1排聚能爆破孔,炮孔间距为600 mm,孔深12 m,炮孔沿铅垂方向。炮孔采用专用切缝钻机程控,钻头采用46 mm三翼岩石钻头。单孔自孔底连续装2根聚能管,第1根聚能管长1.5 m,第2根聚能管长1 m,聚能管内径均为36.5 mm,2根聚能管通过专用连接器连接,聚能管内药卷为矿用水胶炸药,规格为φ35 mm×200 mm。采用黄泥封堵,封泥长度为2 m,正向起爆。要求各个炮孔和聚能管聚能方向沿巷道轴向成一铅垂平面。

2) 恒阻大变形锚索加强支护参数。巷道断面内布置2根φ21.8 mm的恒阻大变形锚索,靠近切缝侧恒阻大变形锚索长为14.3 m,排距1.0 m;另一

侧恒阻大变形锚索长为12.3 m,排距2.0 m。

2.2 双向聚能张拉爆破效果

爆破后1号炮孔孔口形成了长1.0 m、宽1.2 m、高0.8 m的爆坑,各个方案孔内岩性、装药量、孔内裂缝情况如图4所示。

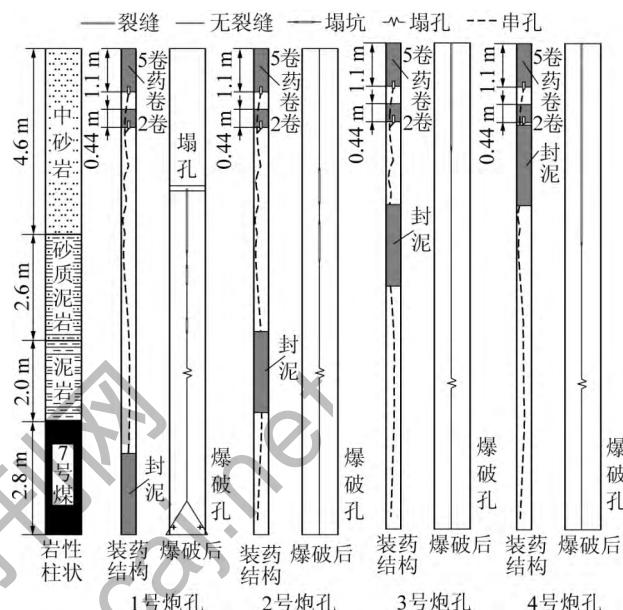


图 4 炮孔装药量及其孔内裂缝情况

Fig. 4 Blasting hole charge and cracks in blast hole

由图4可知,当炮孔装药量、封泥长度相同时,双向聚能张拉爆破后炮孔内裂缝长度随着药卷长度与空气柱长度比值的增大而增大,二者的关系如图5所示。

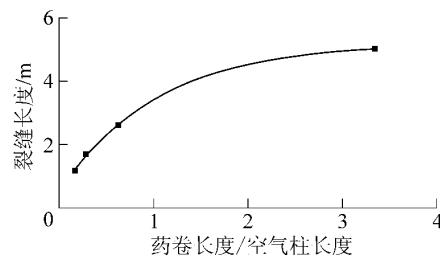


图 5 爆破后炮孔内裂缝长与药卷长和空气柱长比值的关系

Fig. 5 Relationship between length of cracks in hole and ratio of explosive length/length of air column after blasting

炮孔内药卷长度与空气柱长度比值的大小直接决定着双向聚能张拉爆破时炮孔围岩成缝质量,当二者的比值达到合理的区间时,岩层才会发生张拉破裂,否则岩层将发生压裂破坏,不能达到满意的切缝效果。炮孔内封泥位置所对应的岩性决定着炮孔是否在爆破过程中出现塌孔以及成缝质量的好坏。当药卷长度与空气柱长度比值较小,且封泥位置对

应的岩石普氏系数也较小时,炮孔内将在层理、结构面等软弱破碎处出现塌孔,影响炮孔成缝质量。

根据图5可知,当单孔装药量为7个药卷、封泥长度为2 m时,爆破后炮孔内裂缝长度与药卷长度和空气柱长度的比值符合式(1)的非线性关系,相关系数为0.9962。

$$y = 5.182 - 4.68 \exp(-x/1.035) \quad (1)$$

式中: x 为药卷长度和空气柱长度的比值; y 为裂缝长度。

以此类推即可获得预裂切缝范围内的裂缝长度与药卷长度和空气柱长度的比值关系,见式(2)。

$$y = \left[\frac{5.182 - 4.68 \exp(-x/1.035)}{5.182} \right] s \quad (2)$$

式中, s 为预裂切缝范围,即切缝炮孔深度。

若以5.182 m为一个单位,当药卷长度和空气柱长度的比值为3.348时,产生裂缝的长度为5 m,假设该裂缝长度能够满足需要,则切缝炮孔单孔装药量 N 应为

$$N = 1.35s \quad (3)$$

试验炮孔中A号孔双向聚能张拉爆破后孔内裂缝情况如图6所示。爆破后A号炮孔孔内自7.0 m处至孔底沿巷道轴线方向均产生明显裂缝,且其他方向孔壁完好,实际预裂结果与理论分析相符合,能够满足工程中对预裂的要求。

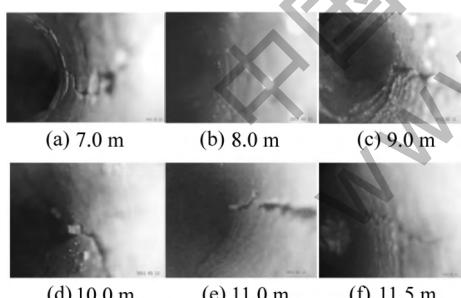


图6 双向聚能张拉爆破后4号炮孔内裂缝长度

Fig. 6 Length of cracks in No. 4 hole after bilateral cumulative energy tensile explosion

3 结 论

1) 在切顶卸压沿空留巷中,采用双向聚能张拉爆破进行切顶试验的过程中,对于这种“坚硬+软弱”的复合岩层组合形式,使坚硬岩层产生有效的、符合标准的裂缝,软弱岩层自行垮落,最终取得较好的预裂效果。

2) 双向聚能张拉爆破过程中,软弱岩层容易吸

收炸药能量。当切缝药包和封泥位置在砂质泥岩或泥岩等普氏系数较小的岩层时,爆破后容易引起炮孔内塌孔,且预裂效果较差。当封泥位置在强度较小的顶板煤层和直接顶中时,爆炸冲击波将对孔口造成破坏,形成孔口爆坑,造成邻近支护结构失效。

3) 通过双向聚能张拉爆破试验,得到了裂缝长度与药卷长度和空气柱长度比值的关系曲线及公式。当药卷长度和空气柱总长度为2 m时,装药量7卷、药卷长度和空气柱长度的比值为3.348,能够产生5 m的裂缝,且效果较好。以此为依据即能得到预裂范围内单孔装药量。因此,在一定范围内,单位装药量越大,越能对硬岩形成有效的聚能,只有有效的聚能,岩层才会发生张拉破裂,否则岩层将发生压裂破坏,不能达到满意的切缝效果。

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